Offshore Outlaws: Brexit and Oil Spills in the North Sea

Anthony Calacino, Federica Genovese, Hayley Pring *

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Abstract:

Globalization has led to various forms of international integration whose effect on environmental behavior has been a long-standing source of debate. Yet, in recent years, there has been a growing backlash against international institutions, in part motivated by the will of taking back control of national borders. Focusing on the United Kingdom's withdrawal from the European Union, this paper explores the effects of this type of backlash on firms' environmental standards. Despite being defined as a sovereignist project to enhance state power and national regulatory oversight, we argue that Brexit caused immediate suboptimal environmental outcomes. Specifically, Brexit created policy misalignment, pushing the UK regulators into a capacity vacuum. This led to a transition period of impunity for polluting firms, further catalyzed by accelerating market changes, which led firms with lower environmental compliance to sort into the market. We test our theory with evidence from the oil sector's offshore rigs in the North Sea between 2015 and 2023. A grid-cell analysis of satellite-detected oil spills compares firm behavior in the United Kingdom, European Union, and Norwegian jurisdictions. We first find that, after Brexit, UK waters experienced significantly less environmental protection compared to the EU and Norway. Additionally, we show that the environmental damages following Brexit are not associated to a decrease of UK public salience for environmental protection, but by a new ecosystem of firms that were allowed to reap short-term profits from Brexit.

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1 Introduction

Decades of globalization have increased cross-border flows of capital and labor to record numbers, with important implications for public good provision such as natural resource management and environmental protection. Accelerated economic transactions have reshaped international interactions, but have also necessitated changes in governance and regulatory structures at national and supranational levels. Against this background, prominent scholars have argued for the positive effects of globalization on environmental behaviors (Vogel 2000; Antweiler, Copeland, and Taylor 2001). According to this view, international integration can lead to larger coalitions of oversight supporters, who are willing to ratchet up environmental regulations (Perkins and Neumayer 2012; Meckling 2018). For example, among the historical expectations behind joining the European Union (EU) was improving environmental protection by reducing individual member-state's regulatory costs, centralizing monitoring, and streamlining enforcement (Selin and VanDeveer 2015; Bradford 2020). Yet, these trade-offs of international integration today remain largely contested.

The perceived positive effect of international integration on public good provision is being revised as the world faces increasing challenges from a so-called globalization backlash (Colantone and Stanig 2018a; Meyerrose 2020; Broz, Frieden, and Weymouth 2021). From the US attack on international organizations (Brutger and Clark 2023; Carnegie, Clark, and Zucker 2024), to the increasing share of internationally skeptic parties in national parliaments (De Vries, Hobolt, and Walter 2021; Obermeier 2025), and the strengthening of coercive and isolationist economic forces (Colantone and Stanig 2018b; Farrell and Newman 2019), many are the manifestations of deep dissatisfaction with international embeddedness are the threats of international integration (Copelovitch and Pevehouse 2019; Dellmuth et al. 2022). Particularly telling is that many disintegration initiatives are designed as popular sovereignist agendas, with hopes of scaling back the powers of foreign markets and domestic exposure to foreign actors.[1] The archetypal case is the 'take back control' slogan of the

[1] Examples include recent U.S. withdrawals from various institutional frameworks, but also South

United Kingdom's EU withdrawal campaign, decided by the June 2016 Brexit referendum.

Against the backdrop of these growing instances of disintegration (Von Borzyskowski and Vabulas 2019) and in light of the relevance these play in public policymaking (Lake, Martin, and Risse 2021; Walter 2021), this paper investigates the effects of international withdrawal, and subsequent disintegration, on environmental behavior. We ask in which ways withdrawing from international cooperation affects environmental public good provision, focusing first and foremost on firms' expectations and responses. We zoom in on the effect of Brexit, which provides a unique opportunity to theoretically and empirically investigate this question. The UK is the only country that has ever attempted to withdraw from the EU, one of the most successful cases of international integration worldwide. Also, EU membership has historically been motivated by the aim of delivering public goods including, among other things, environmental benefits for the region. Furthermore, as disintegration in this instance was framed as a popular project, we ask to what extent Brexit came with explicit hopes of lowering environmental regulatory standards, and who benefited in terms of environmental burden in the short-to-medium term.

We argue that disintegration led to worsened environmental outcomes in the UK, while not necessarily affecting other EU members. This is for two complementary reasons. First, while dropping membership in international agreements can have mixed results depending on the type of agreement (Walter and Plotke-Scherly 2025), in the case of environmental standards the exiting country likely needs to adjust home regulations, creating a dynamic situation that deters regulatory agencies from pursuing high-levels of enforcement (Schimmelfennig 2019). The UK's withdrawal from the EU, we argue, generated policy misalignment, which increased the UK's costs of enforcement, leading to a reduction in the quality of both monitoring and sanctioning. Second, we argue that disintegration from highly coordinated environmental norms like the EU standards changed the market incentives in the relevant sectors to comply, creating new winners and losers (Bayer and Genovese 2020;

Africa's withdrawal from UNESCO, Argentina's withdrawal from the World Health Organization, Gambia's withdrawal from the Commonwealth, and Albania's withdrawal from the Warsaw Pact.

Cory, Lerner, and Osgood 2021; Green et al. 2022). Regarding polluters' behavior following Brexit, we expect that this generated distributional gains and allowed firms to benefit from reduced compliance with environmental standards. We advance the hypothesis that firm non-compliance was partially driven by sorting effects after the referendum, higher compliance firms leaving the UK market, and lower compliance firms remaining or new firms entering.

We test this argument by focusing on the offshore fossil fuel sector in Northern Europe. Firstly, we investigate the spills of oil firms in the pre- and post-Brexit period within UK waters, which we compare to spills of other European oil firms leveraging a quasi-natural experiment in the North Sea.[2] Measurement-wise, we present a novel geospatial dataset that draws on the universe of North Sea oil rigs between 2015 and 2023, as well as independent reports of oil spills from satellite monitoring by the European Maritime Safety Agency (EMSA). Our event-study analysis shows that the immediate aftermath of the Brexit referendum led to up to three times more oil spills detected in UK waters compared to EU and Norwegian waters. The link between Brexit and increased pollution is corroborated by a comparison of satellite-detected oil spills with firms' officially reported spills, and an analysis of the UK's own regulatory activity' monitoring actions vis-à-vis the EU.

On the basis of these results, the paper moves to investigate if this behavior is traceable to UK firms' active lobbying, a shift of UK public preferences, or a UK regulators-based market restructuring following the 2016 referendum. We assess the plausibility of these mechanisms with a number of additional data. First, we compare surveys of UK voters regarding the regulatory implications of Brexit for the oil and gas sector, and find that even among those who voted to leave the EU there is high public concern with North Sea oil spills and willingness to sanction polluters. We also map businesses' opinions on the matter and find that the oil and gas sector had limited concerns regarding the burden of EU regulations prior to Brexit, suggesting that these firms made minimal investments in the Brexit campaign based on these

[2]The North Sea is divided into different jurisdictions between the UK, the EU, and Norway based on continental shelves and the equidistance principle prior to the discovery of resources.

exclusive grounds. Moreover, by examining parliamentary lobbying behavior by oil and gas firms, we find that UK lobbying meetings decreased around the Brexit period, and that there were overall consistent lobbying patterns across the UK and EU countries in this time frame. Instead, we uncover that the most likely mechanism behind the post-Brexit increase in oil spills was a significant sorting of firms in UK waters following the referendum. Merging and acquisition data indicates that low compliance firms distinctively entered UK North Sea oil operations after 2016, many of which owned by companies aligned with the Conservative government's vision of post-Brexit international partners. Altogether, this evidence points less to the agency of the public and traditional firms in determining the new environmental suboptimal status quo, and more to a new ecosystem of lowered sanctioning capacity and exploitative market actors following Brexit.

Our findings have a number of implications for state-firm relations in an era of globalization backlash. To the literature on the environmental political economy of firms (Cao and Prakash 2010; Green 2013; Genovese and Tvinnereim 2019; Kennard 2020; Cory, Lerner, and Osgood 2021), our results indicate that the relationship between polluting firms and environmental regulators is fundamentally conditioned by the politics of international disintegration. Withdrawal from international cooperation generates new winners and losers, and offers new behavioral considerations and opportunities for polluting firms.

The results also speak to the literature on cross-national environmental politics and climate cooperation more generally. With increasing signs of environmental treaty abandonment (Schmidt 2024; Urpelainen and Graaf 2018; Mitchell et al. 2020), our paper indicates international disengagement likely shifts power from states to firms, at the cost of compromising hard-fought-for, democratically successful environmental standards (Ross 2012). To this literature, our findings suggest that political movements that seek to re-establish state control over environmental public goods may not work, especially in cases in which countries have been hollowed of state capacity.

Finally, to the broader international relations debate over the credibility of supranational institutions (Gray 2009; Jurado, León, and Walter 2022; Tingley and Tomz 2022), our study points to a rather significant EU clout over environmental integrity. We find EU-style integration was largely successful at improving both monitoring and sanctioning of oil spills compared to the UK after Brexit. Overall, the results confirm the argument that integrated international institutions overall enable rather than dismantle public good provision among member states (Sandler 2006; Schneider 2020).

The rest of the paper is organized as follows. First, we delineate our theoretical argument. Here we describe how political projects that reclaim full control over national borders in the era of globalization can generate regulatory misalignment that incentivizes suboptimal firm-level behavior, which then deteriorates environmental outcomes. Second, we introduce the case study of Brexit, the context of North Sea oil production, and our testable hypotheses regarding oil spills. We then outline our data collection efforts and research design. The next section goes into the geolocated data analysis and our main statistical results. We then propose a separate empirical discussion of the mechanisms that could plausibly explain the changing behavioral incentives and corresponding decline in environmental standards following Brexit. The final section concludes.

2 Theoretical Framework

2.1 Globalization, Firm-State Relations, and the Environment

A well-known challenge of the 21st century is the interplay between collective welfare by means of material growth and the plight of environmental damages. On the one hand, the type of globalization manifested in the past decades followed a liberal markets model in which firms have been the principal agents of resource-intensive growth (Bernard et al. 2007). On the other hand, the power of states to enhance provision of welfare and to regulate their economies are considered key to maintaining public support for the planks of globalization (Ruggie 1982; Strange 1996). This view of the so-called liberal international order implies that firms need a degree of market interlinkage, but this type of global integration is most stable if nation states can guarantee public goods. According to classical scholarship, the desire for international financial stability and the opportunities from accessing new markets incentivize public good provision (Vogel 2000; Antweiler, Copeland, and Taylor 2001).

Today, there is a renewed debate on how state-firm relations affect environmental public good provision, as new literature suggests that firms have different strategies to face regulators' policies (Genovese and Tvinnereim 2019; Kennard 2020; Bayer 2023), and regulators have multiple ways to adjust to firms' reactions to environmental policy (Allan and Nahm 2025; Finnegan 2023). Importantly, this literature is clear that environmental behaviors are a product of the characteristics of authorities as well as the features of firms, and environmental outcomes vary accordingly.

On the authorities' side, various factors may influence whether governments will increase environmental regulatory oversight in the landscape of globalization. The ideology of the government in place may have an effect on the introduction of regulations concerning environmental standards (Chang et al. 2018; Wang et al. 2022). At the same time, changes to both the quantity of regulations and their stringency have been observed in the absence of ideological shifts in government (Neumayer 2003). Research also highlights the relevance of foreign economic competition (Holzinger and Sommerer 2011; Cao and Prakash 2010; Ross and Voeten 2016), which can pressure regulators to relax enforcement in order to attract investment. Part of this phenomenon is the so called race-to-the-bottom: when states are first and foremost concerned with economic development, they may loosen environmental standards to attract mobile capital (Konisky 2007; Drezner 2001).[3]

[3] If all states pursue this race-to-the-bottom strategy, it would lead to a continual lowering of standards as state executives see relaxing environmental standards as an avenue of generating economic gains and capturing economic voters. This would effectively yield a Prisoner's Dilemma where the outcome is suboptimal since a collective agreement to maintain high standards would be preferred (Bernauer and Caduff 2004; Prakash and Potoski 2006). The argument has been made that such processes generate regulatory differences, which in turn, generate cost gradients for firms to move to less stringent markets.

In addition to these government-focused views of how firm-state relations in the shadow of globalization may lead to various environmental outcomes, the political economy literature points to interest group influence within international systems as the reason for lower public policy stringency (Kim 2017) and fewer environmental regulations (Stokes 2020; Mildenberger 2020). In a highly centralized global economic network, private actors can pursue strategies, such as preemptive regulation, that erode chances for more stringent standards (Malhotra, Monin, and Tomz 2019). At the same time, some studies find that firm lobbying tends to be static, with few firms ever dramatically changing their style of lobbying across time (Green et al. 2022; Genovese 2019), and therefore not a critical mass of firms mobilizing against increases in regulations (Kerr, Lincoln, and Mishra 2014).

Another branch of research also points to a relationship between populism and the hollowing out of democratic institutions (Kyriacou and Trivin 2024; Carnegie, Clark, and Zucker 2024) to explain the patterns of environmental regulation in open economies. Böhmelt (2021) shows that recent waves of populism are associated with lower environmental outcomes, possibly as a result of dismantling established systems that are required to keep checks and balances on ensuring environmental protection. This is corroborated by the empirical finding that radical right populists lead to less environmental protection, as these are more likely to actively campaign on lax regulations and low environmental ambition in the first place (Dickson and Hobolt 2024).

These different sets of scholarly discussion point to various arguments about environmental behavior along the history of globalization, although not without mixed evidence. The lack of consensus on how precisely firm-state relations lead to environmental outcomes is partly because regulation in the era of globalization critically implies a certain degree of embeddedness in the rules of countries' economic ties and networks, i.e. by joining international organizations that govern cross-boundary regulatory rules (Keohane 1982). Along these lines, the European Union is one of the most successful examples of international organizations in the influence of stricter environmental legislation and stringency for its member states (Selin and VanDeveer 2015) and, by consequence, its operating firms (Bradford 2020).

At the same time, the European Union has become an emblematic illustration of international integration that various forces have politicized and even turned against to reshape firm-state relations. Against this background, in the next section we discuss how firm-state relations may influence environmental outcomes when international integration is reversed, and specifically at the onset of an event of international disintegration.

2.2 Distributive Environmental Implications of International Disintegration

Among the scholars who argue that the embeddedness in international organizations crucially conditions the influence of globalization on firms' (and states') behavior, the running assumption is that organizations with a high degree of public policy coordination should yield positive effects for their members (Schimmelfennig 2003; Gray 2009; Hafner-Burton and Schneider 2019). At the same time, as the so-called backlash literature has noted, the high price of integration in international organizations is part of what has characterized the politicization of globalization in recent years. The rest of this section theorizes the implications of international disintegration for firm-state relations and their implications for environmental outcomes.

The causes and consequences of the globalization backlash have generated a lively debate. Most notably, the discipline agrees that the backlash is based on globalization making states highly vulnerable to the uncertainty and weaponization of interdependence (Farrell and Newman 2019). Globalization and its shocks have magnified political polarization and catalyzed the election of populists (Autor, Dorn, and Hanson 2016; Colantone and Stanig 2018b; Copelovitch and Pevehouse 2019), many of whom signal for regaining sovereignty through withdrawals from international cooperation (Von Borzyskowski and Vabulas 2019; Walter and Plotke-Scherly 2025). Parceled into this backlash is a quintessential distributive problem: the transnational mobility of globalization ultimately gives a competitive bargaining advantage to hard-to-regulate corporations in politics (Colgan and Keohane 2017; Kim and Osgood 2019; Kim and Milner 2021). This is in stark contrast with the promise of sovereignist control often framed around the political agenda driving backlashes to international cooperation.

Against this discussion, we argue that disintegration can lead to negative environmental outcomes by undermining the focal country's public services and disrupting channels of oversight. These effects operate through multiple channels; here we focus on the fact that disintegration can lead to a period of uncertain processes and negotiations, which in turn cause misalignment between the regulatory standards of the exiting country and the bloc it is leaving (Walter 2021; Lake, Martin, and Risse 2021). This misalignment is shaped both by the written content of regulations (what exists on paper) and the capacity to enforce these regulations (including the ability to sanction firms). Under these conditions, the exiting country becomes reliant on its domestic regulatory bodies, which face capacity gaps intrinsic to the late stages of capitalism (Beramendi et al. 2015). Under these circumstances, disintegration disrupts both mutual monitoring and centralized oversight. While domestic regulators might eventually adjust to the new regulatory environment, this adjustment often occurs over a protracted period, during which enforcement lapses can occur.[4]

These dynamics highlight the broader relationship between disintegration, regulatory misalignment, and firm behavior that we seek to test in this paper. We claim that disintegration disrupts established enforcement mechanisms and creates uncertainty in regulatory oversight, particularly in markets where compliance is costly or difficult to monitor. As a result, disintegration will have distributive effects on firms in the focal exiting countries. We conjecture that firms with lower reputational stakes, such as equity-backed companies with short-term investment horizons, are more likely to exploit these gaps and enter markets with weakened oversight. This process not only shifts the composition of firms operating in these markets but also exacerbates environmental risks, as such firms are less incentivized

[4]Transition periods can exacerbate these issues, as international bodies may diminish the importance of enforcement against the exiting country, knowing that investigations and remedies will likely lose efficacy after withdrawal. We come back to this in discussing the empirical research design.

to comply with regulations or invest in long-term sustainability. The combination of weaker enforcement and a changing firm landscape amplifies the vulnerability of public goods, such as environmental quality, to degradation.

