Tax neutrality, entry and discoveries: Evidence from oil drilling in the North Sea

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Abstract

Cash-flow taxation calls for cash refunds to loss-making firms to leave entry and exit decisions undistorted. We study the introduction of such a refund program in the Norwegian petroleum sector in 2005. Using data on oil exploration in Norway and the UK, we find that the program generated 37% of all new wells, but only 6% of all new discoveries in the period 2005-2015. The drastic drop in discovery rates is consistent with a common value model with endogenous entry. We find that the social benefits of the new discoveries are roughly offset by the cost of dry wells.

Keywords: Oil exploration, cash-flow corporate taxation, investments, cost-benefits, common value

JEL codes: H2; D22; D83; L71

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1 Introduction

To obtain efficient allocation of resources, economists have for a long time recommended corporate taxation that does not distort the investment decisions of firms (Brown, 1948; King, 1987; Auerbach et al., 2010). In line with these recommendations, many countries aim to tax firms' cash flow, treating revenues and costs symmetrically by allowing for deductions of costs. However, negative taxes for firms whose revenues do not allow for deductions in full are rarely introduced. This distorts the investment decisions of marginal firms, such as potential entrants and exiting firms (Bonds and Devereux, 1995).

This paper studies empirically and theoretically the effects of introducing such negative taxes for loss-making firms in the Norwegian petroleum sector. Since 2005, firms not liable to pay taxes can get the tax value of their exploration costs refunded immediately from the government. The aim of the refund program is to make the tax treatment of exploration investments neutral also for marginal firms, to *"reduce the entry barriers for new actors and encourage economically viable exploration activity"* (Norwegian Petroleum, 2019b). The program seems to be unique in the world and paid out \$11.2 billion in refunds over the period 2005-2015.[1]

We analyze empirically how the tax reform influenced investment in exploration and petroleum discoveries on the Norwegian Continental Shelf. Our identification strategy is a triple-difference approach, utilizing that companies' exposure to the policy change depended on their pre-reform tax position, and that we observe exploration drilling of the same companies on both sides of the international border with the UK. We also take advantage of the fact that we observe the exact location, timing and content of each exploration well.

We find that the introduction of the refund program had strong impacts on exploration. There was a threefold increase in the average number of unique exploration companies drilling per year. Given that there is a physically fixed quantity of oil on the Norwegian Continental Shelf, we might expect that entry only reshuffles deposits from incumbents to new entrants, and does not lead to any additional exploration. This turns out not to be true. We find a

[1]The role of negative taxes (refunds) to loss making firms is recognized in the literature (Auerbach et al., 2010; Henry et al., 2009), but practical applications are lagging behind. While many tax systems allow for limited carry forward of losses, there are no other examples of tax refunds paid out to loss-making firms, according to a survey of 47 corporate taxation regimes studied by Ernst & Young (2015). The most notable exemption is the recently introduced partial cash-back of the UK R&D corporation tax relief, see (HMRC, 2018). EY (2019) identify 24 countries using profit-based resource-rent taxes, with Norway as the only country with cash refunds in place for loss-making firms. For reviews with an emphasis on oil taxation, see Lund (2009) and Daniel et al. (2010).

robust and large increase in exploration investments by 133 wells, or 37 per cent of all the new wells drilled after the introduction of the policy. Yet, the number of new discoveries increases by only 10, corresponding to 6 per cent of all new discoveries. Thus, the marginal discovery rate of the drilling caused by the policy was as low as 8 per cent. In a back-of-the-envelope cost-benefit analysis, we find that the policy was roughly welfare-neutral: Cost of a discovery due to the policy was around \$1.4 billion on average, while the net present value of a discovery, based on the estimated oil and gas production profiles, past discovery sizes and historical oil prices, is estimated at \$1.2 billion.

Both the motivation behind the policy and our findings may seem puzzling at first. Why does the government want to facilitate entry and increase competition over fixed petroleum resources? Why are the new entrants drilling in areas where the incumbent companies chose not to drill? And why are they making so few discoveries? To rationalize these findings, we introduce a common value model where risk-neutral firms independently estimate the likelihood of discovering oil and gas. Motivated by the practice in Norway and the UK, licenses to drill are not auctioned, but they are allocated to companies free of charge. Firms pay a fixed entry cost to draw a private signal of the likelihood of finding oil, leading to ex-post heterogeneity in firms' beliefs. In line with the data, firms make two types of mistakes: they do not drill where oil would have been found (false negatives) and they hope to find oil where it does not exist (false positives). Entry has two effects in this setting. Due to randomness of the signal realization, more firms increases the chance that at least one firm gets a sufficiently optimistic signal and drills. On one hand, this alleviates the mistake of false negatives and leads to more discoveries. On the other hand, this also aggravates the mistake of false positives, leading to more dry wells and, as we show, also lower discovery rates. The socially optimal entry strikes a balance between these two effects.

Our paper relates to two strands of the theoretical literature. First, the conceptual framework builds on the literature studying endogenous and costly entry in common-value auctions (Harstad, 1990; Levin and Smith, 1994). These studies have established that when the value of the item (tract) is known to the seller, the optimal number of buyers (exploration firms) is equal to one. In line with the "business-stealing" effect of Mankiw and Whinston (1986), adding another firm would just lead to more intense competition over the fixed item instead of creating any new welfare. The common value setting has been used to analyze federal sales of offshore oil and gas leases in the US (e.g. Hendricks and Porter 1988; Hendricks et al. 1994). Restricting entry to these auctions by an entry-fee or a reservation price is a way to mitigate the business-stealing effect (Levin and Smith, 1994), although the literature has pointed out that the reservation price has typically been set too low in the US auctions (McAfee and Vincent, 1992). The key difference in our set-up compared to these earlier studies is that the true value of a tract is not known to the seller (government) and may well be negative. This minor change introduces a new trade-off: the new entrants may drill and discover oil where the other firms choose not to drill. Thus, we contribute to the literature by showing that increased entry into a common value setting may create additional welfare, giving merit to entry-inducing policies such as the refund scheme studied in this paper.[2]

Second, the paper relates to the theoretical literature on the optimal design of corporate taxation. The merits of neutrality, that cash-flow based corporation taxes (CFT) can achieve this objective, and the necessity for negative taxes for loss making firms is well established in the literature (Brown, 1948; King, 1987; Bonds and Devereux, 1995).[3] The second theoretical contribution of this paper is to show that full tax neutrality may not be a well-justified objective as it may lead to too many firms entering the market. Intuitively, new entrants create social value only if their drilling is additional, that is, they discover oil where the other firms would not drill. However, when considering entry, private firms also take into account the possibility of making discoveries where incumbent firms would have drilled had the policy not been implemented, introducing a version of the business-stealing effect (Mankiw and Whinston, 1986). The fact that undistorted entry cannot be trusted in providing the social optimum adds a new potential reason for why governments seem to be hesitant to provide negative corporate tax rates, beyond the risk of fraud mentioned by Auerbach et al. (2010).

On the empirical side, this paper relates to a large empirical literature that has estimated the impact of taxes on corporate investments from changing tax rules.[4] In particular, Hall

[2] There is an alternative literature incorporating field development and exploration decisions into the standard Hotelling's framework and focusing on the optimal timing of investments (Pindyck, 1978; Boyce and Nøstbakken, 2011; Venables, 2014; Anderson et al., 2018). We focus on the information problem and the heterogeneous signals of the true value of deposits between exploration firms. Models with (ex-post) symmetric firms cannot easily explain the empirical findings of this paper: that entry leads to non-additional drilling and lower discovery rates.

[3] Tax neutrality has also been analyzed in the specific setting of resource taxation, initiated by Garnaut and Ross (1975, 1979) and generalized to a setting where tax neutrality is achieved in presence of risk-averse firms (Campbell and Lindner, 1985) or option value (Zhang, 1997). The possibility that loss-making firms cannot claim all their deductions, and must be compensated by refunds to reach tax neutrality, is considered by Mayo (1979) and Campbell and Lindner (1985).

[4] Hanlon and Heitzman (2010) provide a review.

and Jorgenson (1967), Auerbach and Hassett (1992), House and Shapiro (2008) and Edgerton (2010) all utilize variation in deduction rules for capital costs in the US and find strong impacts on investments. These tax changes affected tax distortions at the "intensive margin", and we contribute to this literature by studying removal of a tax destortion at the "extensive margin".[5] The reform we study equalized the tax treatment of exploration costs for firms with positive and negative cash flows. Our setting allows us to estimate the effects on entry, investments (exploration wells) and outcomes (well content), among new as well as incumbent firms. By combining expected benefits of the tax change based on our estimates with the costs related to the new deductions, we assess the welfare impact of the tax reform in our sample period. We are not aware of any other empirical papers that have estimated the effects of extensive margin tax distortions.