We bring these insights to the case of environmental pollution after the Brexit referendum. But before moving to the core of the paper, one note on the generalization of our claims. Our argument is tailored to the disruptive and highly costly Brexit case, but evidently, disintegration does not necessarily entail that the position of a country in the global economy is fundamentally altered by default, nor that the resulting uncertainty will be automatically existential. This would depend on the structural equivalence of a country's market compared to the leaving block, and is important because it helps explain the conditions under which disintegration could lead firms across the relevant jurisdictions to converge on standards, thus making the strength of the domestic regulator more or less consequential in transitions or aftermaths of exits. We restrict the focus of our paper on Brexit UK, but offer a discussion of alternate case scenarios of varying levels of disintegration and structural equivalence in Appendix A.[5]

To summarize, our main claim is that domestically induced disintegration from a highly coordinated international body like the EU entails a specific political economy of regulatory misalignment and firm behavior with observably negative environmental implications. In what follows, we qualify how we might trace these observable implications by looking at the case of oil spills in the North Sea following Brexit.

[5] A conceptual framework that focuses on both disintegration and market equivalence altering becomes useful when comparing cases where disintegration can occur, like with the withdrawal from certain international agreements or less powerful economic unions, but structural equivalence is preserved. Under such conditions, firms have clearer expectations of competition even under policy uncertainty or regulatory changes, so that firms are unlikely to diverge in environmental standards. We provide a lengthier discussion of these factors in Appendix A.

3 Oil Production, Sea Spills, and Brexit

Empirically, our investigation focuses on the immediate impact of the UK's withdrawal from the EU on oil spills in the North Sea. Prime Minister David Cameron announced the EU referendum in response to a pledge born from the 2015 UK elections. The 2016 vote was preceded by a relatively short campaign mostly based on issues such as immigration and devolution, but also self-regulation and the improvement of health and water quality services (Curtice 2017). The results on June 23rd, which resulted in 52% of the voting population choosing for 'Leave,' were largely unexpected. Importantly, they led to years of uncertain negotiations with the EU, which officially started with Theresa May's March 2017 trigger of Article 50 of the Treaty of the European Union. The uncertainty around the logistics of Brexit peaked with the December 2019 elections won by the Brexit-focused Conservative campaign (Hix 2019). The Johnson government concluded the negotiations with the official withdrawal of the UK in January 2021.

We focus on the effects of Brexit on the environmental standards of oil drilling in the North Sea due to the specificities of this area. The North Sea is a territory shared between the UK, EU nations and Norway, therefore allowing for a clear comparison of change in behavior among firms with similar operations across these differently integrated territories. The units of observations (rigs) are numerous too: in 2015, the North Sea was the world's most active offshore drilling region, with a total of 173 rigs drilling across jurisdictions and 770 sub-sea installations operating in the UK (Lee et al. 2015).

Also importantly, marine oil spills are salient breaches of public policy that rank high in the monitoring duties of various maritime institutions. Spills at sea pose serious and sometimes persistent ecological harms (Tansel 2014).[6] Spillage occurs when there is over-pressuring, mechanical failures, poor safety procedures, leaking from underwater pipelines, and faulty

[6]Large spills that have onshore consequences have historically cost more than 100 million dollars to clean. However, even small spills can cost in the millions. See International Tanker Owners Pollution Federation's 'The Financial Cost of Oil Spills' 2024 report, https://www.itopf.org/fileadmin/uploads/itopf/data/Photos/Papers/The_Financial_Cost_of_Oil_Spills_ITOPF_TW_JSB.pdf.

equipment and structural failures.[7] Consequently, average-size oil spills are more often than not a direct consequence of maintenance and monitoring deficiencies.

Additionally, the age of an offshore asset increases its maintenance costs. Notably, the North Sea is a relatively old territory for oil fields, where the larger facilities confer larger running costs. It is reasonable to assume that the incentives for public regulation of oil drilling in the North Sea are high for the purpose of public health and environmental protection; at the same time, the operational costs for firms are steep.

Our empirical investigation hinges on this point: if Brexit had significant implications for the uncertainty around regulations from the EU in the North Sea, we should expect that the period right after the referendum generated unique pressure for shirking and non-compliance among UK-located oil firms, and therefore increased the amount of oil spills in British waters. But before we refine our expectations for our empirical purposes, we first describe the regulatory regime of the North Sea to further fix ideas about the role that EU regulators played in the region, and what EU membership withdrawal meant for marine pollution regulation in the UK.

3.1 Baseline Context: The North Sea Regulatory Regime

Today oil pollution governance in the North Sea is split between UK, EU, and Norwegian authorities. Despite the high levels of uncertainty on UK water jurisdiction that followed the 2016 referendum, EU and Norwegian laws formally governed this area until the 2021 UK official exit. All contracting parties – including Belgium, Denmark, France, Germany, Netherlands, Norway, Sweden, and the United Kingdom – are also members of the 1969 Bonn Agreement. The Bonn Agreement requires countries to conduct aerial surveillance to detect oil spills, as well as investigate satellite detections of oil spills.

[7] Oil spills are most often caused by fixed-installations (offshore oil production, coastal refineries, terminals, drilling rigs and wells) and transportation (tanker accidents), or industrial waste release.

In the EU, the North Sea pollution monitoring is overseen by the European Maritime Safety Agency (EMSA), which provides satellite detection alerts to Bonn Agreement countries.[8] Through Article 12, EMSA requires countries to report to the Council on pollution detection at least once every three years.[9] Overall, the EU's monitoring mechanisms are robust, although not optimal.[10] Penalties are in fact a point of weakness for all states governing the North Sea.[11] Despite these weaknesses in enforcement, the broad EU framework around oil pollution regulations have remained consistent since 2004. Furthermore, the EU's oversight capabilities through its infringement procedures are noteworthy. For both the earlier 2005 and updated 2013 offshore directive, the EU has initiated 40 infringement investigations against its members.

For our purposes it is important to note that, since the early 2000s, all EU offshore activity was governed under similar regulatory frameworks amid the different North Sea countries. Further harmonization occurred with the adoption of the aforementioned 2013 directive, which the UK formally introduced into its laws in 2015, and the EU's increased monitoring capabilities of oil spills using satellite detection in 2016. This higher standard meant higher requirements on national regulators in the EU, given the new offshore directive.

[8]The EU Directive 2005/35/EC deals with ship-source pollution and on the introduction of penalties for pollution offenses. The directive was replaced by Directive 2013/30/EU following the Deepwater Horizon incident. Directive 2013/30/EU of the European Parliament and of the Council of 12 June 2013 on safety of offshore oil and gas operations and amending Directive 2004/35/EC. Reference to Deep Water Horizon.

[9]A Council of the European Union report from October 2023 highlighted the lack of compliance with this directive among member states, "Only eight Member States reported within the past five years to the Commission... It can be therefore assumed that the requirement of the Directive to impose penalties is rarely met. Most of the Member State authorities interviewed agreed that pollution incidents rarely or never result in penalties. This suggests deficiencies in the effectiveness of the penalty procedures in place."

[10]The introduction of EMSA's latest monitoring tracker, CleanSeaNet, led to lower proactive reporting amongst member states, "based on the example of the North Sea (Bonn Agreement) and the Baltic Sea (HELCOM), Member State authorities have been deploying less aerial surveillance resources since the introduction of CleanSeaNet in 2007."

[11]For instance, EU council reporting found "Criminal cases are frequently considered burdensome as they usually involve lengthy and resource-consuming processes, which Member State authorities cannot always undertake due to a lack of resources and expertise... Administrative penalties are often considered by Member States authorities to provide timely outcomes with reduced resource allocation."

At the same time, it is also worth noting that the UK government in 2015 had reluctantly embraced the EU regulatory governance. One key move involved the UK government's establishment of an offshore Competent Authority through the Department for Energy and Climate Change and the Health and Safety Executive. The government stated their motivation in implementing these legislative changes were "minimising the burdens on the offshore oil and gas industry".[12] Importantly, the shock of the 2016 referendum affected the pace and credibility of the adjustments that the UK government was in process of embracing in the aftermath of the EU 2016 harmonization directive. In the next section we explain how we leverage these conditions to examine how the nominal gap between Brexit UK and EU regulations would induce shirking from the side of UK-based oil firms.

3.2 Expectations

The history of Brexit and the stages of oil spill regulatory development described above lead us to the following expectations. During the co-occurrence of the Brexit campaign and the 2016 increase in maritime governance standards as a result of improved EU-led sea monitoring, we expect there to be robust and consistent detections of oil pollution across the area.

By contrast, we expect that the aftermath of the Brexit referendum generated regulatory misalignment that incentivized more pollution in UK waters. On this end, we conjecture that the highest amount of spills in UK waters should be detected after the referendum, starting in 2017 (also the year of the invoking of Article 50) and during the height of the Brexit negotiations, with 2018-2019 as the peak of the uncertainty around the UK's withdrawal from the

[12]The Oil and Gas Administration issued a warning in 2015 on the lack of regulatory direction and imminent issues of aging infrastructure in the North Sea, "Oil and Gas Survey: "Rising cost over many years, a fiscal regime that had not evolved with the fortunes of the basin, and the need for stronger regulatory direction, have complicated the challenges already faced by operators using aging industry structure and tackling more demanding fields... The risk that the profitability of producing fields will be insufficient to attract continued investment, leading to premature decommissioning of assets.... The risk that confidence in the future potential of the UKCS will continue to decline, resulting in the failure to secure critical long-term investment."

EU. This period was most unsettling for the UK regulator in the first place, with implications for institutional monitoring but also market actors. Consequently, we expect the increasing oil spills to be much more specific to Brexit UK than other North Sea countries.[13]

This suggests our main hypothesis:

H1: The count of oil spills in the United Kingdom waters increase immediately after the Brexit vote and is significantly higher than oil spills in other North Sea territories.

Notably, in 2020 the UK experienced the new Boris Johnson leadership, born from the December 2019 elections that rewarded the hard Leave wing of the Conservative Party. This, together with the consolidation of EU-UK negotiations in the backdrop of the pandemic, meant that by 2020 the UK's domestic regulator has also become more capable of filling the capacity vacuum and had more explicitly defaulted EU regulations onto UK laws. This leads us to an ancillary hypothesis:

H2: The count of oil spills in the United Kingdom waters should decrease after post-Brexit regulations are finalized.

These expectations test the first stage of our argument, namely that rig-level oil pollution in UK waters varied as a consequence of the Brexit referendum outcome compared to non-UK water pollution. The next two sections describe the research design and the statistical analyses that shed light on these hypotheses. We then move to further unpack the mechanisms behind our statistical results in the last empirical section of the paper.

[13] An interview with a Directorate-General for Energy consultant in January 2025 corroborated the intuition that Brexit triggered levels of uncertainty that specific political and financial 'enterpreneurs' have exploited in the aftermath of Article 50 being triggered. We come back to this point in the discussion of the underlining mechanisms in Section 6.3.

4 Research Design

The proposed hypotheses are tested first with an analysis of geolocated oil spills across time. To measure our main dependent variable, offshore oil spills, we collected data from the European Maritime Safety Agency (EMSA) CleanSeaNet, which uses satellite monitoring to track oil spills in the North Sea. In addition to satellite detection, EMSA alerts nearby vessels to collect observational evidence, which is then subsequently used to further train and improve their detection methods. EMSA has tracked oil spills for all member state's territorial waters since 2008, but data is only available from 2015.[14] Even after Brexit, EMSA has continued to monitor UK waters until 2023.

To track changes to oil spills over time, we create a virtual grid of equal size cells over the North Sea, and assign each cell a unique identifier. We then calculate the total number of spills per year per grid-cell. For our main treatment, the effect of the Brexit process, we create a term for pre- and post-referendum. The year 2017 is selected to align with the timescale of our data and chosen as Artcle 50 was triggered in March that year.[15]

For control variables, we identify the location of every oil rig in the North Sea from the Global Energy Monitor (Global Energy Monitor 2024). We then calculate the total active oil rigs per year per grid-cell (min=0, max=3). Other controls in the model include a dummy for whether the grid-cell sits along a sea border between two country's divisions, as well as yearly national oil production to account for the fact that higher production might induce more spills; we model oil production as annual barrels over total active rigs in each country's territory.

Figure 1 provides a snapshot of our panel data by mapping the EMSA detected oil spills in

[14]Data source: CleanSeaNet Service.

[15]Data available only at the yearly level. The data at the quarterly level was not disclosed to the authors to preserve 'identifiable information'. No additional information was provided; we presume this means that, as spills are more rare at the quarterly level, the identification of the rig would have given possible human monitors involved in some of the infringement cases.

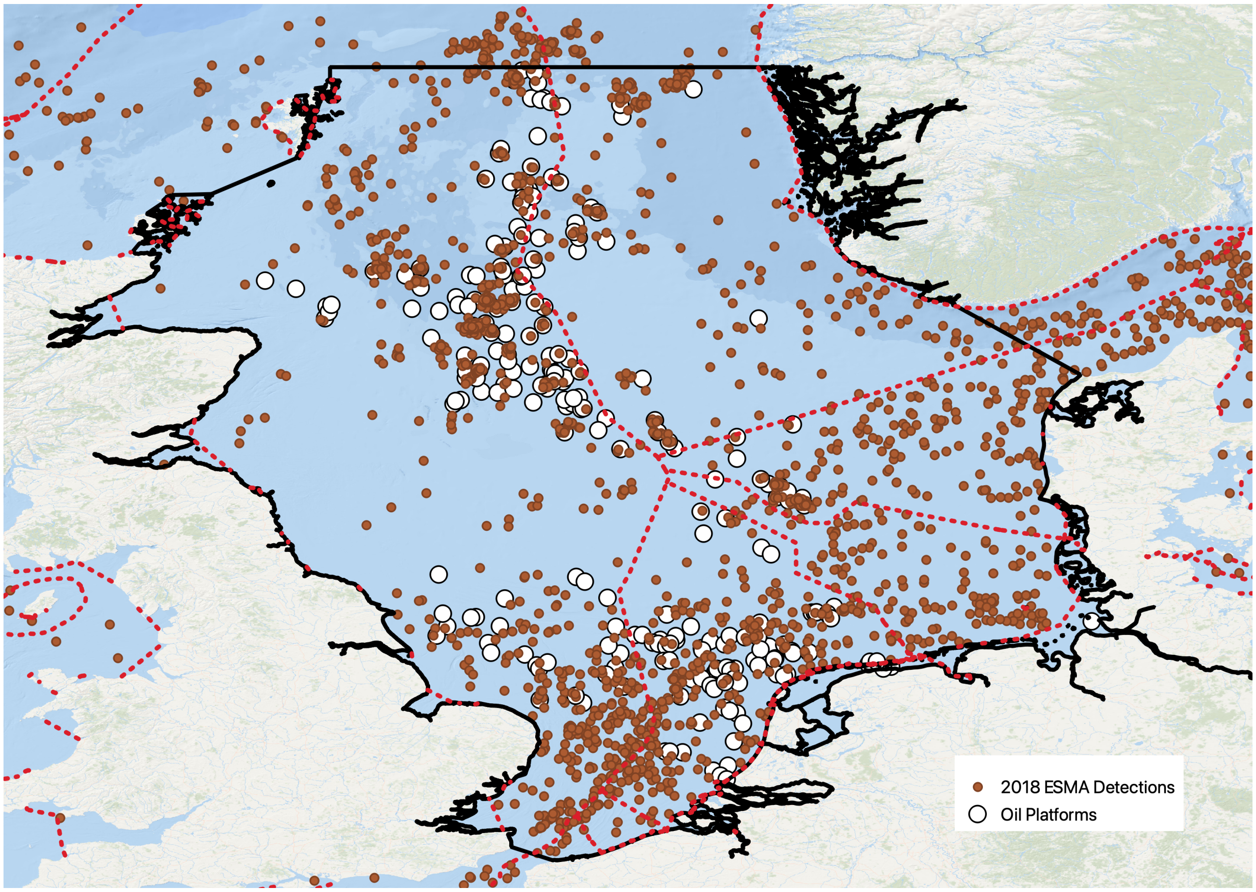

Figure 1: Data illustration. 2018 EMSA spill detections and location of operational oil platforms in the North Sea with territorial divisions.

2018 with the presence of oil platforms. Also in the map are the territorial divisions of the North Sea (red dotted-line), and the location of every active oil rig as of 2018 (white dots).[16]

Our main model specification is an event study estimation. We use the treatment of each year in our sample for those grid-cells in UK territorial waters with grid cell and year fixed-effects, as well as grid cell clustered errors. Non-UK grid-cells are given a treatment status of 0. For robustness, we also test an interaction between a categorical territory variable and period. Our main regression (equation 1) allows us to see how Brexit ($T = 2017$) affected areas of the UK waters ($treat_{i,k} = 1$). In alternative estimations we replace the identification year with 2016 to find qualitatively similar results.[17]

[16]See Appendix B.1 for a zoomed-in map showing the grid.