Our empirical findings carry two main insights. First, the high entry seen in the sector and our quantification of the increased investments in exploration due to the policy indicate that firms indeed respond to tax distortions at the extensive margin, in line with the theoretical literature (Bonds and Devereux, 1995; Auerbach et al., 2010). Large upfront investments, high marginal tax rates, and long lags between discoveries and production in the Norwegian petroleum sector make the economic value of removing this distortion high for firms. Second, our finding regarding falling discovery rates points to the importance of evaluating not only the quantity of investments (total exploration), but also the quality of investments (discovery rates).[6] In the long-run, when discoveries and production should follow each other closely, our finding suggests that production will be less responsive than investments in exploration, potentially dampening the long-run impacts of petroleum taxes or prices on oil production (and associated CO_2-emissions).[7]

The paper continues as follows. The next section presents the institutional background regarding petroleum taxation in the North Sea. Section 3 presents the conceptual framework;

[5] We refer to an asymmetric treatments of revenues and costs, which distort the investment decisions of a firm in tax-paying position, as *"intensive margin distortions"*. Asymmetric tax-treatments of profit-making versus loss-making firms, which distort entry and exit decisions, we refer to as *"extensive margin distortions"*.

[6] The existing empirical literature has shown that investments in petroleum exploration are responsive to future oil prices (Pesaran, 1990; Kellogg, 2014), the quality of institutions (Bohn and Deacon, 2000; Cust and Harding, 2018; Arezki et al., 2019), relationship-specific inter-firm learning (Kellogg, 2011) and other firms' activities through information externalities (Hendricks and Porter, 1988; Hendricks et al., 1994; Lin, 2013; Levitt, 2016).

[7] The recent discussions on the long-term effects of petroleum taxation has on the effects of taxes and oil prices on oil production in the US (Anderson et al., 2018; Rao, 2018; Metcalf, 2018), and the global effects of implementing so-called supply-side climate policy measures (Hoel, 1994; Harstad, 2012; Asheim et al., 2019).

a common values model where firms' entry decisions are endogenous. Section 4 presents our data and empirical strategy. Section 5 presents the empirical results, including the cost-benefit analysis of the refund policy. Section 6 concludes.

2 Background

Following the discovery of the Groningen gas field in 1959, both UK and Norway increased their exploration efforts and eventually made their own major oil discoveries; Arbroath Field in the UK in 1967 and Ekofisk Field in Norway in 1969. Petroleum taxation shares many common features in Norway and the UK. In both countries, participating companies are granted licenses to explore for and produce oil and gas within a specified geographical area essentially for free, through an administrative process. Petroleum producers then face taxes that aim to capture some of the resource rents. Moreover, both countries aim for their taxes to be non-distortionary on the "intensive margin" by imposing taxes on net profits rather than on revenues.[8]

The level of the marginal taxes facing oil companies is 78% in Norway and 40% in the UK. In Norway this marginal tax rate consists of a special tax on petroleum production (*særskatt*), in 2018 at 54%, and an ordinary company tax (*ordinær skatt*), at 24% in 2018. In contrast, the UK does not impose a special tax on petroleum production for fields approved after March 1993. This means that for the time period considered in our analysis, petroleum production in the UK is subject to a *corporation tax* of 30%. In addition, there is a *supplementary charge*, currently at 10 %, on company's profits, adding up to a marginal tax rate of 40%.[9] In the UK tax system, companies can deduct their exploration costs. If a company did not have any taxable income, it could carry losses forward indefinitely. However, companies could only deduct their costs if they were in the tax position at some point in the future.[10] The ordinary company tax of 30% is a Ring Fence Corporation Tax, i.e. losses on other activities cannot be set against profits from offshore fields.[11]

[8]Though initially the tax system in both countries included taxation of gross revenue through royalty payments, neither country has no royalties in place for new wells in our study period, 1995-2015.

[9]As another difference between the UK and Norway, the UK government has relied excessively on taxes and has no direct equity participation in oil production. Norway, on the other hand, owns a majority of Equinor (formerly Statoil) and has a major state ownership through the State Direct Financial Interest (SDFI). We regard this difference to be not directly relevant for our study.

[10]There are few exceptions. If a company is bought, the buyer also inherits the losses which it can deduct conditional on the buyer being in tax position.

[11]For information on the Norwegian and UK tax petroleum tax systems beyond what we provide in this

Although the petroleum taxation was neutral on the "intensive margin" by treating revenues and costs symmetrically, it failed to be neutral on the "extensive margin" by treating firms differently based on their tax position. In other words, incumbents with large profits (and strong tax position) were treated differently from newcomers and potential entrants (with zero or weak tax position), thus distorting the private entry decision. To make the tax system more neutral, the Norwegian government implemented a series of policies, with a self-stated objective to facilitate entry in the exploration sector. Changes to deductions of exploration costs were made in 2002, 2005 and 2007 (Lund, 2012). In 2002, loss-making companies in the petroleum sector were allowed to keep deductions for exploration costs, plus interests, along to reduce future taxes. Should the company leave the sector, they were allowed to sell their tax position to other companies in the sector, or they could receive the tax value of their losses from the government (*opphørsrefusjonsordningen*). In 2005, the Norwegian government further liberalized the rules for deductions of exploration costs and offered the deductions as cash in hand refunds to loss-making companies (*leterefusjonsordningen*). Exploration companies were allowed to claim a refund on the tax value (78%) of direct and indirect costs, i.e. cost of seismic studies, costs related to analyzing the data and costs of drilling of exploration wells (Jansen and Bjerke, 2012).[12] In 2007, the final amendment was made, as companies were then allowed to use the government's share of the exploration costs as a collateral when seeking financing.

Judging from the policy debate in Norway, the exploration cost reimbursement scheme introduced in 2005 is regarded as the major milestone of the three changes. The refunds paid between 2005-2015 have totaled 95.82 billion NOK ($11.21 billion, 4.6% relative to the total tax revenue collected in the same period). There is little precedence for such an arrangement. The uniqueness of the system became clear as Bellona, a Norwegian Environmental NGO, filed a complaint on the system of reimbursement of the tax value of explorations costs in 2017 to the EFTA Surveillance Authority (ESA). In March 2019, ESA ruled that the refund scheme does not constitute state aid and is allowed to continue (see ESA 2019)

These policies were successful in facilitating entry and they had a major impact on the exploration sector on the Norwegian Continental Shelf as can be seen in Figure 1: The annual

section, see Norwegian Petroleum (2019b) and OGA (2019).

[12] Companies submit the refund claim together with the tax return and the refunds are paid during December in the following year. For more information, see https://www.norskpetroleum.no/en/economy/petroleum-tax/ and Lund (2012). Ernst & Young (2015) provides a detailed description of the CFT-element in the Norwegian Petroleum taxation.

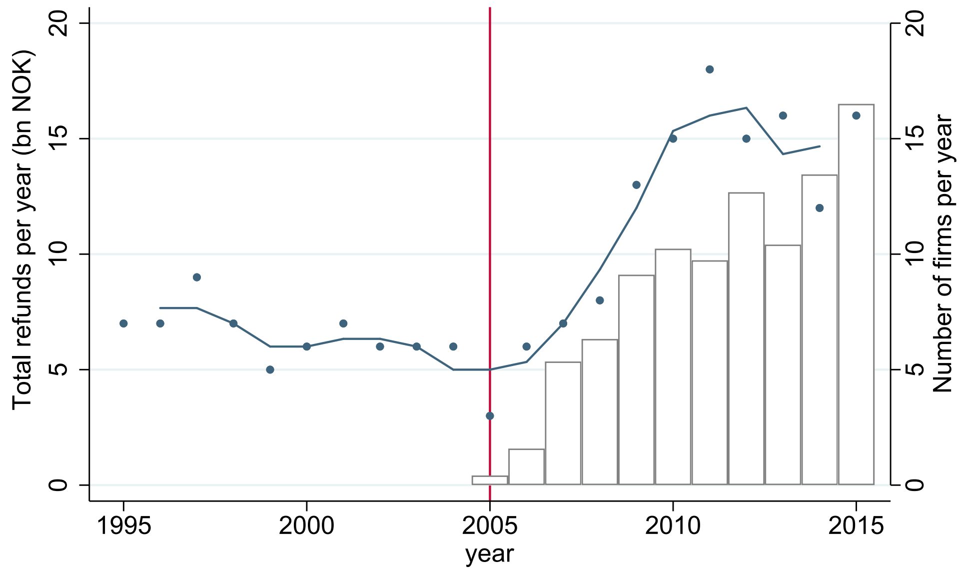

Figure 1: Number of unique firms and paid exploration cost refunds in Norway.