[17]Note that these alternative results rely on a shorter and less substantively justified pre-treatment period, as formally the negotiations started in March 2017.

$$y_{i,t} = \sum_{k=-2}^{T} \beta_k \times \text{treat}_{i,k} + \sum_{k=0}^{T_n} \beta_k \times \text{treat}_{i,k} + X\beta + \theta_i + \omega_t + \epsilon_i \tag{1}$$

The model also includes the set of controls ($X\beta$) as well as grid ($theta_i$) and year ($omega_t$) fixed effects. It is worth noting that oil spills are a count variable. Hence, in additional analyses we use the same specification but estimate a log link for a Poisson distribution in a Generalized Linear Model:

$$y_{i,t} \sim \text{Poisson}(\lambda_{i,t}) \tag{2}$$

$$ln(\lambda_{i,t}) = \sum_{k=-2}^{T} \beta_k \times \text{treat}_{i,k} + \sum_{k=0}^{T_n} \beta_k \times \text{treat}_{i,k} + X\beta + \theta_i + \omega_t + \epsilon_i \tag{3}$$

Then in a second step we estimate the following average treatment effect (ATE):

$$\text{ATT} = \frac{1}{T_n + 1} \sum_{k=0}^{T_n} \beta_k \tag{4}$$

In addition to these models, we propose two other regressions. First, because the variance of the dependent variable is larger than that of the mean, we also use a negative binomial regression and report the dispersion parameter. Finally, we also use a simple ordinary least squares (OLS) to which we add a spatial lag perimeter to capture spatial autocorrelation. The main substantive results remain unaltered across all of these specifications, as we show below.

5 Main Results

Table 1 reports the results from our main models. Overall, the statistical findings show support for our main hypotheses. Modeling Brexit as a natural quasi-experiment, we find that UK North Sea waters experienced an increase in detected oil spills in the immediate years after the referendum. In a Poisson count model, we find that the coefficient for UK oil detections is positive and significant ($p < 0.05$) every year since 2016 up until 2021 (model 1). A linear model (OLS) also finds a significant increase but only in years 2018 and 2019 (model 2). In both these models we find that the 2016 referendum may have increased spills already, although the largest positive effects are clearly across the two estimations are identified for the years 2018 and 2019. These results dissipate after 2020, and possibly reverse in 2023.

A negative binomial regression also finds positive and significant increases in UK oil spills in 2018 and 2019 (model 3). These patterns hold even when controlling for whether a specific grid has one or more oil rigs, and whether we include a spatial lag to account for contamination from other cells (model 4). The absolute number of rigs is estimated to be positive, but insignificant in the model, likely due to the fact that no new rigs enter our sample during the studied period.[18]

For further robustness, we use the EMSA's own classification of detected oil spills and filter only those spills that are declared 'high-confidence' detections by the European authority (model 5). Such detections are more likely to be true positives, as sometimes detections can have error. EMSA's own documents indicate that false positives can often be other types of pollution, like non-mineral oil. However, even using high confidence attribute to filter potential detections, we find similar results for the years 2018 and 2019.[19]

[18] In additional regressions we estimate the association of oil rigs to oil spills that avoid the pitfalls of unit and time fixed-effects. The results remain largely unchanged (see Appendix B.4).

[19] Notably, the year 2023 is no longer significant where it was negative and significant in every other model. This prompts us to be cautious about the 2023 result in the previous models.

Table 1: Brexit and Oil Spills in the North Sea: Main Regression Results

Dependent Variables:	Spills				High Confidence Spills
Model:	(1) Poisson	(2) OLS	(3) Neg. Bin.	(4) OLS	(5) OLS
Variables					
UK × year = 2015	-0.0513	-0.2533	-0.1520	-0.2533	-0.2954
	(0.3559)	(0.2703)	(0.3017)	(0.2703)	(0.2828)
UK × year = 2016	0.1957**	0.1358**	0.1395	0.1358**	0.0098
	(0.0977)	(0.0691)	(0.0982)	(0.0691)	(0.0935)
UK × year = 2018	0.2235**	0.2959***	0.2178***	0.2959***	0.2417***
	(0.0918)	(0.1067)	(0.0820)	(0.1067)	(0.0746)
UK × year = 2019	0.4398***	0.4682***	0.4120***	0.4682***	0.4315***
	(0.0777)	(0.1085)	(0.0724)	(0.1085)	(0.1424)
UK × year = 2020	0.2340**	0.1589	0.1296	0.1589	-0.0583
	(0.1012)	(0.1003)	(0.0856)	(0.1003)	(0.1155)
UK × year = 2021	-0.2389*	-0.1290	-0.1695	-0.1290	-0.0573
	(0.1351)	(0.1415)	(0.1038)	(0.1415)	(0.0788)
UK × year = 2022	-0.2149	-0.0004	-0.1367	-0.0004	-0.0242
	(0.1403)	(0.0863)	(0.1209)	(0.0863)	(0.0720)
UK × year = 2023	-0.5644***	-0.2090**	-0.5466***	-0.2090**	-0.0575
	(0.1431)	(0.0820)	(0.1284)	(0.0820)	(0.0598)
Oil rig count	0.2986*	0.1193	0.3481		-0.3617
	(0.1704)	(0.1429)	(0.2527)		(0.2662)
Oil spills ($t-1$)	0.0062***	0.4205***	0.0133***	0.4205***	0.1680***
	(0.0022)	(0.0405)	(0.0041)	(0.0405)	(0.0378)
Mean Oil Production (per rig)	0.1635*	0.0966	0.1094*	0.0966	0.0342
	(0.0946)	(0.0722)	(0.0600)	(0.0722)	(0.0570)
Oil rig (+ spatial lag)				0.1194	
				(0.1429)	
Fixed-effects					
cell id	Yes	Yes	Yes	Yes	Yes
year	Yes	Yes	Yes	Yes	Yes
Fit statistics					
Observations	8,364	12,348	8,364	12,348	12,348
Squared Correlation	0.83374	0.73320	0.79369	0.73320	0.48699
Pseudo R^2	0.55105	0.26244	0.27266	0.26244	0.15323
BIC	25,453.7	58,702.5	25,147.2	58,702.5	58,396.7
Over-dispersion			6.1443		

Year 2017: triggered Article 50 that started Brexit. Clustered (cell id) standard errors in parentheses.
*Significance Codes: ***: 0.01, **: 0.05, *: 0.1*

Figure 2 plots the coefficients for UK grid cells pre- and post-Brexit estimated in model 5 from Table 1.[20] The graph helps to provide information on how oil spills increased following 2017 as the event year. In particular, high-confidence spills suggest that compared to 2015 and 2016, oil spills increased markedly in 2018 and 2019 ($p < 0.01$). The estimated effects are also quite similar to that of the other models with all potential detected spills. This provides further evidence of the general model and that even using the lowest thresholds,

[20]Further information on all oil spills, not just those that are high confidence detection, is available in Appendix B.2.

there appears to be congruence between the empirical results and the proposed theory.

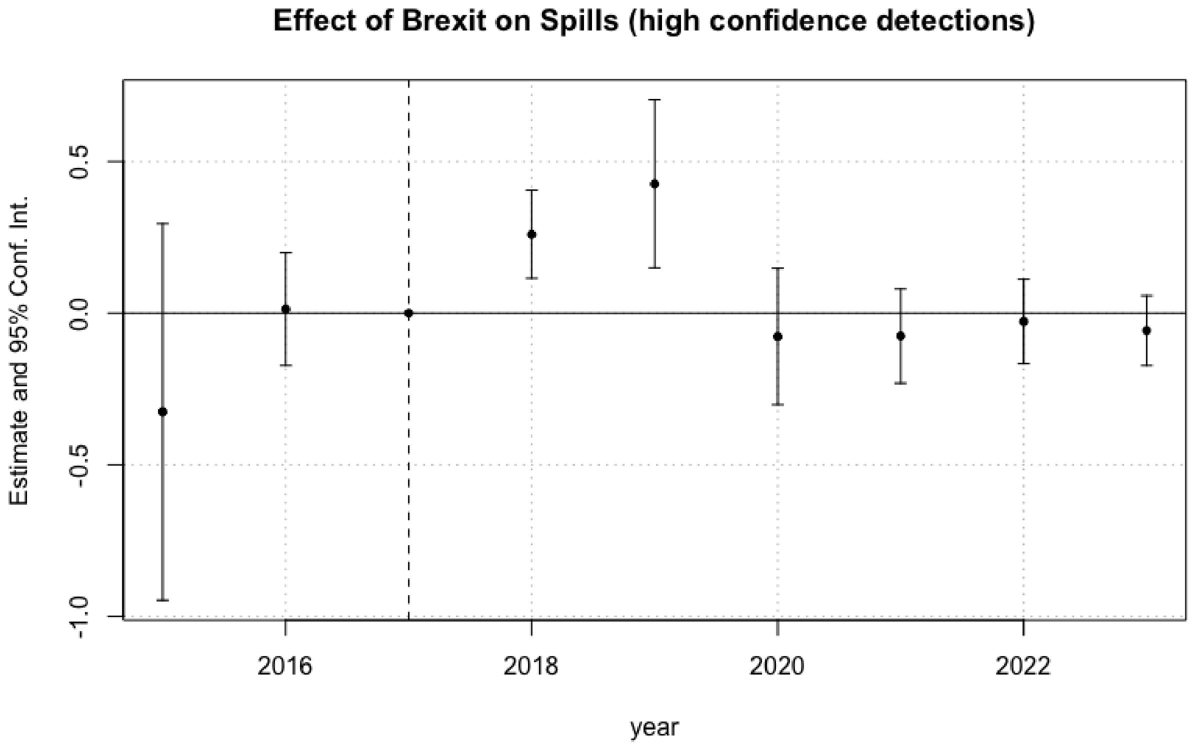

Figure 2: Results of OLS model of count of spills in each grid cell of each country, pre- and post-Brexit. Grid cell and year fixed-effects with clustered errors at the grid-level. Only high confidence spill detections included.

The results are robust to a number of additional and alternative tests. In separate analyses we create factor treatments to compare the UK not only against a grouped non-UK territory (as the models in Table 1 require), but to each of the other North Sea countries in our dataset: Denmark, the Netherlands, and Norway. This model (Appendix B.3) returns similar findings as the results presented above. The trends are clear: there is a highly pronounced increase in oil spills in 2018 and 2019 in UK especially compared to all other regulatory jurisdictions. The predicted count of spills in the UK increases to 3 per grid in 2018-19, while it never goes up to 1 per quadrant in the next most polluting countries, the Netherlands and Norway (see Appendix B.3).

Another robustness test examines the strength of the regulator in the UK, as its regulations

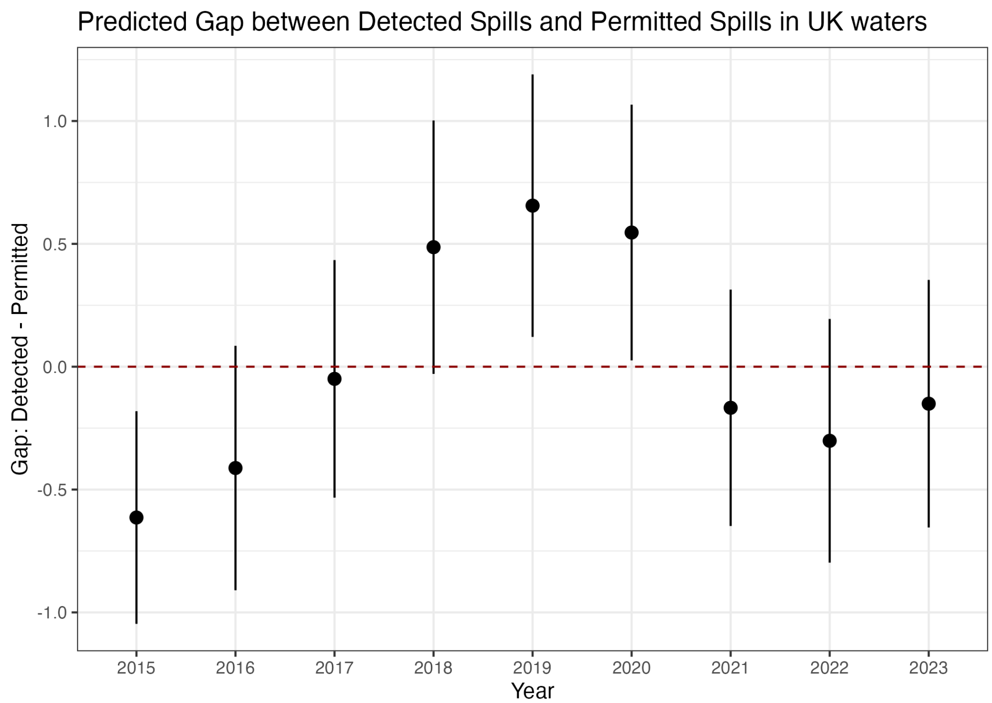

Figure 3: Model of UK oil spills only per grid-cell, with detected minus permitted spills. Even accounting for permitted spills, there is a surplus of unaccounted for oil spills between 2018 and 2020.

requires companies to report spills, as well as seek permits for spills related to essential operations. Because some recorded spills might be due to legal spills, we use a different approach that models the gap in permitted spills to detected spills. The expectation is that if there is a greater positive gap in the period in which we see more spills in 2018 and 2019 from the main analysis, we can be fairly confident that some spills are likely clandestine and not well reported. As Figure 3 shows, we find that most of the results over our time period are driven by unreported spills. This implies that UK firms are spilling more oil than was legally allowed by the regulator in the window of time corresponding to the Brexit negotiations.

It is also noteworthy that the augmented rate of oil spills between North Sea waters is temporary and disappears after 2020. This can be explained in several ways. The first explanation is that UK oil production and domestic demand declined during Covid-19, indicating less oil to spill. Second, after the Brexit transition period ended on January 1, 2020, the UK no longer had access to the single market. While tariffs were not implemented on goods, administrative and customs barriers led to an overall reduction in UK exports to the EU (Webb and Ward 2024), and this was also the case for oil.[21] An additional reason for the reversal in oil pollution comes from increased independent monitoring by the UK in 2020, which we examine in the next section.

6 Mechanisms

We have presented evidence that Brexit led to more oil spills in UK waters relative to other adjacent European nations. We argued that this difference in oil spills came from a misalignment of regulations between UK and the EU due to uncertainty during the Brexit negotiations. These, together with accelerated structural changes in oil markets in this time window, contributed to UK-based oil firms to disinvest from maintenance and cause more oil spills.

In this section we seek to uncover the exact ways in which these conditions during Brexit incentivized the negative environmental outcomes identified in the previous analyses. We first start with highlighting evidence of the decreased UK regulatory capacity following Brexit, a baseline feature of our theory. We then move to evaluate whether the decreased regulatory capacity was a direct product of public or traditional firms' regulation preferences. We conclude by unveiling patterns of market sorting and a new emerging ecosystem of short-sighted firms populating the UK North Sea in the aftermath of Brexit.

[21]Indeed, oil exports from the UK decreased overall due to lower production, but exports to the UK decreased 3.8 times more than to other destinations: oil exports decreased 1220 thousand tonnes to non-EU markets between 2020 and 2021, while exports to the EU decreased by 4720 thousand tonnes despite similar domestic consumption. See Appendix C.1.

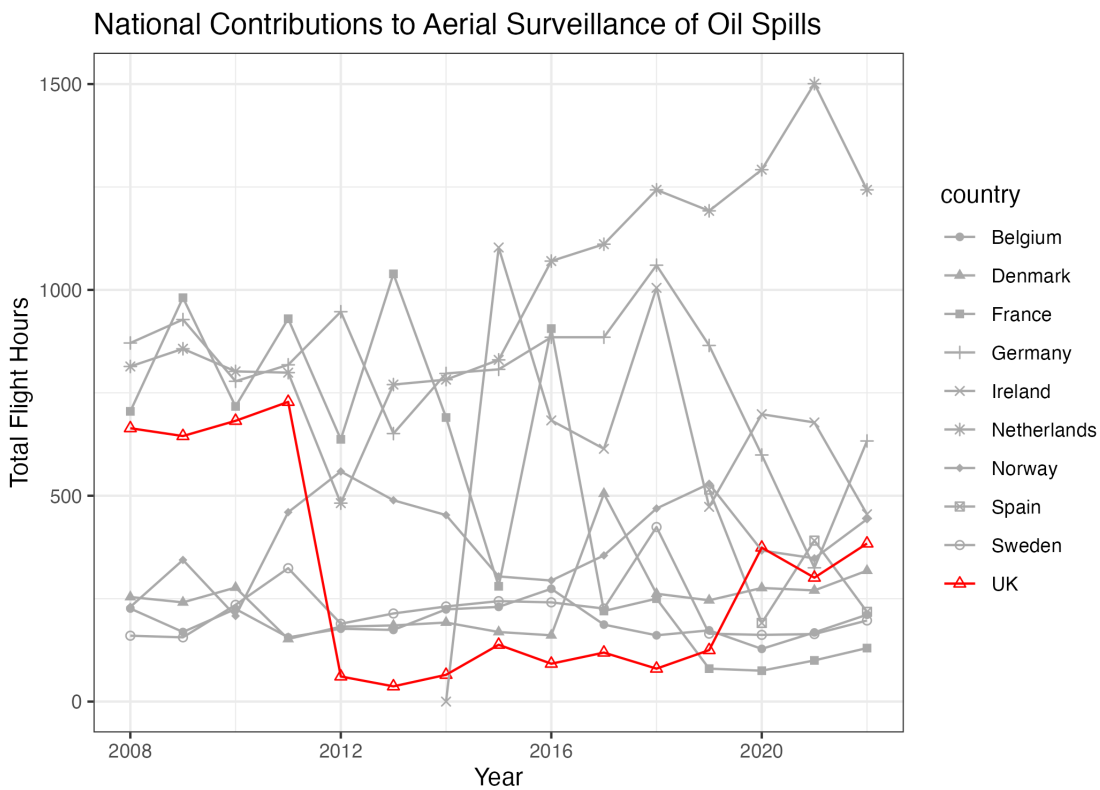

Figure 4: Bonn Agreement total reported routine surveillance flights and satellite detection investigation flights per country. Source: Bonn Agreement.

6.1 Capacity Differentials and EU Oversight

A central piece of our theory, and a crucial way to interpret our results, is that the Brexit referendum and the uncertain period following the triggering of Article 50 hit the UK at a point of low regulatory capacity. This, we argued, contributed to firms' calculations about operational investments directly connected with the odds of spills. To clarify this point, we look at national contributions toward routine aerial surveillance and investigations of satellite monitoring of oil spills as organized with the Bonn Agreement. This data reveals the relative intensity of each nation's efforts to independently monitor and sanction oil rigs for oil spills leading up to Brexit and after.

As Figure 4 indicates, the UK was one of the leading nations of this initiative until 2011, when a government austerity measure led it to cut the program. Until 2020, the UK had the least active aerial surveillance compared to all other participating nations, despite having the most oil rigs of any North Sea country, and hence the greatest risk of oil spills. When the Brexit referendum occurred, the UK's offshore regulatory capacity was clearly the weakest of the North Sea in terms of capturing violators if they chose not to report oil spills to the UK regulator. This likely created a sense of impunity among oil firms, leading to an increase in oil spills after 2011. As the gap between detected and permitted spills in the UK also indicates (Figure 4). The evidence lends itself to an interpretation that oil firms understand the lower monitoring capabilities of EMSA and the UK regulator. It also helps explain the reversal of oil pollution after 2020: the number of flights the UK takes for aerial surveillance - after many years of low activity - increased in 2020 and continued this new pace in 2021-2022.

To further assess whether the loss of EU oversight may have played a role in the reduced environmental protections in the UK, we turn to assessing all EU infringement cases for the environment, energy, and climate action. A critical assumption of our theory is that part of why the EU's integration led countries other than the UK to adapt to the raised environmental standards in 2016 was due to the threat of potential oversight. Absent this oversight, the UK faced significant policy misalignment. The EU's primary means of environmental oversight is through infringement cases. Infringement cases can begin when an individual or another EU member files a complaint about a country's adherence to EU directives. The EU then can open a case, and can even levy a fine.[22]

The data suggests that the EU is active in pursuing environmental infringements of its directives in the UK, including of its offshore directives. The UK was frequently cited with environmental infringements, indicating an important role played by EU oversight. This evidence corroborates the notion that the EU was active in policing environmental and related issues, and that absent this oversight, the UK had much lower oversight capacity of its offshore oil and gas operations.[23]

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[22] Most cases are resolved through dialogue and agreements for the member state to become compliant. However, the threat exists in principle.

[23] For instance, once the Brexit referendum occurred, new infringements were unlikely to compel the UK to become compliant given the uncertainty and eventual shift to a "hard Brexit", whereas all

6.2 Regulatory Preferences among the Public and Mainstream Firms

We argued that Brexit led to regulatory misalignment between the EU and the UK, comprising different rules, enforcement capacity, and a lack of oversight. Given that Brexit was a popular vote, here we turn to assessing evidence of the preferences amid voters and firms in connection to Brexit and oil spills.

For the public, we rely on data from a substantively unique poll conducted by the not-for-profit organization Oceana (through YouGov) in May 2024. This survey collected responses from a representative sample of UK citizens (n=2111).[24] Figure 5 presents the most relevant patterns. We find that amid both Leave and Remain voters, there is high concern for oil spills, and even higher agreement that oil companies that spill oil should be fined. This evidence indicates that even among pro-Brexit voters, their motivations are not to lower regulatory standards for the oil and gas sector. In fact, the public opinion patterns indicate that, despite the sovereignist campaign fueling Brexit, the preferences for public good provision among the public were more in line with maintaining with EU regulations and oversight, which helped compensate for weak domestic UK monitoring capacity.

For firms, we turn to the UK business perception surveys conducted by the UK government.[25] For 2016, we find that only 7% of all surveyed firms expected burdens resulting from regulation due to the EU bringing in new directives. This percentage was higher for the "Agriculture/Mining/Energy" sector that is relevant to our studies; however, the percentage for these firms was still only at 15% and constituted responses from only 9 companies. Later business surveys indicate that one business in three is concerned with the economic impli-

other North Sea countries would still face potential infringement cases.

[24]While 2024 is of course a few years after the 2016 referendum, UK politics has never completely moved on from Brexit in the past decade, and research has shown that Brexit preferences have remained relatively stable overall (Tilley and Hobolt 2023).

[25]See Department for Business, Energy and Industrial Strategy, 2016, 'Business Perceptions Survey Report. https://assets.publishing.service.gov.uk/media/5a81acc240f0b6230269894e/beis-16-21-business-perception-survey-2016.pdf.

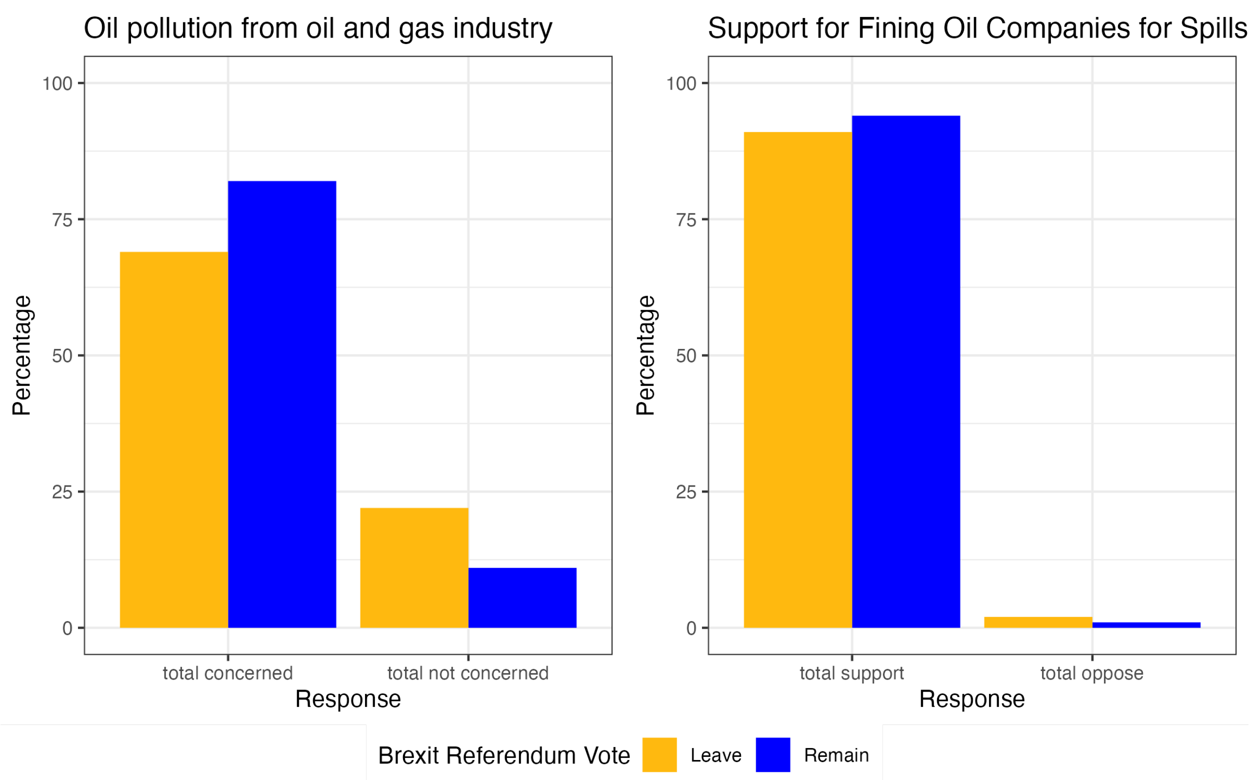

Figure 5: Survey respondents among a representative sample of UK citizens (Source: Oceana). Left: level of concern regarding oil pollution from oil and gas industry. Right: support for fining oil companies for oil spills.

cations of Brexit but the majority of companies stably discount the burden of pre-Brexit EU regulations.[26] Taken together, the evidence suggests that firms were unlikely to have pursued Brexit as a means of having the lower environmental standards identified in our results.

To further corroborate this, we examine lobbying data by the oil and gas industry in both the UK and the EU. Firm influence and interest group activity is often the central actor of globalization perspectives on firm versus regulator power (Stokes 2020; Strange 1996). However, we do not find evidence of increased lobbying amid oil and gas sectors during the Brexit transition period (Transparency International UK 2024).[27] Filtering for meetings

[26]See Department of Business and Trade, 2023, 'Longitudinal Small Business Survey: panel report UK, 2019-2022.' https://assets.publishing.service.gov.uk/media/65043425dec5be000dc35f4f/Small_Business_Survey_2022_-_Panel_Report.pdf.

[27]Lobbying to the European Commission on oil-related topics was obtained from LobbyFacts. The European Commission began publishing this information from December 1st 2014; all high-level meetings are required to be posted online within two weeks, although this rule is not always followed. We used the search terms 'oil' and 'petroleum' which searches for meetings that include

between elected officials and the oil and gas sector we find similar patterns between oil and gas company lobbying in London and Brussels, with less lobbying between 2016 and 2020 in both capitals (see Appendix C.2).[28]

6.3 The New UK Ecosystem of North Sea Firms After Brexit

We finally evaluate whether specific firm-level dynamics occurring as the Brexit negotiations raised regulatory uncertainty may have explained the behavior leading to more UK-based oil spills. This is an important piece of the puzzle to determine, as a part of our argument that connects withdrawal in the form of Brexit to oil spills involves the latitude afforded to firms and the ability to move capital quite freely. This meant that amid regulatory misalignment between the EU and the UK, the UK regulator had to confront a shifting landscape of oil firms.

As the political economy literature of firms argues, fossil fuel companies are well poised to quickly react to major disruptions through one strategy, which some scholars call de-risking. This strategy includes selling off controlling shares of firms as a means of diminishing capital losses because of uncertainty. Rather than exit, de-risking tends to maintain operations, but the changes in corporate structure are likely to lead to environmental degradation. This is also called a 'harvesting strategy' whereby firms establish a mid-to-long term exit strategy by limiting production to mostly profitable products and utilizing production-sharing contract structures on oil and gas licenses. The UK Treasury acknowledged this occurrence in a 2017 Tax discussion paper, stating "licensees are focusing on strategic hubs... and seeking to reduce their ownership of older, outlier fields in the UKCS" (Hunter and Waterman 2016).[29]

this descriptor in their goals/ remit; main EU files targeted; and meetings.

[28]We also do not find evidence that the operating costs of running oil rigs increased following Brexit. See Appendix C.3.

[29]Incumbents and new entrants have different incentives when it comes to extraction, incumbents can claim relief when decommissioning, while smaller and "new entrants to the UKCS have to be confident that the acquired asset will generate enough tax history over its remaining life to equal the decommissioning costs at the end of the field's life" (Hunter and Waterman 2016). The UK Environmental regulations also claim that "Clearly a very small company with little experience should expect

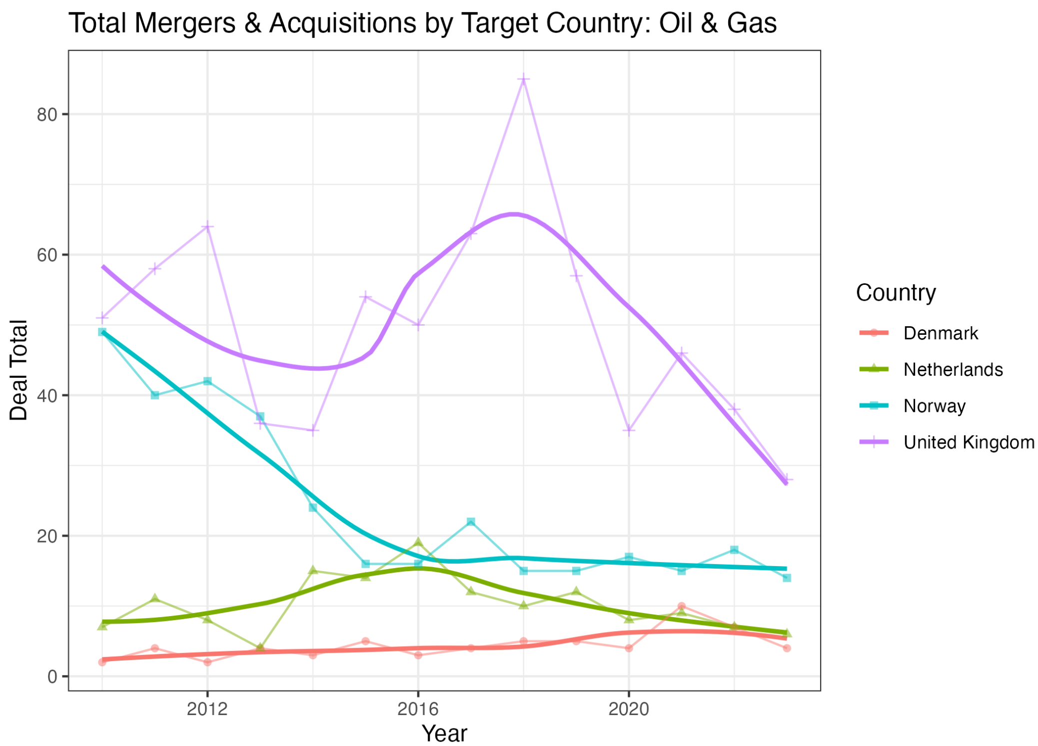

Figure 6: Data from LSEG (formerly Thomson/Refinitiv) SDC Mergers and Acquisitions filtered for oil and gas industry label in the four target countries.

To measure the volatility of firms in the oil sector across the North Sea countries, we analyze mergers and acquisitions (M&A) within the sector. Research has found that M&A are often motivated by firms seeking under-performing assets, with the hope of turning a profit later on (Crippa 2023). As such, we expect M&A to increase in the UK oil and gas sector after the Brexit referendum, whereas there should be fewer M&A in EU or Norwegian markets.

Figure 6 shows this was the case, with a sharp increase in M&A after 2016 in the UK and the UK only. In fact, 2017 exhibits the highest rate of M&A in the time span with over 80 reported M&A deals. We take this as suggestive evidence that speculative firms, equity firms, and inexperienced oil and gas owners selected into the UK market as a result of the existential uncertainty generated by Brexit. This highlights the power of multinational firms to seize the opportunity of international disintegration to disinvest in environmentally sensitive

to come under greater scrutiny and have to provide more information than an established operator with a good record." (UK Gov 2014).

activities, at the detriment of the public good.