Notes: Dots represent the number of unique firms drilling on the Norwegian continental shelf per year, lines are the three-year moving averages, bars represent the annual refunds on exploration costs paid in Norway. The definition of a firm is based on their unique tax number in Norway.

number of firms exploring in Norway has increased from six in 2004 to sixteen in 2015, hand in hand with the paid refunds. Although the policy met its stated objective of more entry, it is not clear how entry impacted drilling activity, discoveries, the size of discoveries, expected tax revenues and expected welfare. We study this question first in a theoretical framework in Section 3 and analyze it empirically in Sections 4 and 5.

3 Conceptual framework

To understand how entry shapes outcomes in oil exploration, we develop a model that captures the most important features of oil exploration in the North Sea, including (i) common value of a deposit among the companies; (ii) heterogeneous beliefs about the true value; (iii) endogenous entry to the industry; (iv) the fact that the government does not know the true value of tracts and

(v) licenses that are awarded for free combined with a tax on profits.[13]

Firms' problem. Consider a tract with a state $\omega = \{L, H\}$, such that $\omega = L$ refers to a dry deposit and $\omega = H$ to a discovery, with respective prior probabilities $1 - q$ and q.[14] This state is unknown both to the government and the risk-neutral exploration companies, and it becomes publicly known if drilled by a firm i, $x_i = 1$ ($x_i = 0$ denotes no drilling). We consider a pure common value setting where the value of the deposit, net of production costs, is the same for all the firms and denoted by $v_H > 0$ and $v_L < 0$.[15] In addition, firms pay a cost c upon entry. Before the policy change in Norway, the government sets profit taxes τ, and firm's after-tax profits are given by:

$$\pi_i = \begin{cases} (1-\tau)\big(v_\omega x_i - c\big) & \text{for } v_\omega x_i - c \geq 0 \\ v_\omega x_i - c & \text{for } v_\omega x_i - c < 0 \end{cases} \tag{1}$$

The firms could deduct the tax value of their costs if they made positive profits, $v_\omega x_i - c \geq 0$. If not, they face the full cost incidence. This was changed by the introduction of the refund program, after which profits for all the companies were $\pi_i = (1-\tau)(v_\omega x_i - c)$. For loss-making firms the term in parentheses is negative, and companies receive cash refunds.

Upon paying a sunk cost, c, firms receive a private signal, s_i, on the true content. These signals are independently and identically distributed conditional on the state: $s_i \sim \mathcal{N}(s_\omega, \sigma^2)$, with

[13] Properties (i)-(ii) are the basic ingredients of a standard common value model as in Wilson (1977), the property (iii) was first analyzed by Harstad (1990), McAfee and Vincent (1992) and Levin and Smith (1994) in environments where the value is known to the seller, in which case entry beyond the first buyer harms both welfare and auction revenues. Fundamentally, our property (iv) flips this result and entry may be (locally) welfare increasing. Last, property (v) differs from most previous papers focusing on auctions, not taxes, but is motivated by the lack of license auctions in the UK and Norway among many other countries (see EY 2019).

[14] These prior probabilities may include commonly known geological factors and drilling outcomes of neighboring tracts. In Norway and the UK outcomes of production and exploration wells are generally made public two years after a well is completed (NPD, 2014; OGA, 2019). This justifies our assumption that information is symmetric, unlike in the US where evidence shows that owners of adjacent tracts hold private information (Hendricks and Porter, 1988). Note, that we could have instead modeled the discovery size as an unknown variable. In the data, however, we do not have discovery size estimates for the full sample. To make the theory and the empirical section consistent, we focus on binary types (dry well or discovery).

[15] Our parameters v_H and v_L, representing the net-present values of optimally developing a field, essentially capture all the dynamics of the problem. This optimal development of oil fields is characterized by Venables (2014) and Anderson et al. (2018). Even if firms differ in their ability or cost of producing oil, the common value assumption can be justified by the fact that the drilling rights are tradable.

$s_H > s_L$.[16] Firms update their beliefs about the true state:

$$p(s_i) = \frac{f(s_i)q}{f(s_i)q + g(s_i)(1-q)}, \tag{2}$$

where we denote $Pr(s_i|\omega = H) = f(s_i)$ and $Pr(s_i|\omega = L) = g(s_i)$.[17] Also, let the cumulative distribution be denoted by $Pr(s \leq s_i|\omega = H) = F(s_i)$ and $Pr(s \leq s_i|\omega = L) = G(s_i)$; $F(s_i) < G(s_i)$. After observing their signals, firms evaluate whether to find drilling profitable. Motivated by the current practice in Norway and the UK, there is no formal auction and licenses to drill are allocated free of charge. In case several companies want to drill, we assume a uniform tie-breaking rule: the drilling rights are assumed to be randomly allocated to one of them.[18]

We consider the unique symmetric Bayesian Nash equilibrium of the exploration game where firm i finds it profitable to drill if it receives a signal above a cut-off $s_i \geq s_n^*$. The equilibrium cut-off balances the expected marginal benefits of making a discovery to the expected marginal costs of drilling a dry well:

$$p(s_n^*)\mathbb{E}_k\big[\frac{v_H}{k}\big] = (1 - p(s_n^*))\mathbb{E}_k\big[\frac{-v_L}{k}\big], \tag{3}$$

where expectations are taken over the likelihood that in total k firms want to drill. If $k-1$ other firms (following the same equilibrium cut-off s_n^*) receive a high signal, there is competition over the deposit and, in expectation, a firm must share the deposit. Yet, it is more likely that a firm needs to share a discovery rather than a dry well. This follows from $F(s_i) < G(s_i)$ (for all s_i) implying $1 - F(s_n^*)^{n-1} > 1 - G(s_n^*)^{n-1}$: it is more likely that at least one competitor receives a high signal when the true type is high. Firms avoid the winner's curse by taking this effect into account: a larger number of firms increases the cut-off value and makes a given firm more conservative.[19] On aggregate, however, having more firms also leads to more "draws" and it is likely that at least

[16] We focus on normally-distributed signals to guarantee the uniqueness of the symmetric cut-off equilibrium. In the appendix, we also discuss the case of general distributions satisfying the monotone likelihood ratio property. Parameter c is meant to capture the cost of gathering and analyzing seismic data for a given area.

[17] The likelihood of discovering oil or gas consists of: probability of finding a reservoir formation in a prospect, probability of an effective trap in that prospect and the probability of charging that prospect with hydrocarbons (Ofstad et al., 2000). Firms may have different views on all these prospect characteristics, these captured by signal s_i.

[18] We focus on the symmetric equilibrium and it seems reasonable that the ex-ante probability of getting a license to drill through an administrative process with $k-1$ competitors is $1/k$. In practice the companies may apply for licenses in groups. This would be an alternative interpretation of our model; the important feature is that when the true type is high, a firm is, in expected terms, more likely to share the oil deposits.

[19] The evidence for whether firms properly account for increased competition is mixed, see Hendricks et al. (1987). However, we show in the appendix that our predictions are robust to firms using the same cut-off $s_n^* = s^*$ for all n. This would be the case if firms suffer from the winner's curse (for behavioral reasons) or if they do not observe the number of competitors.

one firm gets a signal above the cut-off s_n^*. The model predicts that: (i) the aggregate probability of making a discovery, $q(1 - F(s_n^*)^n)$, is increasing in the number of firms n, (ii) the aggregate probability of drilling dry well, $(1 - q)(1 - G(s_n^*)^n)$, is also increasing in the n and (iii) the effect is larger on dry wells, leading to a drop in the aggregate discovery rates. These predictions are illustrated in Figure 2, they are proven formally in the Appendix and tested empirically in Sections 5.1 and 5.2.

Planner's problem. The welfare-maximizing social planner would only want drilling where oil is to be found, but lacks the means to observe the true content of the deposit directly. However, the planner can indirectly influence drilling through entry because the welfare is a function of the number of firms, n:[20]

$$\mathbb{E}[W(n)] = \underbrace{q\big(1 - F(s_n^*)^n\big)}_{\substack{\text{Expected}\\ \text{discoveries}}} v_H + \underbrace{(1 - q)\big(1 - G(s_n^*)^n\big)}_{\substack{\text{Expected}\\ \text{dry wells}}} v_L - \underbrace{cn}_{\substack{\text{Entry}\\ \text{costs}}}, \tag{4}$$

In this set-up, firms make two types of mistakes.[21] First, they miss oil where it would have been found (false negatives); on aggregate n firms make this mistake with probability $F(s_n^*)^n$. This probability is decreasing in n and entry therefore alleviates the problem of false negatives, as is shown in the first term of equation (4). Second, oil companies hope to find oil where there is no oil (false positives); on aggregate this happens with probability $1 - G(s_n^*)^n$. This probability is increasing in n and entry aggravates the problem of false positives. This is shown in the second term in equation (4). Last, more firms also lead to higher entry costs as shown in the last term. In this set-up, entry is welfare-increasing if the increased value of additional discoveries (alleviating false negatives) outweighs the decreased welfare from dry wells (aggravated false positives) and the increased entry costs.[22] In other words, this framework gives a reason for why a small number of firms may behave too "conservatively" from the government's perspective, and offers a rationale

[20]Respectively, the planner could maximize the tax revenue for a given tax rate, τ, because the tax revenues are proportional to welfare, $\tau\mathbb{E}[W(n)]$ under neutral taxation.

[21]We assume that the deposits have the same value for the planner and for the firms. However, it would be straightforward to allow for different private and social valuations, for example because: (1) firms are more risk-averse than the planner (as in Campbell and Lindner 1985); (2) firms use a higher discount rate than the planner who might have concerns for inter-generational equity (as in Caplin and Leahy 2004); or (3) if the government takes climate externalities of production into account (as in Hoel 1994, Harstad 2012) and Asheim et al. 2019.

[22]Note, that as firms decide their entry costs prior to learning their signals, cost c does not screen in the most optimistic firms. This follows Harstad (1990) and Levin and Smith (1994), while the opposite case is considered by Murto and Välimäki (2019). Here we consider entry in pure strategies in which exactly n firms enter. This is in contrast to Harstad (1990) Levin and Smith (1994) where entry is in mixed strategies and there is always a positive probability that no firms enter.

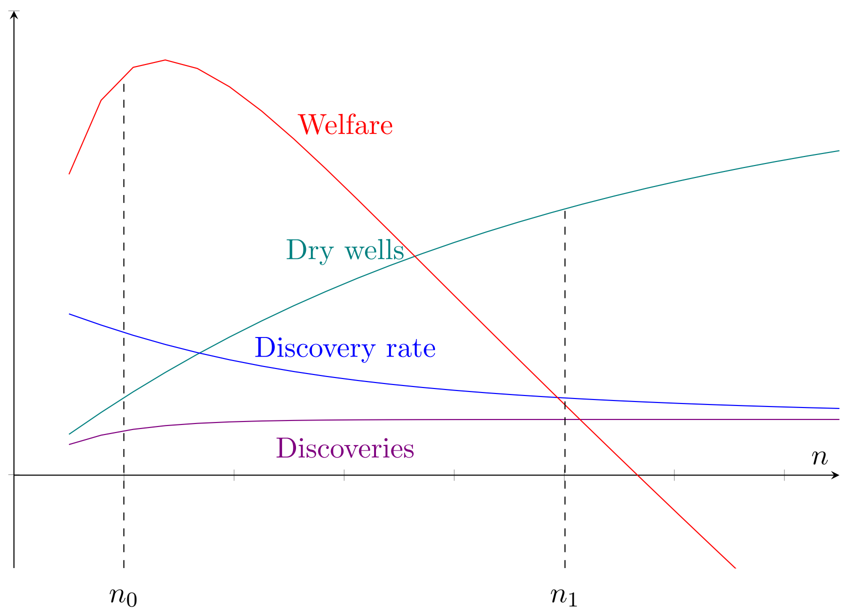

Figure 2: Illustration of the model. A change from non-neutral taxation (n_0) to taxation that is fully neutral on the extensive margin (n_1) and the implied effects on discoveries, dry wells, discovery rates and welfare.

for entry-inducing policies.

However, excessive entry is also possible. Intuitively, entry is socially optimal only if it leads to additional discoveries, that is, discoveries in areas where none of the incumbents would have otherwise drilled. Technically, entry is socially beneficial only if $\mathbb{E}[W(n) - W(n-1)] \geq 0$. In contrast, private entry incentives also include non-additional discoveries in locations where another firm would have drilled. Under free entry and neutral taxation the private entry incentives remain if $\mathbb{E}[\pi(n)] = \mathbb{E}[W(n)]/n \geq 0$; a firm enters as long as there are positive expected private profits to be made[23] This wedge between private and social incentives is a manifestation of the "business-stealing effect" by Mankiw and Whinston (1986), which calls for restricting entry in common value auctions, where it can be done by setting an optimal entry fee or a reservation price (Levin and Smith, 1994). The net welfare effect of increasing entry from n_0 to n_1 is thus ambiguous, as Figure 2 illustrates. In section 5.4 we will look into the welfare consequences of the policy by comparing the exploration costs to the estimated number and values of new discoveries by the policy.

[23] A similar "paradox", where corporate taxation revenues dissipate under free entry, perfect competition and dissipation of profits has been recognized before e.g. by Sandmo (1974).

4 Empirical approach

4.1 Data

We use data on offshore oil exploration in the form of wildcat wells over the period 1995-2015, which constitutes ten years before the tax policy change and eleven years after.[24] We acquire drilling data from the Norwegian Petroleum database (www.norskpetroleum.no/) run by the Ministry of Petroleum and Energy and the Norwegian Petroleum Directorate (NDP) and from the UK Oil and Gas Authority (OGA: www.ogauthority.co.uk/). The company-level tax and refund data are from the Norwegian Tax Administration (www.skatteetaten.no/).

Our definition of companies is based on their unique ID number in the Norwegian tax data, and the classification of company groups in the UK Oil and Gas Authority (OGA, 2018).[25] Our sample consists of 68 companies, of which 36 drilled on the Norwegian Continental Shelf, 54 on the UK Continental Shelf and 22 drilled in both countries. Most of the large international oil companies operate on both sides of the international border. In total, 68.3 per cent of all the wells were drilled by companies that operated in both countries.

We observe the exact location of the wells drilled by the different companies. For the regression analysis described in section 4.4, we divide the study area into quadrants. These are shown as grid cells in Figure 4 below.[26] There are in total 132 active quadrants, 73 in Norway, 59 in the UK and 6 are split between the two countries. We split the quadrants at the border, such that quadrants are nested into countries. In our analysis we always use quadrant fixed effects to control for quadrant sizes, geology and location.

We observe the drilling outcomes at the well-level. In our main analysis, we use the discovery classification by the UK and Norwegian authorities, which includes both commercial and technical discoveries. Conveniently, this definition of a discovery is independent of the current oil price. Based on this classification, the total discovery rate was 35.5%. For robustness, we also include all the exploration wells that have oil or gas as their content as

[24]Wildcat exploration wells are drilled to find out whether petroleum exists in a potential deposit. We exclude appraisal exploration wells, which are drilled to establish the extent of an already discovered deposits.

[25]We define companies at the company-group-level, e.g. BP Exploration, rather than at the branch-level, e.g. BP Exploration Alpha ltd, BP Exploration Beta ltd, etc. We manually went through each company's history to deal with mergers and acquisitions, such that we have stable units throughout the sample-period.

[26]Each quadrant is divided into 12 blocks in Norway and 30 blocks in the UK. These blocks form a basis for exploration licenses. Alternatively, we could have worked on the production license level. However, shapes of licenses are endogenous to exploration outcomes (discoveries and fields), licenses are not stable over time and licenses may even consist of several non-adjacent areas. The advantage of using quadrants is that they are only determined by geography and country borders.

discoveries. In that alternative classification, the discovery rate was 45.5%.

For the size of a deposit, we use values for original recoverable oil, gas and oil equivalents (including oil, gas, NGL and condensates). However, annual reserve estimates are released at the discovery and field level only in Norway and this information is not available for small discoveries where production is deemed unlikely. Last, we use annual oil and gas production data from every field in Norway going back to 1971 in order to estimate the value of new discoveries.