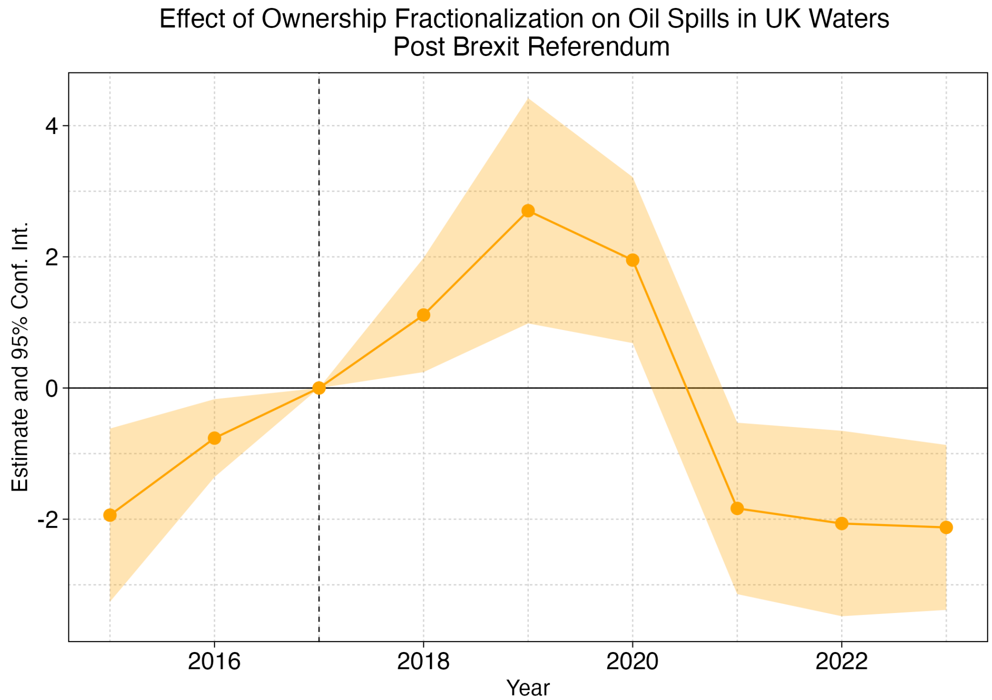

Figure 7: Results from an event study where the treatment indicates above median number of owners per grid cell for the UK (set year for estimation purpose is 2017, corresponding to the invoking of Article 50). Outcome is number of oil spills detected per grid cell year. The full model is reported in Appendix B.5.

Were the companies that entered the UK oil rigs after Brexit structurally different than any other companies in the North Sea beforehand? We can answer this question by looking at changes in oil drilling license ownership across years and nationalities.

The UK data on license ownership comes from the North Sea Transition authority and shows that significantly more owners populated the rigs in UK waters and that these owners were less likely to represent equity monopolies after 2017 (North Sea Transition Authority 2025).[30] On the basis of this data, we can see which grid cells have had the highest fractionalization of ownership pre- and post-Brexit referendum and subsequently use this fractionalization as a mechanism to test whether those grid cells experience more oil spills. Figure 7 shows the UK's grid-cell heterogeneity by changes in oil drilling license ownership over

[30]See also see Appendix B.5.

time. We find that the identified effect of Brexit is particularly strong in UK grid cells whose ownership becomes more fractionalized after 2016. Indeed, an event study where treatment is above the median total owners of license in a grid shows significant ($p < 0.01$) and positive effects on oil spills in grid cells (rigs) with more total owners after Brexit (Appendix B.5).

Furthermore, in terms of nationalities of new companies in the UK market – i.e., large license share companies who had no ownership prior to 2016, we find that many of these companies are subsidiaries whose parent company is headquartered in the UK, with some new firms from the United States and Australia.[31] These companies manifest the spirit of the Conservative party's vision of international partners in the post-Brexit era.[32] In sum, the firm sorting dynamics unveiled in this section confirm that the structural changes that Brexit accelerated were not in contrast to the post-Brexit view of political elites in place.

6.4 Beyond the Sea? External Validity

Our paper concentrated on the negative consequences of Brexit on oil operations at sea, but a legitimate question is whether similar dynamics extend beyond offshore oil rigs. We believe our argument should extend to other sectors in the UK. To probe the external validity of our argument, we investigated the trends of the UK's privatized potable water and water treatment sector over time – a highly problematic one often reported in the news.

We collected official discharge data[33] and analyzed it in an event study fashion. We see an increase in the total reported hours of discharged sewage after 2017, consistent with the increase in oil spills (Appendix D). We go further by estimating a longer time series by using bathing site bacteria tests and predict sewage discharge. Our predicted data matches reported data for available years, and further supports the conclusion that similar to offshore

[31] These include Finder, Heartshead, and Triangle Energy Global. See Appendix C.4.
[32] See Boris Johnson's 2022 'The Commonwealth gives Britain a boost' speech, https://www.gov.uk/government/speeches/pm-boris-johnson-the-commonwealth-gives-britain-a-boost.
[33] Source is Department for Environment, Food and Rural Affairs, https://environment.data.gov.uk/dataset/21e15f12-0df8-4bfc-b763-45226c16a8ac.

oil outlaws, water companies behaved as onshore outlaws after the Brexit referendum. Altogether this data suggests water companies were likely to have discharged more sewage to avoid costs and also under-reported their discharges after Brexit (see Appendix D). This gives further credence to the broad scope of our argument.

7 Conclusion

The politics of international disintegration have stirred questions about the conditions under which withdrawal from international organizations occurs, yet we have little evidence of what concretely happens to public goods in the shadow of international withdrawals. Our paper challenges the portrayal of the globalization backlash as one that reinstates sovereignty and boosts state capacity for the purpose of providing better public services. Focusing on the case of Brexit, we argue that international withdrawal can cause periods of regulatory misalignment, which makes the withdrawing country's regulatory capacity relevant to environmental outcomes. We conjecture that international disintegration coupled with misalignment leads to a transition with little monitoring and oversight, and as the exit country remains with low state capacity, we also expect certain low-compliance firms to take advantage of this leniency and circumvent regulations as a means to extract higher rents. These dynamics, we argue, exert environmental damage to public resources in the withdrawing country in the first place.

We show empirical support for our theory with a temporal analysis of geo-coded offshore oil spills in the North Sea. Our findings suggest that the Brexit referendum led to poorer environmental outcomes in UK waters compared to EU and Norwegian waters, especially at the peak of the uncertain Brexit negotiations between 2017 and 2019. Further analyses show that, as the EU improved its oil spill monitoring capabilities, Brexit shifted the problem to the austerity weakened UK regulator. Additional UK fine-grained data also indicates that the oil spills are not traceable to a shift in public opinion or new lobbying activity by older mainstream companies. Rather, the post-Brexit increase in oil spills is attributable to many new private actors populating the UK oil and gas sector in the years immediately after the referendum.

Our findings have public policy relevance and make several contributions to different types of scholarly debates. First and foremost, our results highlight that the success of political campaigns against international cooperation likely entails negative public externalities. While the deterioration of public good standards may depend on the withdrawing country's economic structural equivalence to international partners, we think that overall environmental protection is likely to be an immediate victim of political projects such as Brexit.

Secondly, our research provides insightful evidence on the effectiveness of international organizations in substituting national actors in public good monitoring. Namely, our findings underscore that European integration has generated a significant commitment for environmental policy compliance. While past work has debated the credibility of European institutions to foster public performance, most empirical evaluations have lacked proper counterfactuals. Our causal inference analysis clearly shows that - in the case of oil spills - the EU provides for better monitoring than most national authorities, especially those weakened by years of austerity, like the UK. Importantly, we find that EU oversight incentivizes the governance of the hard-to-regulate sector of offshore oil extraction. This is an important finding not just for the battle against sea pollution, but also for other areas of public relevance such as water sewage and climate emissions.

Lastly, our finding that environmental outcomes became collateral damage to Brexit politics highlights the misalignment between voters' expectations around the Brexit referendum and real policy consequences. Despite the momentum of ideas such as fixing the democratic deficit and 'taking back control,' our results suggest that Brexit undermined UK sovereignty by enabling novel private actors to operate without punishment in an elite-backed ecosystem of fractionalized markets. While the majority of the British electorate voted Leave in 2016, our paper offers systematic evidence that, at least in the short run, this outcome betrayed first and foremost the British public's desire for better public goods.

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Appendix

Offshore Outlaws:

Brexit and Oil Spills in the North Sea

Contents

A Generalizability of the Argument

Our argument zooms in on Brexit, however our framework allows for a broader conceptualization of the link between withdrawing from (of embedding in) international organizations and environmental outcomes. We argue that understanding regulatory stringency and firm compliance under global interconnection can be understood with two dimensions: structural equivalence (which can be preserved or altered with respect other nations/foreign partners) and the degree of integration (moving towards integration or disintegration). Following previous research (see, e.g.,Cao and Prakash (2010)), structural equivalence can be defined as the positions of specific countries in the trading network. Some processes of integration and disintegration alter a country's position in the global economy; that is, they alter which markets they compete with. Other types of integration or disintegration preserve structural equivalence. In the paper we use this framework to locate the case of interest, i.e. Brexit. However, this framework can also be used to draw wider theoretical insights for other potential cases beyond the scope of this paper. See Table 2.

These two factors help explain cases where regulatory stringency converges (integration) or diverges (disintegration). Regulatory stringency refers to how increased economic integration may force regulators and firms to adjust their compliance practices. Firm behavior, in this context, examines whether companies align with similar standards across countries (convergence) or diverge, potentially leading to lower compliance with regulations.

We argue that when integration alters structural equivalence—meaning the relationships or conditions that make different markets or firms comparable—it creates uncertainty, leading to varied compliance as firms react to new competitive pressures and potential price changes. In cases of disintegration, firms in the affected market are likely to diverge from strict regulatory standards, driven by policy uncertainty and the need to adapt to the altered market conditions. Meanwhile, firms in other markets who maintain structural equivalence are less likely to deviate from existing regulatory norms. We see then that even in the absence of regulatory change (like with what happened with integration), disintegration can also lead to divergent firm behavior.

For example, with the ratification of NAFTA, Mexico's structural equivalence was altered. Before Mexico's entry into NAFTA, its position in the global economy was more aligned with other developing countries that had looser environmental regulations. After NAFTA, Mexico now became more closely integrated with the U.S. and Canada, countries with more stringent environmental regulations. Still, NAFTA led to a harmonization of various policies, including environmental regulations. Mexican firms found themselves in a new competitive environment. They now competed not only with domestic firms but also with US and Canadian firms, as well as manufacturing giants that export to the US (e.g., China). To maintain competitiveness, some firms opted to circumvent these new, more stringent environmental standards. Indeed, evidence suggests NAFTA has shifted dirtier industries from the US to Mexico, at least through intermediate inputs (Cherniwchan 2017). The Mexican government faced challenges in enforcing new regulations uniformly across all sectors, leading to inconsistent compliance among firms; essentially resulting in a pollution haven.[34]

[34] Others found similar evidence of this pattern, like with dumping of dirtier and out-dated pas-

Table 2: Broad Conceptual Implications – Global Relations, Regulatory Stringency and Firm Behavior

	Integration (policy alignment)	**Disintegration (policy uncertainty)**
Structural Equivalence Preserved	Outcome: convergent stringency, convergent firm behavior *Case: MERCOSUL agreement	Outcome: divergent stringency, convergent firm behavior *Case: US exit from Paris Climate Accord
Structural Equivalence Altered	Outcome: convergent stringency, divergent firm behavior *Case: Mexico ratifies NAFTA	Outcome: divergent stringency, divergent firm behavior *Case: Brexit

Contrary to this, greater economic integration can be achieved without seriously altering the position of members' economies. For example, MERCOSUL is an economic union between countries that are primarily commodities exporters in South America; but this trade union does not seriously alter any member country's position in the global economy or its competitors.[35] Still, MERCOSUL brings greater stringency convergence, and as a result, likely leads to greater convergence of firm compliance with regulations across markets. Market competition is unlikely to be a source for firms to circumvent regulations or for governments to under-enforce them. As a result, the effects of MERCOSUL lead to more similar compliance rates of firms across countries, and are unlikely to lead to high non-compliance in any single country.

senger vehicles (Davis and Kahn 2010).

[35]While a deep exploration of structural equivalence is beyond the scope of this paper, countries are unlikely to achieve structural equivalence alterations with trade unions among similar members, especially those that are primarily commodities producing.

B Main Analysis: Robustness Checks

B.1 Data Description: Refined Map

The map below illustrates our oil spills data for a zoomed in area of the North Sea in 2018. The red-line indicates the UK and Norway maritime border. Points indicate where there are oil rigs, and smaller brown points indicate unique oil spill detections.

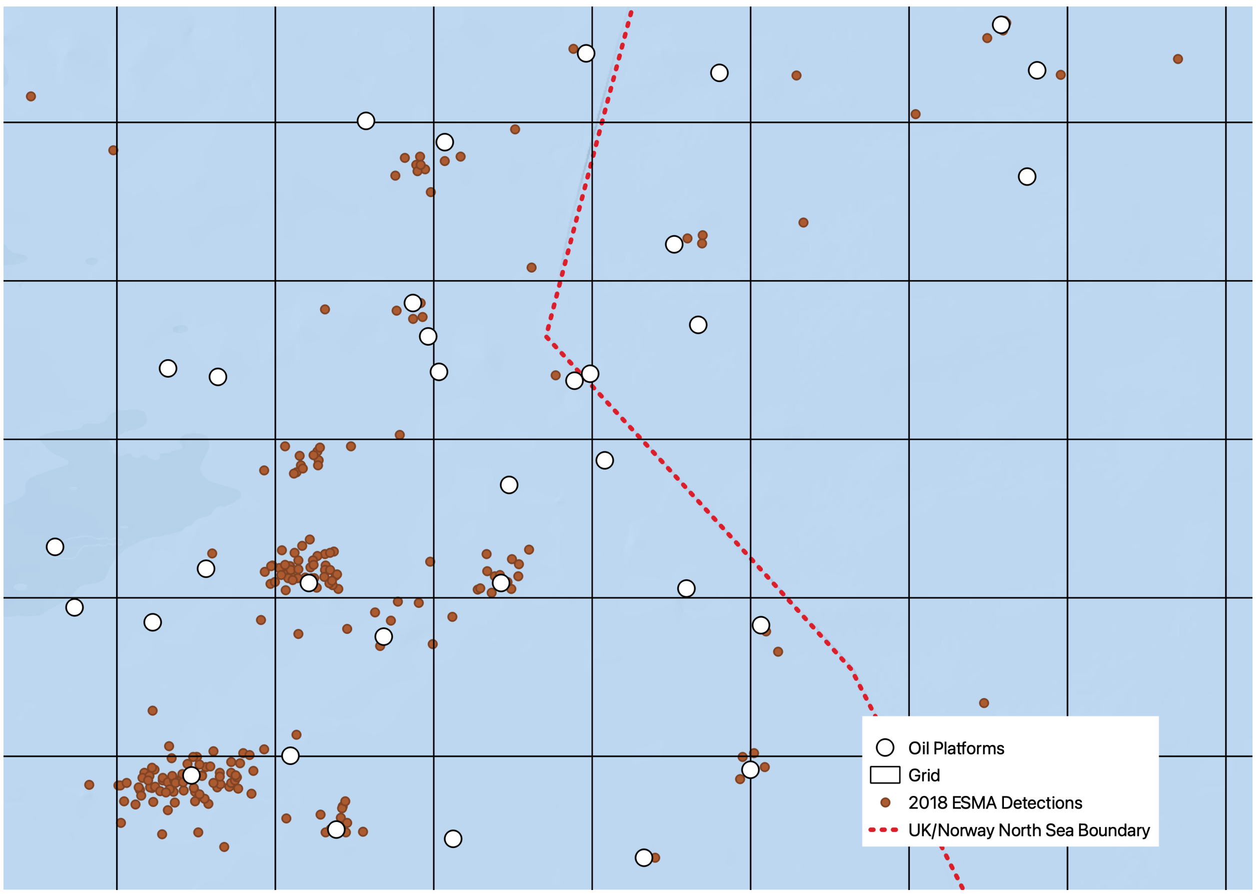

Figure 1: Illustration of data points – 2018 EMSA spill detections and location of operational oil platforms in the North Sea with territorial divisions (UK versus Norway).

B.2 All Oil Spills

We run regressions that include all oil spills (i.e., both low-and high-confidence spills) in the sample pre and post-Brexit, with grid cell and year fixed-effects, and standard errors clustered at the grid level. In Figure 2 below we can see that the count of spills increases post-Brexit, with a peak in 2018-2019. The count goes down after 2021. The significant decline in 2023 may be related to the UK government passing legislation that imposes unlimited financial penalties on companies who pollute from the Environment Agency (but see also our discussion on UK oil production and consumption in Appendix C.1).

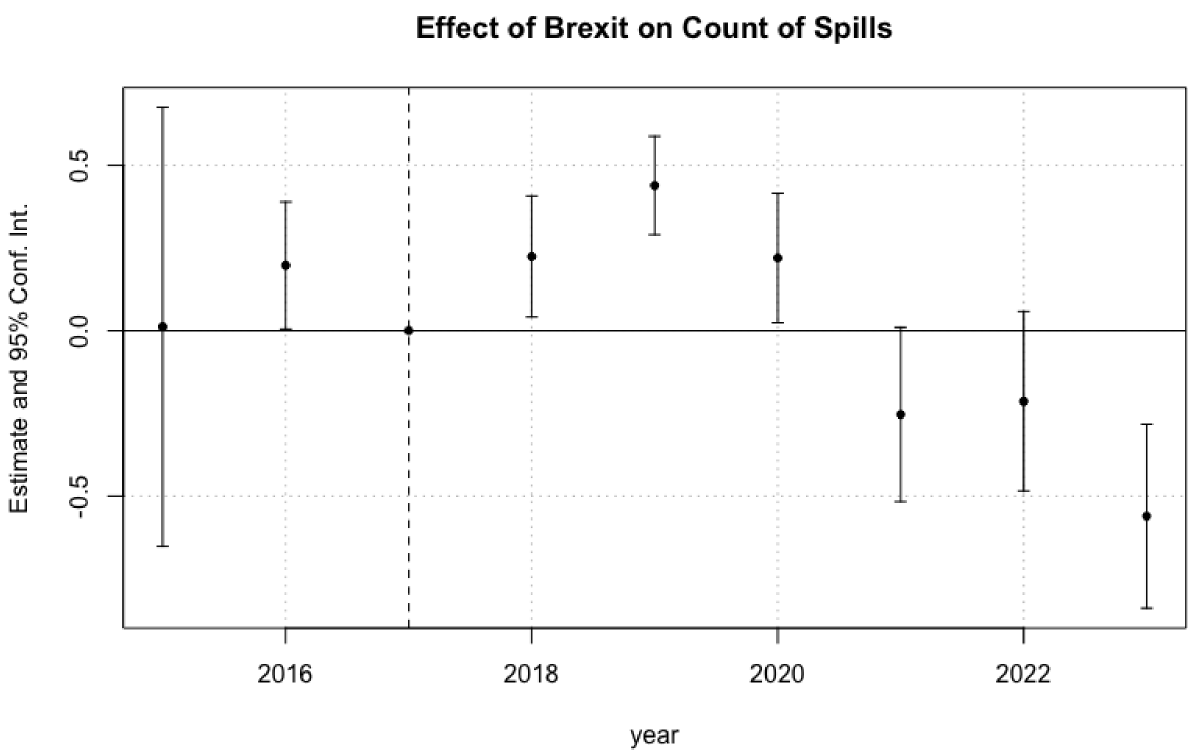

Figure 2: Results of GLM model of count of spills in each grid cell, pre- and post-Brexit. Grid cell and year fixed-effects with clustered errors at the grid-level.

B.3 Alternative Analysis: Country Dummies

In alternative analyses, we use country factors (dummies) rather than a ‘UK vs other countries’ framework (reported in the main paper) to assess relative changes in predicted oil spills over the studied period. As Figure 3 shows, we see increases across the North Sea, but especially in the UK, consistent with our theory.

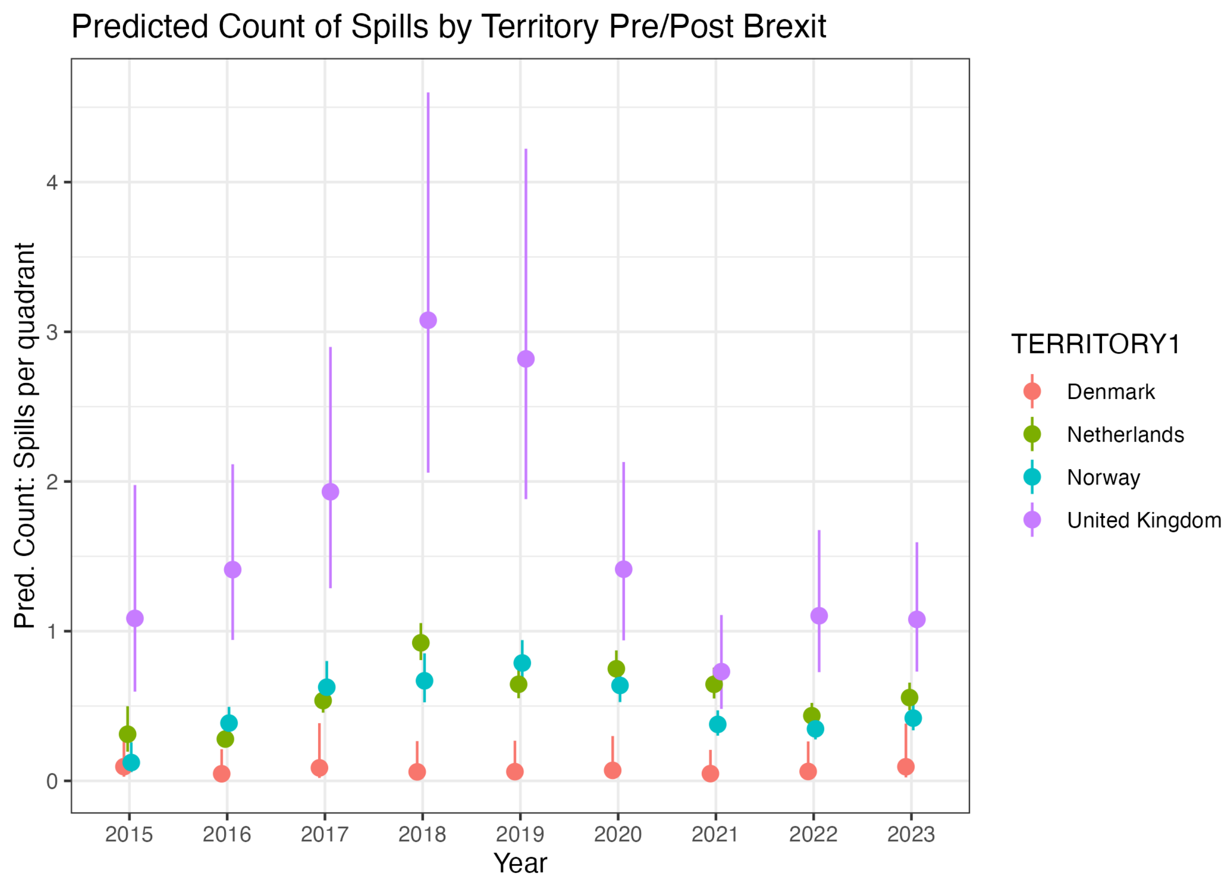

Figure 3: Results of GLM model of count of spills in each grid cell of each country, pre and post-Brexit.

B.4 Relationship between Oil Rigs and Oil Spills

As a sanity check, we run a simple model of how the number of oil rig platforms affects the number of detected oil spills. In line with baseline expectations, we find a significant increase in expected oil spills as proximity to oil platforms increases.

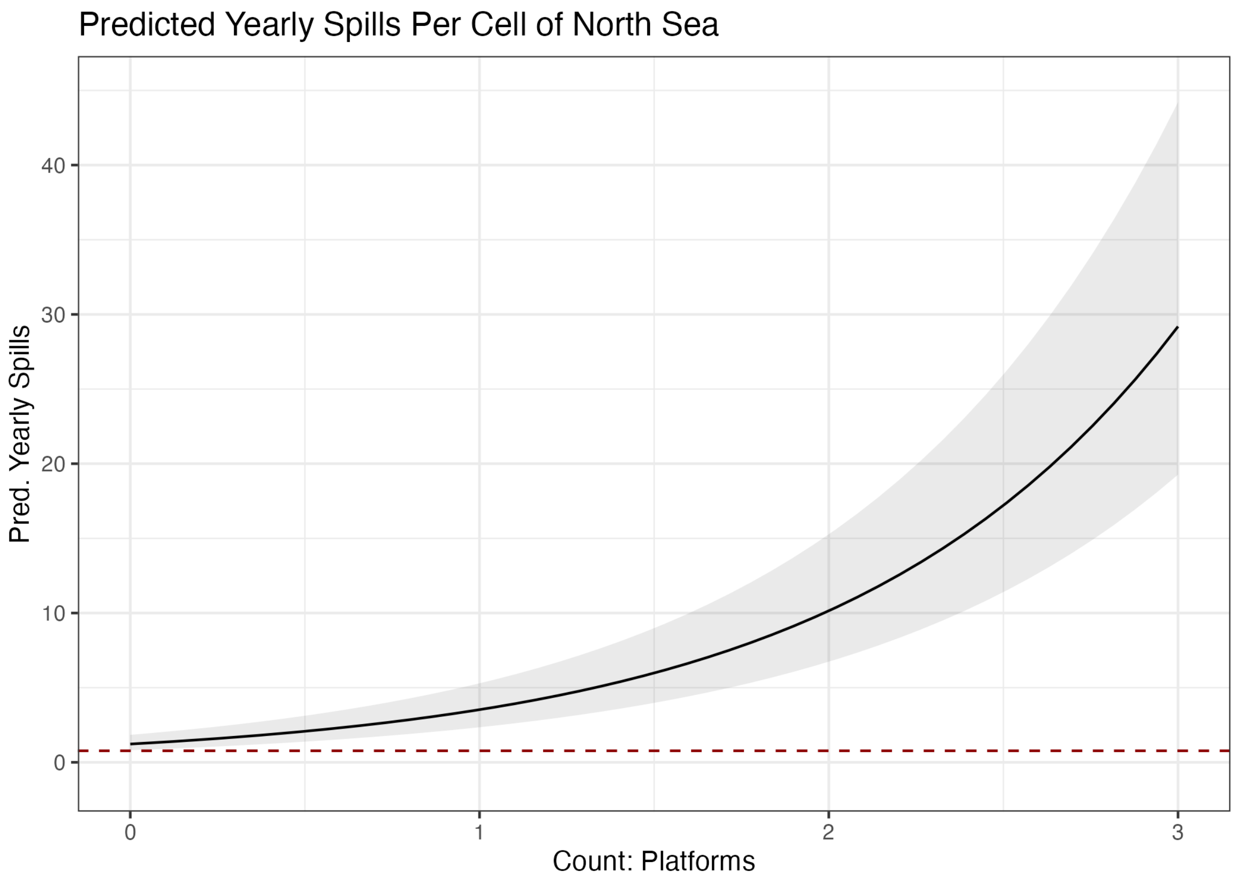

Figure 4: Predicted spills per grid cell with GLM model which includes year by territory interaction, a one-year lag for count of spills, logged shipping rout intensity per cell, dummy for boundary cell, and country's total oil production per rig. The model allows for seeing correlation (but not causal effect) between rig presence and oil spills in the North Sea. Red dashed horizontal line marks sample average (0.77).

B.5 Heterogeneity of Grid Cells: Ownership Fractionalization and Equity Structure

Our data can be further analyzed by modelling the mechanism of ownership fractionalization on oil spills. To begin with, Figure 5 indicates that significantly more owners populated the rigs in UK waters and that these owners were less likely to represent equity monopolies after 2017.

Importantly for our investigation of oil spills, a linear regression (Table 3) finds that the more fractionalized the ownership of oil rigs in a grid cell in the years 2018 and 2019 (and 2020), the more oil spills are detected. This is in line with our argument that the peak of uncertainty during the Brexit negotiations led to a change in market structures in the UK offshore oil sector, which consequently led to suboptimal environmental behavior.

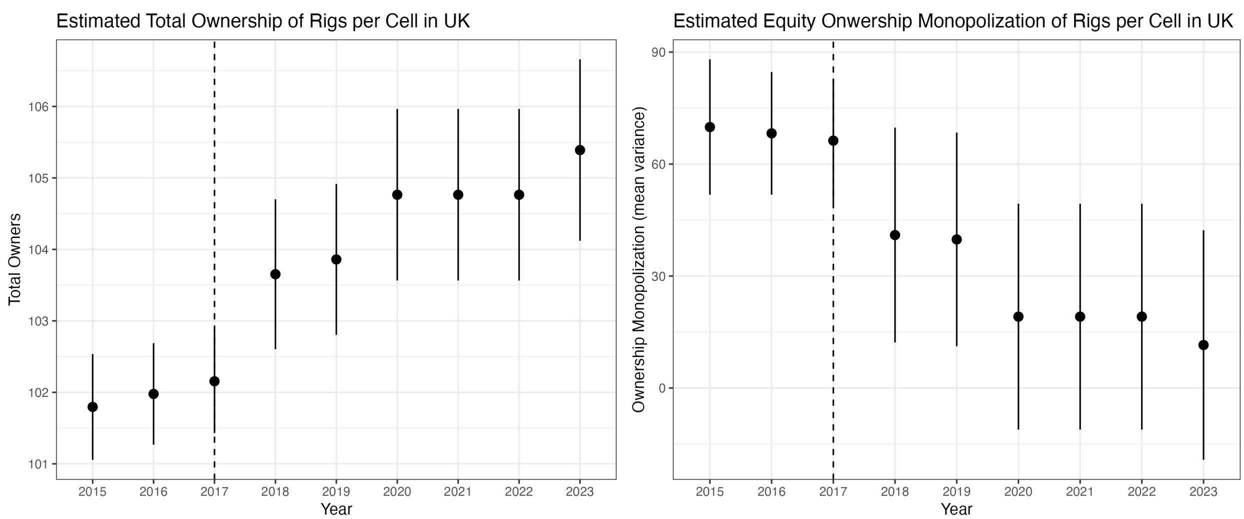

Figure 5: Predicted values from OLS regression with grid cell fixed effects showing change of total owners of rigs per grid cell and degree of equity concentration per owners changes in the UK over time.

Table 3: Multiple Owners Per Grid (Dummy) and Detected Spills

Dependent Variable:	Detected Spills
Model:	(1)
Variables	
many owners × year = 2015	-1.938***
	(0.6692)
many owners × year = 2016	-0.7639**
	(0.3012)
many owners × year = 2018	1.113**
	(0.4411)
many owners × year = 2019	2.703***
	(0.8707)
many owners × year = 2020	1.950***
	(0.6416)
many owners × year = 2021	-1.835***
	(0.6624)
many owners × year = 2022	-2.066***
	(0.7167)
many owners × year = 2023	-2.125***
	(0.6374)
oil rig count	-0.8839
	(0.6537)
Fixed-effects	
cell id	Yes
year	Yes
Fit statistics	
Observations	1,675
R^2	0.70845
Within R^2	0.05859

Clustered (id) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

B.6 Comparing Permitted to Observed Spills: the Gap in UK Reporting

Since the UK regulator allows offshore companies to request permits for oil spills related to operations, safety, or other issues, a threat to our interpretation of our main event study results is that much of these spills were reported and allowed, so not clandestine. To assess the extent of this potential problem, we compare within-grid tallies of oil spills that were permitted by the regulator and the oil spill tally from EMSA satellite detections.Using the same model as our event study of our main regressions but analyzing only those within the UK, we see evidence pointing to subptimal behavior in 2018 and 2019. This means that even amid increased permitted spills, offshore operators went beyond what was permitted.

Table 4: Permitted versus Observed Spills Across Time

Dependent Variable:	Spills gap
Variables	
year=2016	0.2014
	(0.1369)
year=2017	0.5643***
	(0.1601)
year=2018	1.100***
	(0.1806)
year=2019	1.269***
	(0.2268)
year=2020	1.160***
	(0.1963)
year=2021	0.4466***
	(0.1242)
year=2022	0.3123**
	(0.1379)
year=2023	0.4632***
	(0.1308)
Oil rig count	-0.0052
	(1.510)
cell id	Yes
Fit statistics	
Observations	6,530
R^2	0.59985

Clustered (id) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

C Mechanisms: Additional Evidence

C.1 UK Oil Consumption and Exports Across Time

We argued that oil production in itself is not the main determinants of our UK-relevant results, and that rather the politics of the Brexit negotiations drove the incentives for pollution in UK wanters. To shed light on this point, we gathered data on UK oil consumption and exports varied by destination across time (Figure 6). Some elements help support general features of our analysis. First, we see that after the Brexit referendum in 2016, exports to EU countries remained flat relative to exports of oil to the rest of the world. Also, we see that after the Brexit negotiations concluded and the transition period ended in January 2021, exports of oil to the EU decreased significantly more than to anywhere else in the world.

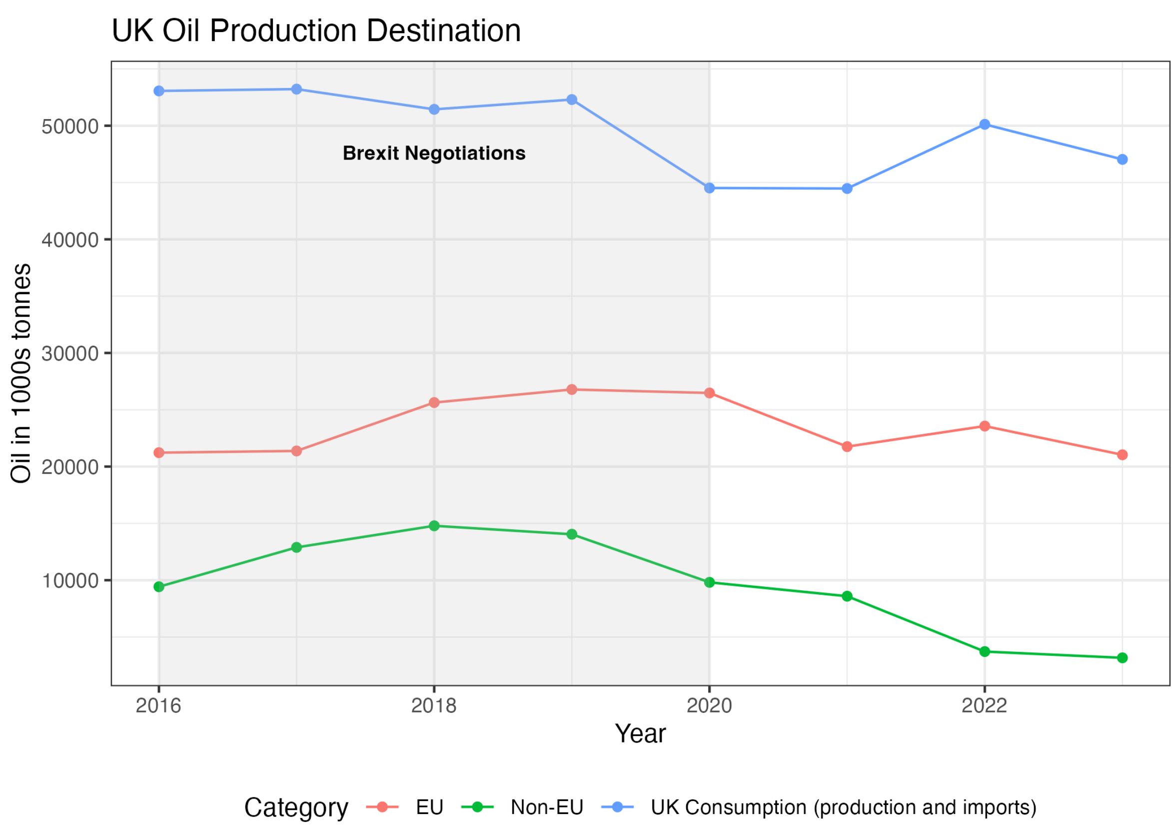

Figure 6: Oil exports by destination and UK total consumption by year, according to Digest of UK Energy Statistics (DUKES).