4.2 Treatment vs. control

To define exposure to the policy, we use the fact that the tax refunds introduced in 2005 only make a difference for companies in weak tax positions, whose income stream may not be sufficient to allow for deductions. Firms in a strong tax position could deduct their exploration costs after as well as before the policy change, and they are therefore considered "never eligible" to receive exploration refunds and we define them as the control group. This group consists of the six biggest taxpayers in the year before the policy change: Equinor, Norsk Hydro, ExxonMobil, Total, ConocoPhillips and Royal Dutch Shell. In total, they paid 89% of all the taxes in 2004 and were the six largest taxpayers every year between 2000-2004 on the Norwegian continental shelf.[27] The remaining companies operating on the Norwegian shelf, as well as all the companies without operations in Norway prior to 2005, are considered to be in the treatment group.

Figure 3 plots the number of new exploration wells per year by country and company-type. The most striking development is the large increase in total drilling of the treatment group in the years after 2005, as shown in the top left panel. We return to the discussion about parallel trends across the different groups in section 4.4.

[27]The relative shares of all the taxes paid in 2004 are Equinor (31.6%), Norsk Hydro (17.2%), ExxonMobil (14.0%), Total (12.0%), ConocoPhillips (9.4%) and Royal Dutch Shell (5.4 %). The next firms on the list of the largest tax payers were Eni (3.0%) and BP (2.5%) and Idemitsu Petroleum (1.4%). This group of six has been stable over the years as shown in Figure B.1. For example, they had paid the most taxes in every year for the period 2000-2004.

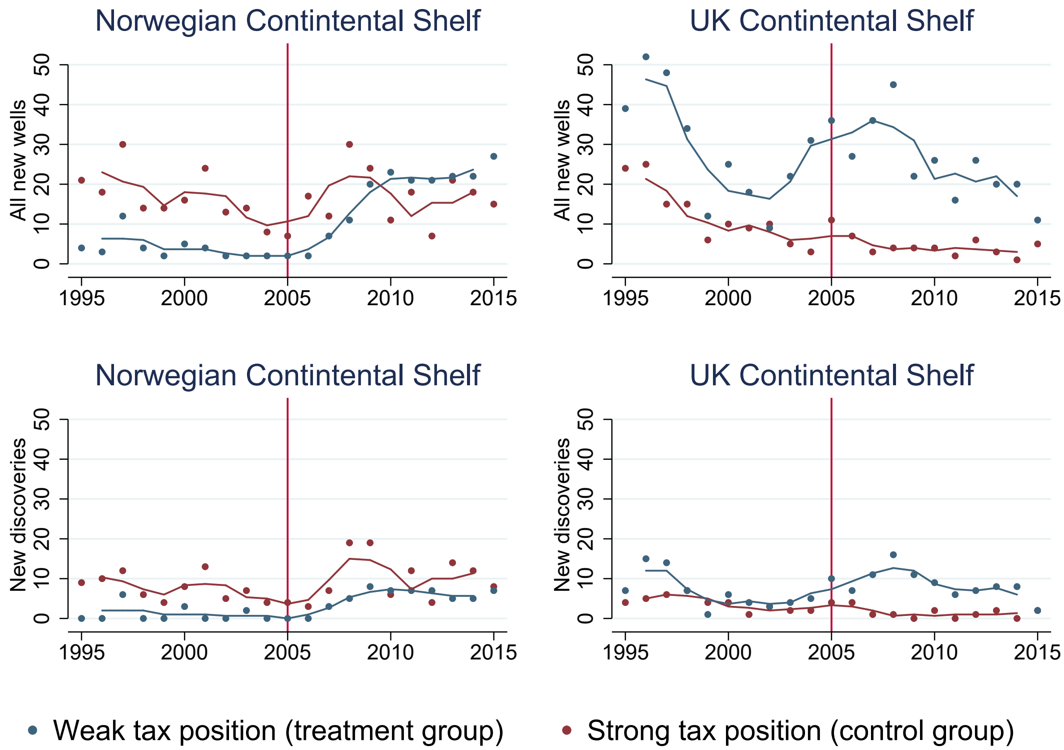

Figure 3: Number of new exploration wells.

Notes: The graphs present the number of exploration wells and discoveries by treated (blue) and non-treated (red) companies in UK and Norway. The lines represent three year moving averages of the sum of actual annual drilling, indicated with the dots.

The locations of new exploration wells are plotted in Figure 4. Most drilling in Norway was carried out by the control group, and most drilling in the UK by the treatment group. In addition to that, there does not seem to be systematic differences in the geographical preferences for the treatment and control groups. For example, the gradual expansion of exploration drilling to the Barents Sea was carried out by companies from both groups.

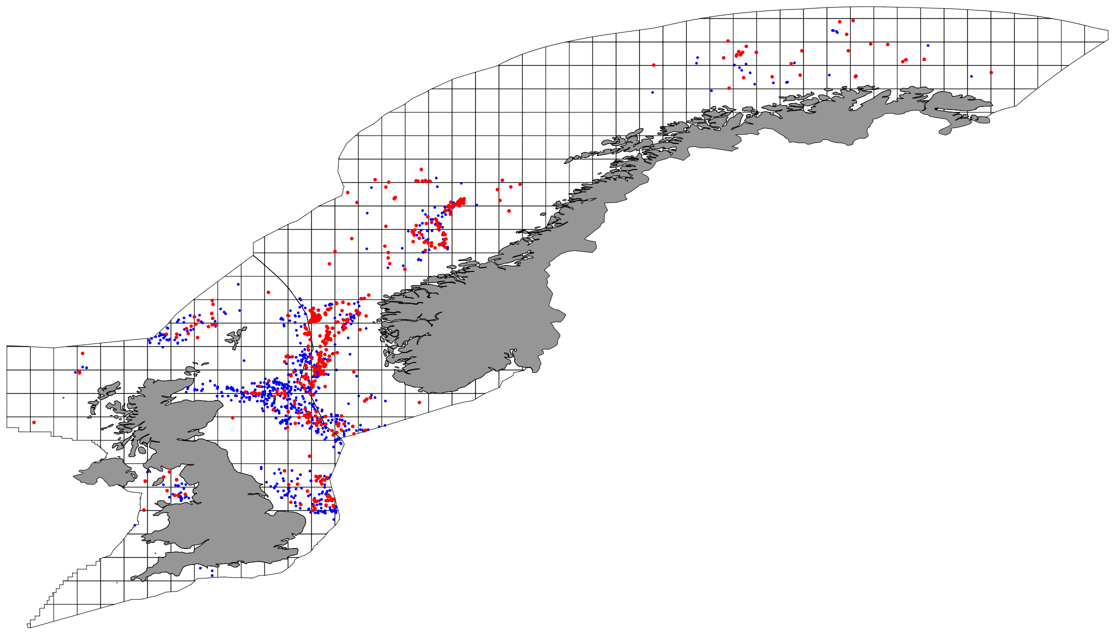

Figure 4: Exploration drilling on the Norwegian and the UK Continental Shelf (1995-2015).

Notes: The map plots exploration wells drilled by treated (blue) and non-treated (red) companies in the two countries. The gird represents our study area and grid cells are quadrants. This paper covers drilling in the North Sea, the Norwegian Sea and the Barents Sea.

4.3 Descriptive statistics

Table 1 presents descriptive statistics for exploration drilling and oil and gas discoveries in Norway and the UK. There are in total 1317 new offshore wildcat wells drilled in the study area 1995-2015, 570 of these are located in Norway and 747 in the UK. The control group drilled 62% of all the wells in Norway and the treatment group drilled 38%. The respective number is 23% for the UK for the control group and 77% by for the treatment group.

As for drilling outcomes, we consider both oil and gas discoveries, that is, deposits where hydrocarbon has been discovered. There were 486 discoveries and the average discovery rate, defined as the proportion of discoveries to total wells, was 35.5 percent over the entire period. The control group had a higher discovery rate in both countries, before as well as after the policy was introduced. Apart from the treatment group in Norway after 2005, Norway had a higher average discovery rate than the UK. Discovery rates have been increasing over time, likely due to technological development and increased prevalence of 3D and 4D seismic surveys.

The sizes of discoveries in terms of oil equivalents are shown in the lower part of Table 1.

Table 1: Descriptive statistics: Treated and control companies in Norway and the UK.

	Norway				United Kingdom			
	Control		Treatment		Control		Treatment	
	1995-2004	2005-2015	1995-2004	2005-2015	1995-2004	2005-2015	1995-2004	2005-2015
Total wells	0.0337	0.0320	0.0009	0.0036	0.0295	0.0110	0.0079	0.0071
	(0.2416)	(0.2468)	(0.0339)	(0.0725)	(0.2203)	(0.1339)	(0.1148)	(0.1136)
Discoveries	0.0153	0.0192	0.0002	0.0011	0.0092	0.0037	0.0018	0.0024
	(0.1432)	(0.1848)	(0.0156)	(0.0335)	(0.0980)	(0.0646)	(0.0443)	(0.0510)
Dry wells	0.0184	0.0128	0.0006	0.0025	0.0203	0.0073	0.0061	0.0047
	(0.1547)	(0.1259)	(0.0278)	(0.0597)	(0.1735)	(0.0993)	(0.0973)	(0.0874)
Discovery rate	45.4%	60.0%	27.5%	30.3%	31.2%	34.0%	22.7%	33.3%
Average oil in a discovery	6.37	3.84	2.81	9.98				
(mill Sm^3)	(10.47)	(10.07)	(4.90)	(41.39)				
Average gas in a discovery	7.77	2.94	4.58	1.30				
(bill Sm^3)	(37.46)	(6.35)	(10.92)	(2.75)				
Taxes paid	9121.2	32082.7	339.2	473.7				
(mill NOK/year)	(9011.6)	(31245.6)	(744.4)	(1614.8)				
Received refunds	0	0	0	172.6				
(mill NOK/year)				(327.7)				

Notes: Total wells, discoveries and dry wells given per company-quadrant-year, with standard deviation in parenthesis. Annual reserve estimates are released on the field level only in Norway. We use the Norwegian tax data to divide firms into control and treatment groups. Tax values and received refunds are presented at the company-by-year level.

Before the policy change, the control group discovered larger reservoirs of both oil and gas. After the policy change, the treatment group discovered larger oil reservoirs, mainly due to the giant oil discovery of Johan Sverdrup in Norway in 2010.[28]

4.4 Empirical specification

To identify the effect of the Norwegian tax policy change in 2005 on drilling, we use a triple difference specification. We use the Poisson estimator, as our dependent variables are count variables with many zeros. Specifically, we estimate equations such that:

$$\ln \mathbb{E}[y_{ijt}] = \alpha + \beta Policy_{ijt} + \delta X'_{jt} + \gamma_{ij} + \gamma_{it} + \gamma_{ct} \quad (5)$$

where y_{ijt} denotes the total number of exploration wells, the number of dry wells or the number of discovery wells, drilled by company i in quadrant j in year t. Note that quadrants are perfectly nested into countries, and therefore j also denotes the country, c. Our variable of interest is $Policy_{ijt}$ and β gives the treatment effect of the policy.[29]

[28] For comparison, the post-2005 average oil discovery for treatment group in Norway would be 4.41 million Sm^3 without the Johan Sverdrup discovery, compared to the average 9.98 million Sm^3 including that discovery.

[29] $Policy_{ijt}$ is defined as the following triple interaction: $D_{NOR} \times D_{WeakTax2004} \times D_{Post}$, where D_{NOR} takes

In our setting, both the control group and the treatment group encompass companies that drill in Norway, the UK or in both countries. We do also observe the exact location of the wells drilled by the different companies. These aspects of our data provide us with several advantages in terms of econometric identification.

First, company-by-quadrant fixed effects, γ_{ij}, capture time-invariant geology, company-specific factors and the combination of the two.[30] For example, the geological prospects and hence the ex-ante NPV of drilling may differ across geographic areas. Firms differ also along a set of obvious dimensions, such as ownership, access to capital and in-house geology know-how. And finally, companies may not have the same expected NPV of drilling in a given area due to for example company-specific knowledge about the local geology or preferences for a particular area. The company-by-quadrant fixed effects help with keeping the ex-ante NPV of drilling as similar as possible in the control and treatment group. As no drilling by a company in a given quadrant is represented with a zero, all companies are represented in all quadrants in both countries.

Second, company-by-year fixed effects, γ_{it}, control for unobservable time-varying characteristics at the company-level that may change drilling behavior.[31] They capture aspects such as how companies react to changes in general economic conditions, technological de-

1 for quadrants in Norway and 0 for quadrants in the UK, $D_{WeakTax2004}$ takes one for companies in a weak tax position in 2004 and zero otherwise, and D_{Post} takes 1 for the years from 2005 and later and zero otherwise. We control for D_{NOR}, $D_{WeakTax2004}$ and $D_{NOR} \times D_{WeakTax2004}$ by company-quadrant fixed effects and for D_{post}, $D_{WeakTax2004} \times D_{post}$, and $D_{NOR} \times D_{Post}$ by year fixed effects as well as with interactions between D_{post} and company fixed effects and D_{post} and country fixed effects. In some specifications, we go further and replace the latter two controls by country-year and company-year fixed effects. The estimate of β can be expressed in terms of three differences, where $\bar{y}$ expresses the conditional mean of the dependent variable in question:

$$\begin{aligned}\beta &= [(\bar{y}_{WeakTax2004,Post} - \bar{y}_{WeakTax2004,Pre}) - (\bar{y}_{StrongTax2004,Post} - \bar{y}_{StrongTax2004,Pre})]_{NOR} \\ &\quad -[(\bar{y}_{WeakTax2004,Post} - \bar{y}_{WeakTax2004,Pre}) - (\bar{y}_{StrongTax2004,Post} - \bar{y}_{StrongTax2004,Pre})]_{UK}\end{aligned}$$

Intuitively, the three differences in our setting are: between treated and non-treated companies, between Norway and the UK and before and after the introduction of the policy in 2005. The treatment effect in a standard difference-in-differences specification would consider Norway only, and would be based on firms in Weak vs. firms in Strong pre-policy tax positions before vs. after the policy was introduced. In the triple difference specification, we also take into account a similar difference-in-differences for the UK. We can think of UK acting as a "placebo country", which helps us difference out any general differences across the two company groups over time. See Muralidharan and Prakash (2017) for the use of this approach in a different setting.

[30] Inclusion of this set of fixed effects, is possible because we observe which company that is drilling each well as well as the exact location of each well.

[31] Inclusion of company-year fixed effects is made possible by the fact that we observe companies operating in several quadrants and, since companies operate in both countries, we can separate this from the effect of the policy.

velopment and expectations regarding the future oil price.[32] Third, country-by-year effects, γ_{ct}, capture any country-specific shock, such as country-specific economic conditions.

We present our results with successively tougher sets of fixed effects: We always include company-by-quadrant fixed effects. We then move from year fixed effects, to adding more comprehensive fixed effects: post times company, post times country, both post times company and post times country, company-year, country-year, and both company-year and country-year. We comment further on this in the results section 5 below.

Last, the covariate-vector X'_{jt} includes the accumulated number of exploration wells, discoveries and facilities (processing, offloading, storage and housing) at the quadrant-level. These controls are meant to take into account previous investments and potential learning externalities in the area.[33] In the Appendix we also present the results without these controls.

We use two-way clustered standard errors. We cluster at the country-by-year level, to account for potential Moulton-bias, as we observe multiple observations facing the same tax regime. We cluster at the company-level to take into account potential serial correlation.

As is the case for a difference-in-differences specification, the key identifying assumption in our triple difference setting is common trends in absence of the policy change. It is standard to justify this assumption by testing for differential trends in the years before the policy came into force. In Appendix Tables B.1-B.2, we introduce leads in our standard specifications. We find that the dummies in the years before the policy change are in general insignificant and that the coefficient on the treatment dummy keeps its magnitude and statistical significance. In Figure 5, we show graphical evidence in support of common trends in the years before the policy change took place.

[32]Kellogg (2014) find that both the mean and the variance of the future oil price, as captured in derivative prices, are important for determining investment in oil exploration.

[33]Hendricks et al. (1994) and Lin (2013) have found evidence for such information externalities. In practice, observing outcome of competitors exploration drilling in the same area creates valuable information and encourages others' drilling if discoveries are made. Although not causal evidence, our estimation results are in line with these findings: Quadrant-level historical discoveries are positively associates with future exploration activity and outcomes.