C.2 Lobbying Data

We compared trends in lobbying by oil and gas companies for the EU parliament and the UK parliament. Overall, we find a decrease in lobbying during the Brexit Transition period in both contexts (Figure 7). Thus, we do not find evidence that differences in lobbying can explain the outcomes of interest.

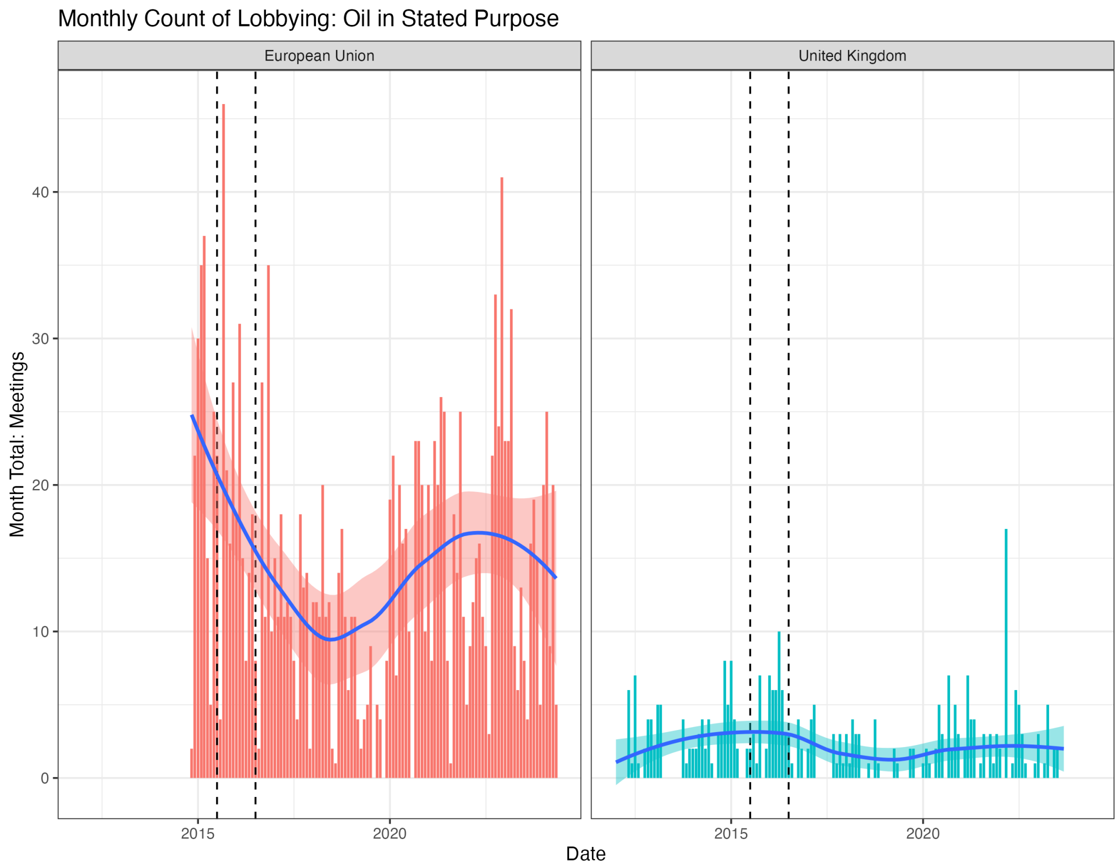

Figure 7: First vertical bar is release of new oil regulation plan, second bar is UK referendum vote.

C.3 Oil Rig Operating Costs

Annual reports submitted by the UKCS reveal that operating costs of oil rigs did not increase following Brexit. Here we detail unit operating costs over time in the UK.

In 2016 UKCS total operating costs were 14% lower than in 2015, with approximate £1.1 billion reduction in OPEX. Despite the decline in operating costs, total oil and gas production rose by 5% to 598 million boe in 2016, compared to 571 million boe in 2015.

In 2017, UKCS reported that there was only a 2% rise in UKCS oil and gas operations compared to 2016. Surprisingly, over half of companies surveyed saw a reduction in their total field OPEX from 2016 to 2017. The small 2% rise in operating costs was the result of a fall in production, not inflation of operating costs.

In 2019, united operating costs and operating expenditure (OPEX) remained stable. Half of operators saw a decrease in their average UOC, with this improvement in cost efficiency driven by both OPEX reductions and production gains. At field level, 51% of operators reduced their total OPEX in 2019. Reporting on direct operating of offshore oil fields, in 2019 logistics and administration (L&A) OPEX decreased by nearly a quarter (24%). Unmanned platforms and sub-sea tiebacks are the cheapest infrastructure types to operate. The stabilization in operating costs despite increased ageing of oil rigs and changes to production suggest investment delays.

C.4 Company Equity & New Entrants

One of the mechanisms through which Brexit triggered changes in a) spill-increases and b) reporting gaps between the UK and Norway/EU jurisdictions can be the effect on company de-risking decisions. Effectively, we should see a reshuffling of entrants into the UK market, and potentially more new entrants with less experience or resources to cope with maintenance and infrastructure costs, compared to other proximate markets. Below we show descriptive statistics of firm investment dynamics in the North Sea that support this intuition. We use Norway as the comparison unit, as it has a similar amount of oil rigs compared to the UK. Figure 8 shows the relative distribution of small, medium, and large companies (and Norwegian SOEs) in Norway over time.[36] While Equinor is the largest producer of oil on the Norwegian continental shelf, it is noticeable that some small companies and a couple of majors leave the dataset after 2016, suggesting that Norway did experience similar global market pressures as the UK and is therefore a good comparison unit.

Figure 9 shows the average equity per company age group (older versus younger firms) across UK licenses in the North Sea between 2010-2025. The age of an equity owner is determined by their first entrance as an equity owner in the North Sea. The sharp divergence in the UK sector begins in 2017. The figure suggests structural changes to the UK market aligned with Brexit, where more established, older firms exited, and where replaced by newer, younger equity owners. We compare this with data on the average age of equity owners in Norway (Figure 10), where the divergence is much less sharp.

In terms of the country of origin, we computed the top 28 equity owners post-2016 who had never entered the UK North Sea as a license owner before. From this list we used Capital IQ Pro to detect the country of origin of the parent company. Figure 11 illustrates that most of these firms (and many of the larger ones) are home-grown as the are predominantly head-

[36] 2023 companies, *Large*: Equinor, Petoro. *Majors*: ConocoPhillips, Shell, Total. *Medium-sized*: Aker BP, DNO, Harbour Energy, INPEX Idemitsu, KUFPEC, Neptune Energy, OMV, Repsol, Sval Energi, Vår Energi, Wintershall Dea Små selskap. *Small-sized*: Concedo, Kistos Energy, Lime, Longboat Japex, M Vest Energy, OKEA, Pandion Energy, Petrolia, Source Energy, Wellesley Europeisk gass.

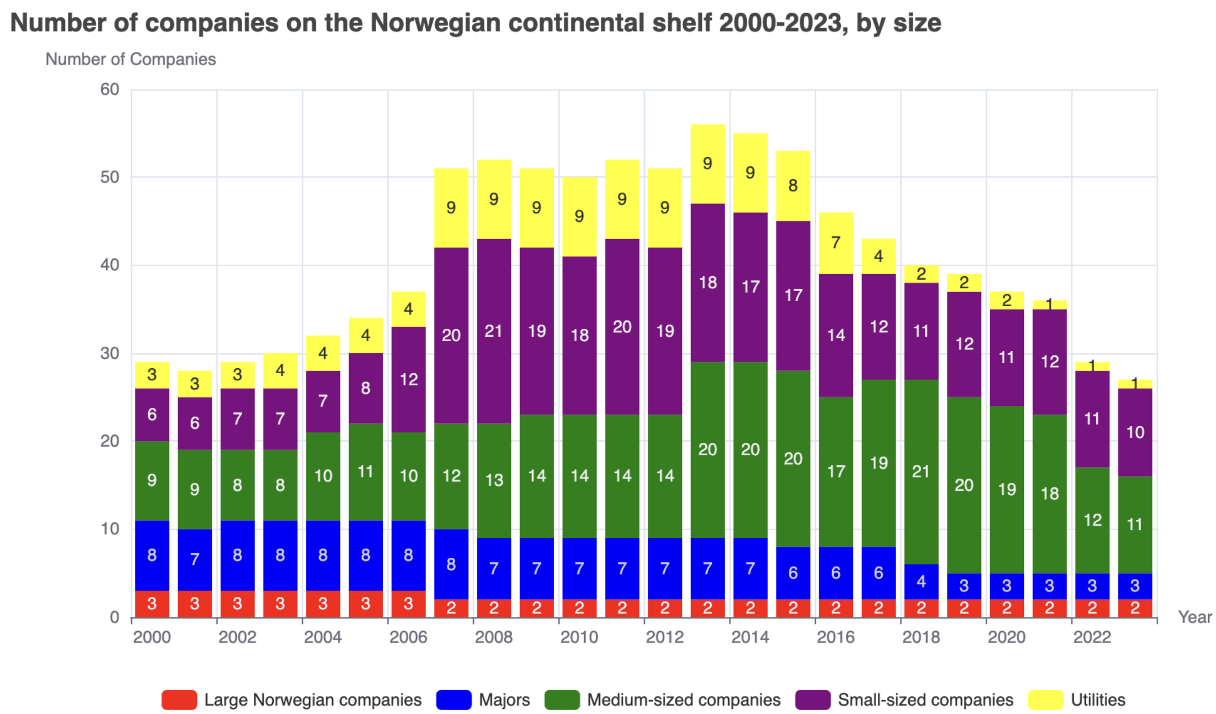

Figure 8: Number of companies on the Norwegian continental shelf 2000-2023, by size.

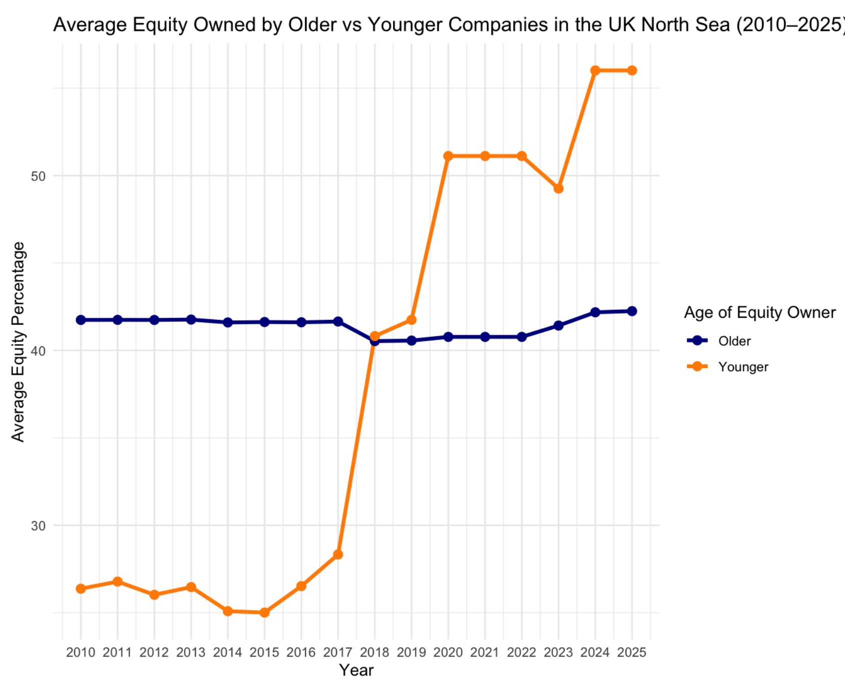

Figure 9: Average equity per company age group (older vs younger companies) across UK licenses in the North Sea.

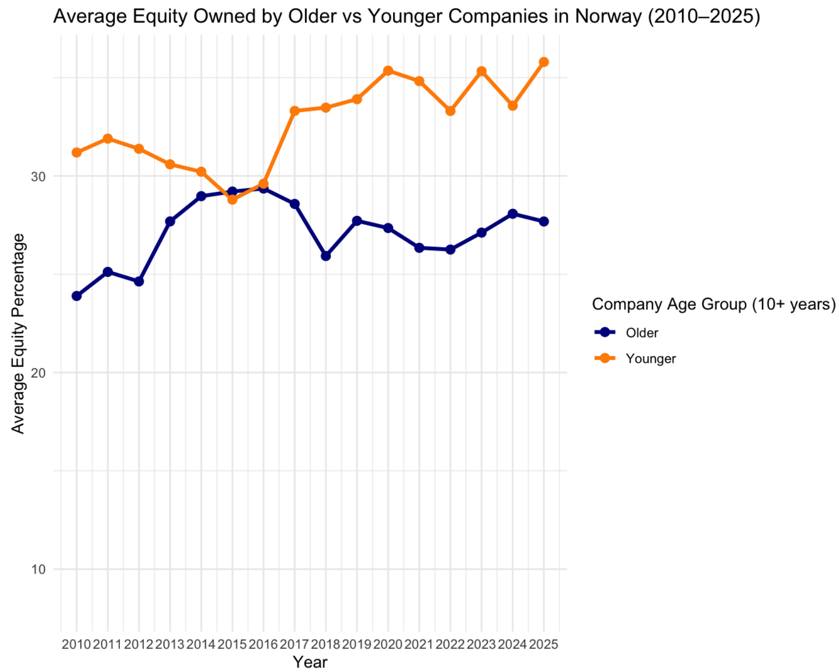

Figure 10: Average equity per company age group (older vs younger companies) across Norwegian licenses in the North Sea.

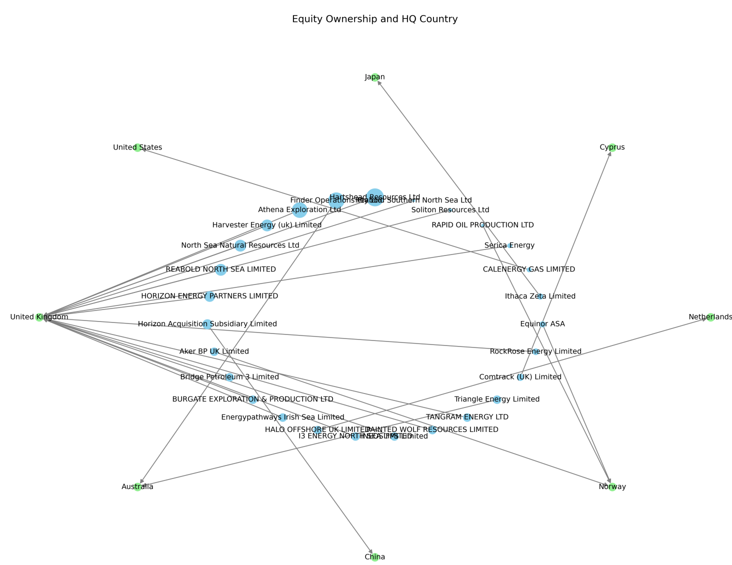

Figure 11: Top firms with equity ownership of UK oil licenses in the North-Sea post-Brexit. Blue dots for each company represent larger equity ownership.

quartered in the UK. We then searched Orbis for the parent company unit ID (BVDID) and used Wharton Research Data Services to match to company headquarters. Figure 12 shows the firms we could find matches to. Once again, we find that most of the new companies' license holders are from the UK, followed by US and Australia.

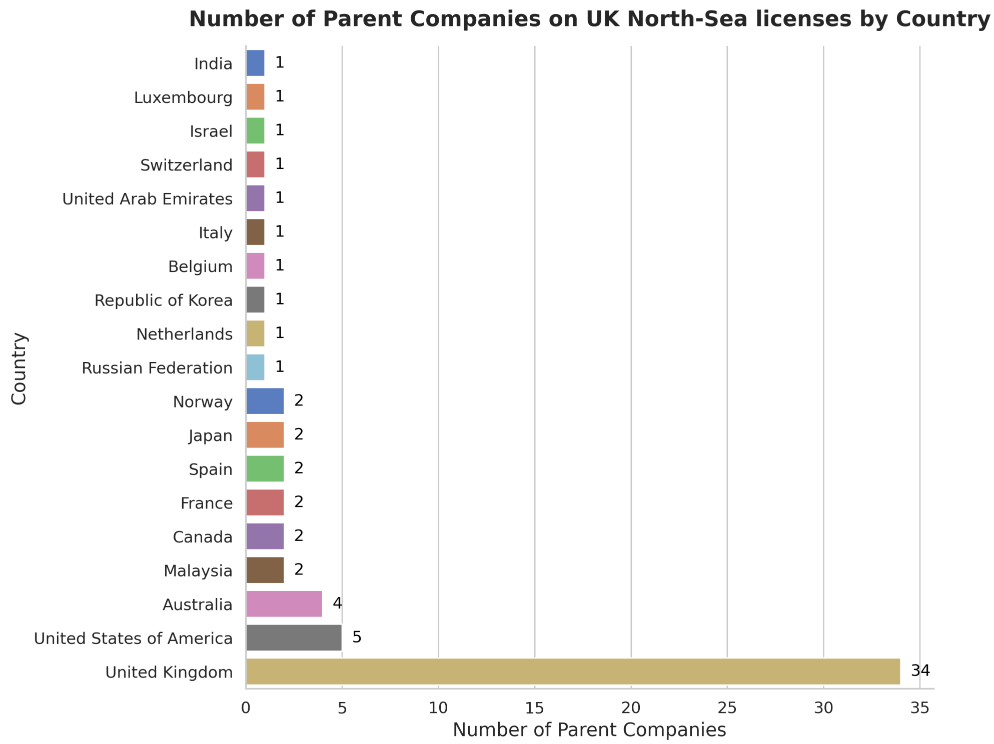

Figure 12: UK parent company license holders aggregated by country

C.5 UK Inspection Reports

To further corroborate our intuition that the Brexit negotiations conditioned the relationship between the British state and the firms in the British oil sector, we gathered data from the UK's annual offshore statistics and regulatory activity reports published between 2015-2024. Data was collected on the HSE's Energy Division Offshore inspections of oil rigs where the agency "aims to ensure its regulatory activity is proportionate to the risks to people, taking into account the operator's performance in controlling risks. This means that ED Offshore will inspect higher hazard installations and operators with poorer performance with greater frequency and in greater depth than installations and operators where risks are perceived to be better managed" (Health and Safety Executive 2023). We collected the number of inspections undertaken within a year, as well as the number of completed investigations completed during that year. We also collected data on non-compliance issues from operators and/or duty-holders. Inspectors assign scores related to health and safety management, including maintenance management, operational risk assessment, loss of containment, structural integrity of the rig, marine operations, pipeline, well control, well compliance, and verification among others. Within these compliance issues, the most inspected topic is maintenance of the rig.

Figure 13 shows that the rate of non-compliance cases over time sharply increases in 2017-2019 and falls in 2020, corresponding with our timeline of Brexit's effects on oil spills more generally. The pattern suggests that operators and duty-holders were more likely to be reported for non-compliance from the regulator during this period of time. In parallel, Figure 14 shows that the percentage of completed inspections by the regulator drops dramatically in 2017-2019, before rising again in 2020, indicating less regulatory enforcement. This is also demonstrated in Figure 15, where the total number of enforcement actions by the regulator drops in 2018-2019. Figure 16 shows that after 2017, the proportion of non-compliant cases that lead to enforcement drops sharply in 2018-2019. All of this evidence points to the vast volatility of behavior – at the firm level and at the institutional level – during the peak of Brexit negotiations, as postulated by our theory.

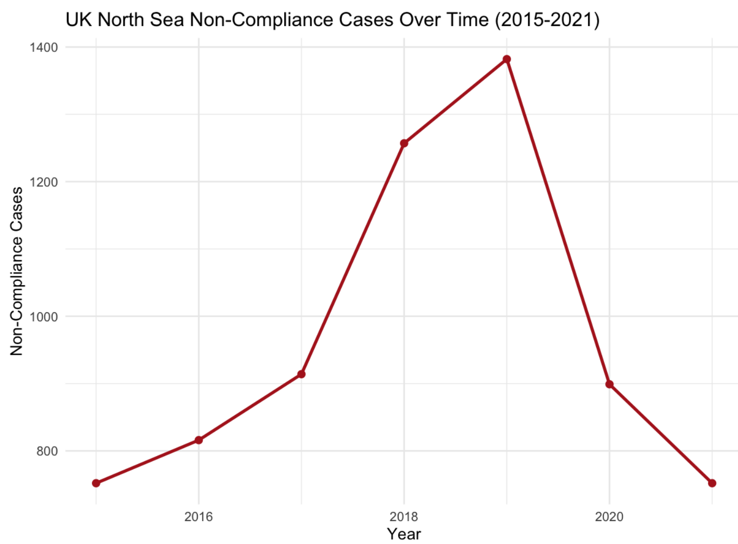

Figure 13: UK North Sea non-compliance cases over time

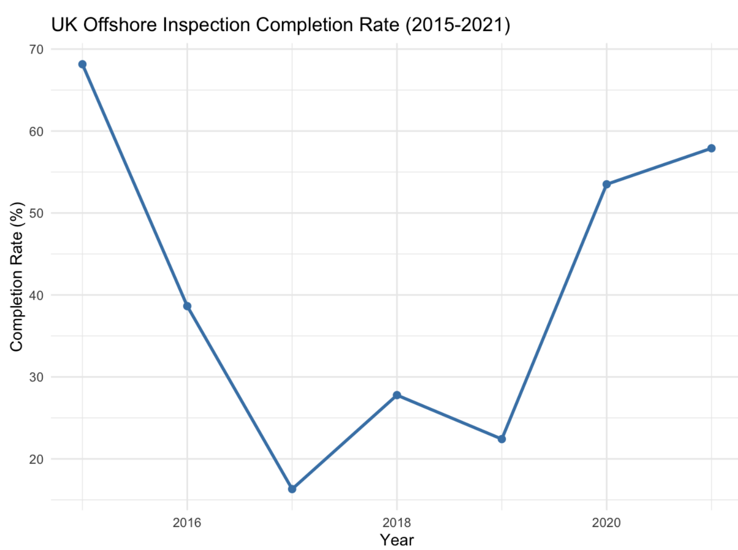

Figure 14: UK offshore inspection completion rates over time

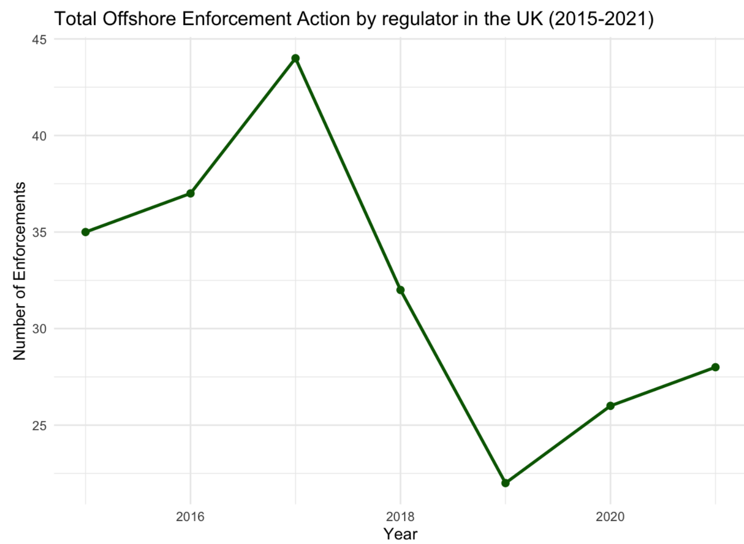

Figure 15: UK regulator's enforcement actions over time

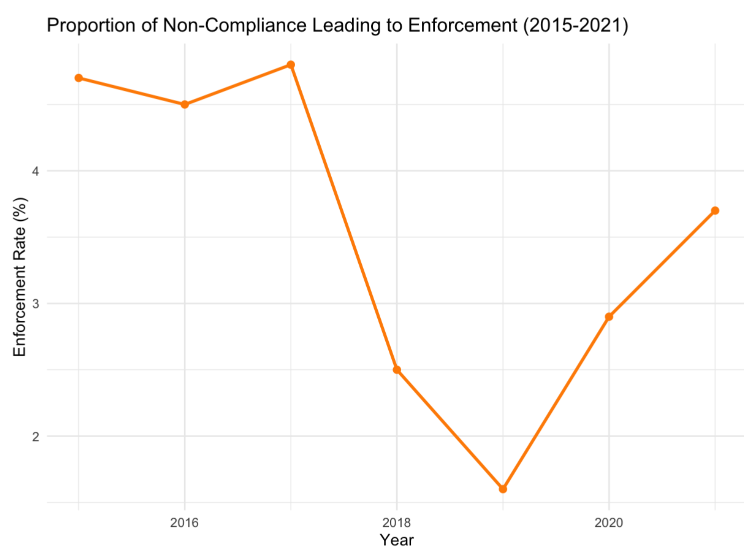

Figure 16: Proportion of UK non-compliance cases that led to enforcement

D Beyond the North Sea: Sewage Discharge After Brexit

Our argument is mainly tested with oil spills data in the North Sea; however, the theoretical premise should exist beyond this context. Indeed, the forces identified behind the pollution increases after Brexit could have had similar effects in other public policy era. In this section we expand on this observation with an exploration of sewage data in UK waters.

Official data about the total hours of discharged sewage into UK waters shows a visible post-Brexit referendum increase. As Figure 17 indicates, there is a distinguishable uptake of hours of sewage discharge between 2018 and 2020.

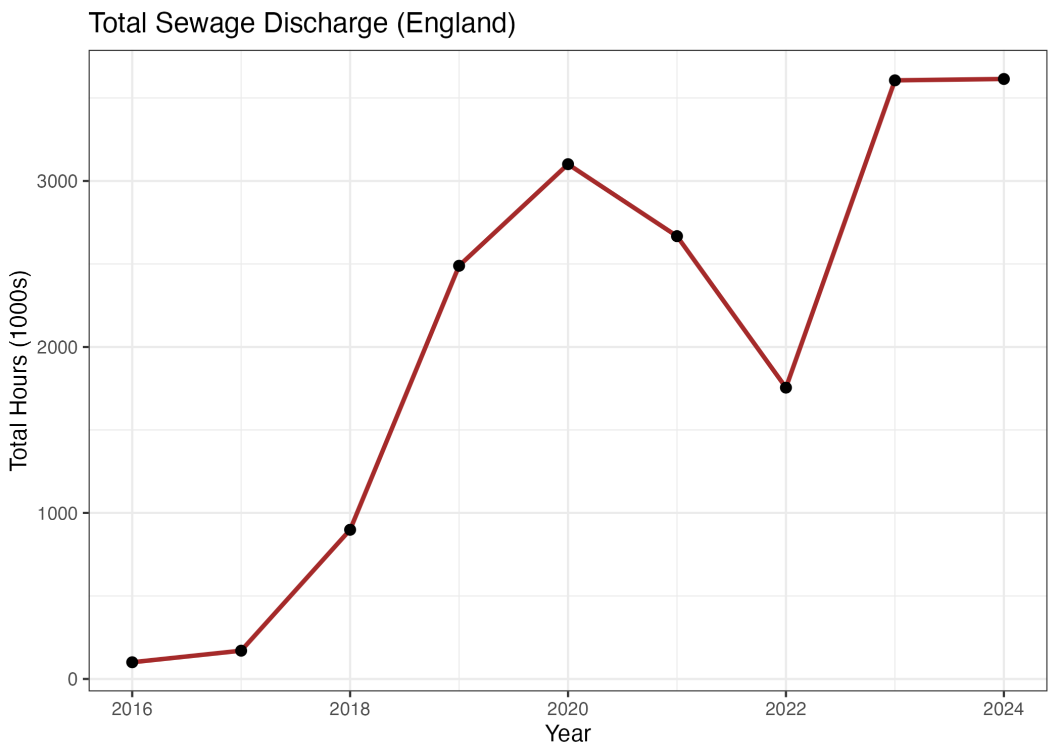

Figure 17: Total annual hours reported to UK regulators about water companies untreated sewage discharges (England data).

While this generally supports our theory, the lack of data prior to 2016 means we cannot draw strong conclusions. Also, disaggregated data on which water companies discharge sewage and in which parts of the UK are only available after 2020. To make further assessments, we match English bathing site bacteria tests to topographical data on hydrological flows in England. English bathing sites are tested in summer months at weekly intervals to determine their safety for bathers. Data on e coli and other intestinal bacteria go back to 2013. Using an OLS model with bathing site and month-level fixed effects as well as total rain per month (an important indicator of bathing site bacteria), we find a significant correlation between hours of discharged untreated sewage in the vicinity of a bathing site and high bacteria counts (logged in the model).

This model can be reversed so that bacteria counts are used to explain total discharge hours. This model returns significant ($p < 0.01$) correlation between nearby bathing site bacteria and upstream sewage discharge. We then use this model to predict discharge in each hydrological zone where we have bathing site data. Taking the average for each bathing site and summing together, we get the total sewage discharge data for England depicted in Figure 18. This figure shows that (with the exception of 2014), the increase in sewage discharge into English waterways

Dependent Variables:	Mean Bacteria (log)	Sewage Discharge
Model:	(1)	(2)
Variables		
Sewage Discharge	0.2930***	
	(0.0754)	
Mean Bacteria (log, $t-1$)	-0.3183***	
	(0.0322)	
Mean Bacteria (log)		0.0389**
		(0.0174)
Rainfall		0.0963***
		(0.0033)
Fixed-effects		
bathing site	Yes	Yes
year	Yes	
Fit statistics		
Observations	4,768	6,394
R^2	0.71030	0.92943
Within R^2	0.11825	0.44296

Clustered (bathing site) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Using the model to predict average discharge hours per bathing site zone (the average is computed by taking the average hours from each site's predicted nearby discharge), and then multiplying by the number of bathing zones, we can estimate the total likely discharge.

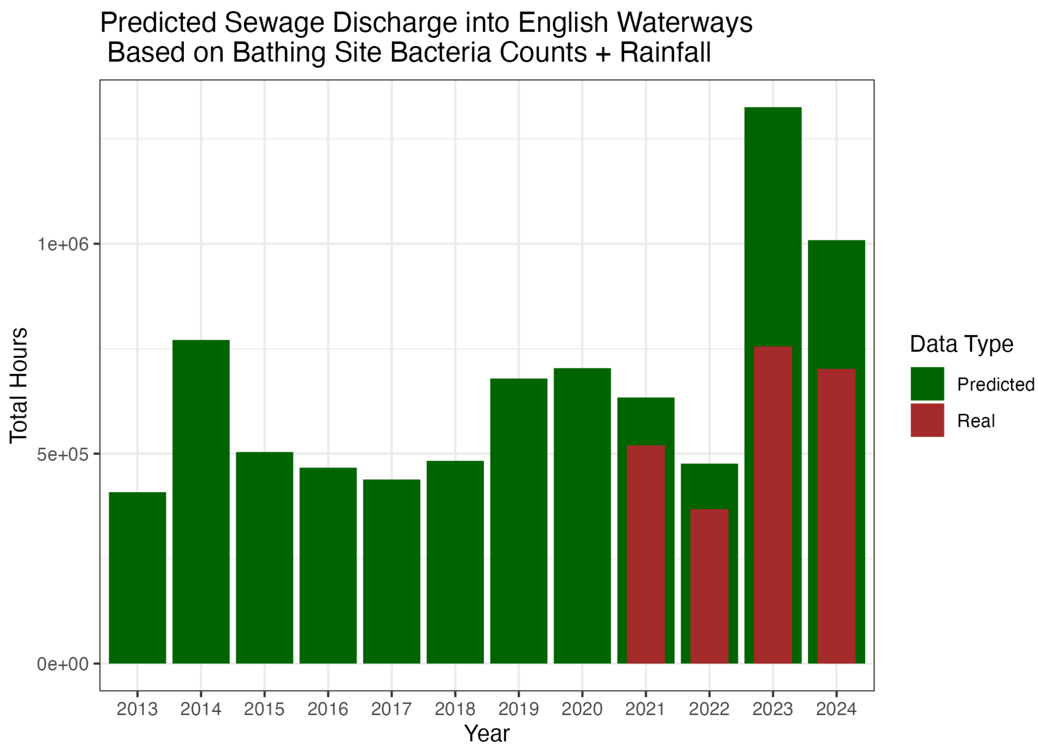

Figure 18: Predicted sewage (green) based on UK (English) bathing site tests of bacteria in the summer and monthly rainfall data. Red bars are reported total hours. The year 2020 was not used to train the dataset due to some unreliable information about the coverage of local meters on sewage outlets.