5 Empirical results

5.1 Results: Drilling

Results from estimating equation (5) are reported in Table 2. The upper panel presents the estimates for total exploration drilling, the middle panel the estimates for discoveries and the lower panel the estimates for dry wells. All columns include company-quadrant fixed effects, and the columns differ due to the inclusion of different combinations of year, company and country fixed effects. All columns include control variables as described above, except column 1, which has no controls included.[34] We prefer column 5 and column 8, as they represent fully specified triple difference models as described in footnote 29. However, all columns point to the same conclusions.

We find that the policy increases the total number of exploration wells by a factor of three.[35] As for outcomes, we find positive and statistically significant coefficients for dry wells. The coefficient for dry wells is always larger than the coefficient for all wells in the same column. Consistent with this, we find that the coefficient for discovery wells is always smaller than the coefficient for all wells in the same column. The coefficients for discovery wells are statistically significant only in the two least demanding specifications (column 1 and 2).

To evaluate the effect sizes in terms of number of new wells, we apply the coefficients on the pre-policy annual averages. We report the resulting figures in the rows below the estimated coefficients and standard errors. According to the estimates in columns 5 and 8, the policy added 12-13 more wells per year, of which about 1 was a discovery wells. The marginal discovery rate was thus 8%, which is about 70% lower than the counterfactual discovery rate, as reported in the lower part of Table 2.[36]

To put these numbers in context, there were on aggregate 358 new exploration wells drilled in Norway since 2005. Our estimates suggest that 133-144 (37%-40%) additional drilling is caused by the introduction of the refund policy. However, out of the 162 discoveries made

[34] For completeness, we include this table without controls in all columns in the appendix.

[35] This factor can be derived from the Poisson estimate in columns 5 and 8: $e^{1.454} - 1 = 3.28$ and $e^{1.391} - 1 = 3.02$

[36] In the Appendix we present a similar table without quadrant-level controls (Table B.3) and using a broader definition of discoveries, including all the wildcat wells that have oil or gas registered as their content, whether or not classified as new discoveries (Table B.4). Our main results are robust to these changes: the policy leads to an increase in oil exploration and a drop in the discovery rates.

Table 2: The effect of the tax refund policy on exploration effort and outcomes.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A - All wells								
Treatment effect	1.619	1.497	1.928	1.565	1.454	1.459	1.440	1.391
	(0.573)	(0.565)	(0.682)	(0.716)	(0.754)	(0.739)	(0.767)	(0.706)
Effect size (wells/year)	16.2	13.9	23.5	15.1	13.1	13.2	12.9	12.1
N	10731	10731	9646	10731	9646	6026	9646	6026
Panel B - Discoveries								
Treatment effect	1.401	1.254	1.089	1.225	0.669	0.584	0.717	0.621
	(0.712)	(0.710)	(1.128)	(0.799)	(1.318)	(1.123)	(1.417)	(0.871)
Effect size (wells/year)	3.4	2.8	2.2	2.6	1.0	0.9	1.2	0.9
N	4851	4851	4277	4851	4277	2132	4277	4336
Panel C - Dry wells								
Treatment effect	1.762	1.676	2.146	1.919	1.643	1.700	1.629	1.691
	(0.530)	(0.545)	(0.607)	(0.741)	(0.719)	(0.733)	(0.742)	(0.921)
Effect size (wells/year)	14.0	12.6	22.1	16.9	12.1	13.0	11.9	12.8
N	8988	8988	8083	8988	8083	4336	8083	4348
Marginal discovery rate	20.8%	19.9%	9.2%	17.5%	8.0%	6.6%	9.0%	7.8%
Change in discovery rate	-24.4%	-27.8%	-66.5%	-36.4%	-71.0%	-76.0%	-67.5%	-71.5%
Time FEs	Year	Year	Year Post-company	Year Post-country	Year Post-company Post-country	Company-year Post-country	Country-year Post-company	Country-year Company-year
Company-quadrant FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Quadrant-level controls	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The table presents Poisson coefficients for the time period 1995-2015. The effect on new wells is calculated by $\overline{y}_j(e^{\beta_j} - 1)$ where $\overline{y}$ is the pre-policy annual average of (j = total wells/discoveries/dry wells) and β is the estimated Poisson parameter. The change in discovery rate is given by $(e^{\beta_k} - 1)/(e^{\beta_j} - 1) - 1$ with k=non-dry wells and j=total wells. Fixed effects (FE) and controls included as indicated in the bottom rows. Covariate controls include historical exploration drilling and discoveries, as well as the presence of processing or other (offloading, storage, quarter) facilities, all measured at the quadrant level. Robust standard errors in parentheses clustered on the company and country-by-year level.

since 2005, only 10-12 (6%-7%) can be attributed to the policy.[37]

To understand the timing of the effect, Figure 5 plots the treatment effect (β) per year. We also plot the three main events in the implementation of the policy change: (1) when losses become transferable in mergers and takeovers in 2002, (2) the beginning of the refund policy in 2005 and (3) the possibility to pledge the claim for the refund against the Norwegian state in 2007. Interestingly, the effect kicks in with full power only after the last one of these changes, and it has been almost constant and persistent since then.[38]

[37]The aggregate numbers are based on the main specifications in columns 5 and 8 of Table 2 multiplied by the length of the post-policy period, 11 years.

[38]In Table B.5 we redo Table 2 with the post dummy defined as taking 1 from 2007 and the years after, instead of from 2005 as in our baseline analysis. The results are qualitatively the same, but the effect size is, unsurprisingly, somewhat larger.

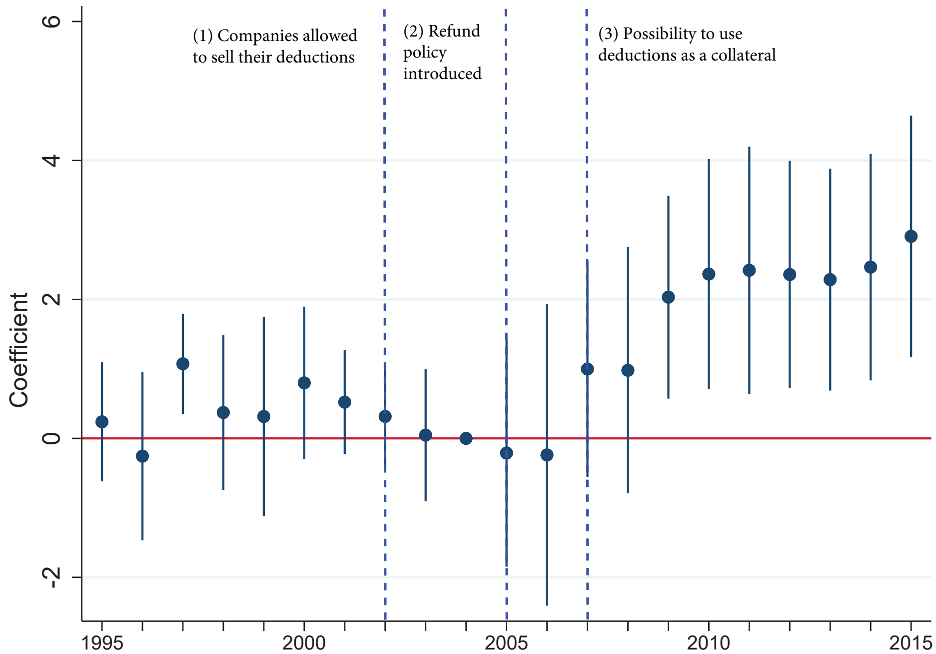

Figure 5: Estimated impact of the policy change.

Notes: The graph shows the coefficients on a dummy taking one for the treatment group and zero for the control group for each year with year, post-country and post-company fixed effects. The vertical lines indicate the changes in the deduction rules in the Norwegian petroleum tax system: (1) In 2002-2004, companies going out of business were allowed to sell their deductions (78% of their costs) to other companies operating in the sector; (2) from 2005, the companies could get the deductions as cash in hand, i.e. they did neither have to earn profits higher than the deductions nor did they have to sell their deductions do other companies when the left the sector to take advantage of the deductions; and (3) from 2007, the companies were also allowed to use the deductions as a "collateral" when financing their projects. Only for companies with pre-tax profits smaller than the value of the deductions, these three changes would have an effect.

5.2 Results: Spillovers

We have so far focused on a triple difference specification, which relies on the assumption that the firms in strong tax position, the control group, are not affected by the refund policy. In this section we provide an indirect test of this hypothesis that the estimated drilling is additional, and not just shifting drilling activity from incumbents to new entrants. As we observe the two company groups in both countries, we can investigate spillover effects directly: In Table 3 we introduce two post-dummies, one for firms in weak tax position that are eligible to receive refunds and therefore directly affected by the policy, and one for firms in strong tax position. This new variable replaces either post-dummy times country fixed effects or the country-year fixed effects used in the previous Section. We therefore

Table 3: Direct and indirect effects of the policy.

	(1) All wells	(2) All wells	(3) All wells	(4) Discoveries	(5) Discoveries	(6) Discoveries	(7) Dry wells	(8) Dry wells	(9) Dry wells
Direct effect	1.454	1.945	1.884	1.258	1.104	1.073	1.566	2.160	2.075
(weak tax position)	(0.530)	(0.680)	(0.700)	(0.685)	(1.127)	(1.016)	(0.509)	(0.607)	(0.629)
Indirect effect	-0.111	0.491	0.425	0.007	0.435	0.489	-0.354	0.518	0.375
(strong tax position)	(0.457)	(0.302)	(0.305)	(0.457)	(0.598)	(0.602)	(0.493)	(0.373)	(0.387)
Time FEs	Year	Year Post-company	Company- year	Year	Year Post-company	Company- year	Year	Year Post-company	Company-year
Company-quadrant FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Quadrant-level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	10731	9646	6026	4851	4277	2132	8988	8083	4348

Notes: The table presents difference-in-differences estimates for the treated firms (weak tax position), the direct effect, and for the non-treated firms (strong tax position), the indirect effect. The comparison groups are treated and non-treated firms in the UK, respectively. Fixed effects (FE) and controls included as indicated in the bottom rows. Covariate controls include historical exploration drilling and discoveries, as well as the presence of processing or other (offloading, storage, quarter) facilities, all measured at the quadrant level. Robust standard errors in parentheses clustered on the company and country-by-year level. Panels (1)-(3) show the effects on all wells, panels (4)-(6) on discoveries and panels (7)-(9) on dry wells.

only present three columns per dependent variable (total drilling, discoveries, dry wells). This approach builds on the stronger identifying assumption that there are no time-varying country-specific shocks influencing exploration drilling.

In all columns, we find that the indirect effect on the companies in strong tax position is insignificant. Table 3 essentially splits the coefficients in Table 2 into a direct and an indirect effect. Columns 4, 5 and 6 in Table 2 corresponds to columns 1, 2 and 3 in Table 3, respectively. The coefficient of 1.565 in column 4 in Table 2, is a mix of 1.454 more drilling by treated companies and 0.111 less drilling by the companies in weak tax position, column 1 in Table 3. The coefficient of 1.454 in column 5 in Table 2 consists of a direct effect of 1.945 and an indirect effect of 0.491 (column 2 in Table 3). The coefficient of 1.459 in column 6 in Table 2, consists of a direct effect of 1.884 and an indirect effect of 0.425 (column 3 in Table 3). The same goes for discoveries in columns 4-6 and dry wells in columns 7-9 in Table 3. In summary, in seven out of the nine columns, the coefficients for the non-treated companies are positive and in all nine cases the coefficients are insignificant. We conclude that both the new exploration and the new discoveries were additional, and there is no evidence of significant crowding out of incumbent firms' activity.[39]

[39]Note that these findings lend credence to our identification strategy. The validity of our triple-difference design relies on the Stable Unit Treatment Value Assumption (SUTVA), i.e. that the companies in strong tax position are unaffected by the policy.

Table 4: The effect of the refund policy on the average discovery size in Norway.

	Well count			Oil discoveries		Gas discoveries		Total discoveries	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	All wells	Discoveries	Dry wells	Oil (small=0)	Oil (drop small)	Gas (small=0)	Gas (drop small)	Total (small=0)	Total (drop small)
Policy	1.611	1.326	2.007	-2.614	1.007	-1.954	-0.847	-2.954	0.639
	(0.753)	(0.859)	(0.799)	(1.437)	(0.723)	(0.611)	(0.335)	(1.378)	(0.932)
N	4641	2289	3675	140	98	140	98	140	98
Time FE	Year	Year	Year	Year	Year	Year	Year	Year	Year
Company-quadrant FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Quadrant-level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Columns 1-3 represent the Poisson coefficients for total wells, discoveries and dry wells in Norway for 1995-2015. The table represent the OLS-estimates for average oil (in million Sm^3, columns 4-5), gas (in billion Sm^3, columns 6-7) and total (million oil equivalents, coluns 8-9) discovery size, for inverse hyperbolic sine transformations. Fixed effects (FE) and controls included as indicated in the bottom rows. Covariate controls include historical exploration drilling and discoveries, as well as the presence of processing or other (offloading, storage, quarter) facilities, all measured at the quadrant level. Robust standard errors in parentheses clustered on the company and year level.

5.3 Results: Discovery size

From an economic point of view, it is not sufficient to evaluate the number of discoveries induced by the policy change. We also need to take into account the size of the discoveries. For example, it could be that the companies for which the policy had an effect take more risk and accept lower discovery rates expecting to discover larger deposits than the companies in the control group. We do not observe the size of each discovery at the well level in the UK, and must therefore investigate the effects on size in a difference-in-differences specification for Norway only.

First, we include difference-in-differences estimates for all wells, discovery wells and dry wells for Norway only in columns 1-3 of Table 4, for comparison. We find qualitatively the same results as in Table 2: The policy increased exploration drilling, but had a larger effect on dry wells than discoveries.[40]

Columns 4-9 of Table 4 present the effects on oil, gas and total discovery sizes. For some small discoveries production is deemed unlikely with the present oil price and reserves are not estimated. When these discoveries are treated as zeros (columns 4,6 and 8), we do not find evidence that the policy increased the average discovery size of the treated firms; rather the policy seems to decrease the average size. For robustness, we also include estimations where we only include discoveries that are large enough so that the reserve size has been estimated (columns 5,7 and 9), that is, we only focus on discoveries where production is

[40]We present the distribution of discovery sizes for the treatment and control group in the Appendix (Figure B.2).

either likely or has already begun. In that case we find weak evidence that the new firms are making larger oil discoveries after the policy, although this is not statistically significant.

5.4 Results: Cost-benefit analysis

To get a sense of the welfare effects of the policy, we use our estimates for a back-of-the-envelope cost-benefit analysis. In our specific setting, we are able to estimate the welfare impacts of the policy directly as, first, production in the North Sea does not affect the global oil price and, second, we are able to observe the firms' costs (reported by the firms to claim the refunds).

The cost per discovery is calculated to be \$1382 million. We arrive at these figures as follows. The companies reported total costs of \$14.38 billion, of which 78% was paid to them as exploration cost refunds. Using our main point estimates from column (8) of Table 2, the policy lead to 132.8 new wells and 10.4 new discoveries during 2005-2015.[41] Consequently, the price tags are \$108 million per new exploration well and \$1382 million per new discovery that was found because of the policy.[42]

The benefit per discovery is calculated to be \$1210 million. We estimate this average value as follows. First, we estimate the production profile of an oil or gas discovery based on historical oil and gas production in Norway, following Arezki et al. (2017).[43] Second, we use this profile to calculate the net present value of a discovery. For the analysis we use the 4% social discount rate of as recommended by the Norwegian Ministry of Finance (2012). If we take the average discovery size in Norway for 2005-2015 (6.35 million Sm^3 for gas, 2.27 billion Sm^3 for gas), use the average oil (\$78.6 per barrel) and gas (\$5.2 per MMBTU) prices for the same time period (Macrotrends, 2019) and use the estimated production costs of \$21.3 per a barrel of oil equivalent WSJ (2016) for both oil and gas, we arrive at rents of \$57.3 per barrel of oil and \$1.3 per oil-equivalent barrel of gas. The resulting value of a discovery is then \$1210 million.

Figure 6 shows the value of oil and gas deposits for various discovery sizes and "rents" (oil price minus production costs), building on our calibration. The break-even lines are where

[41] Although the effect on discoveries is not statistically significant, we use the point estimate rather than zero as the "best guess" in the cost-benefit analysis.

[42] These values are gained simply by dividing the reported total costs by our estimated effects of the policy. Note, that our estimated cost per an exploration well is close to the actual costs of drilling exploration wells: \$68-\$99 million per well for 2007-2015 (Norwegian Petroleum, 2019a).

[43] The details of this estimation and the parameter values are provided in Appendix C.

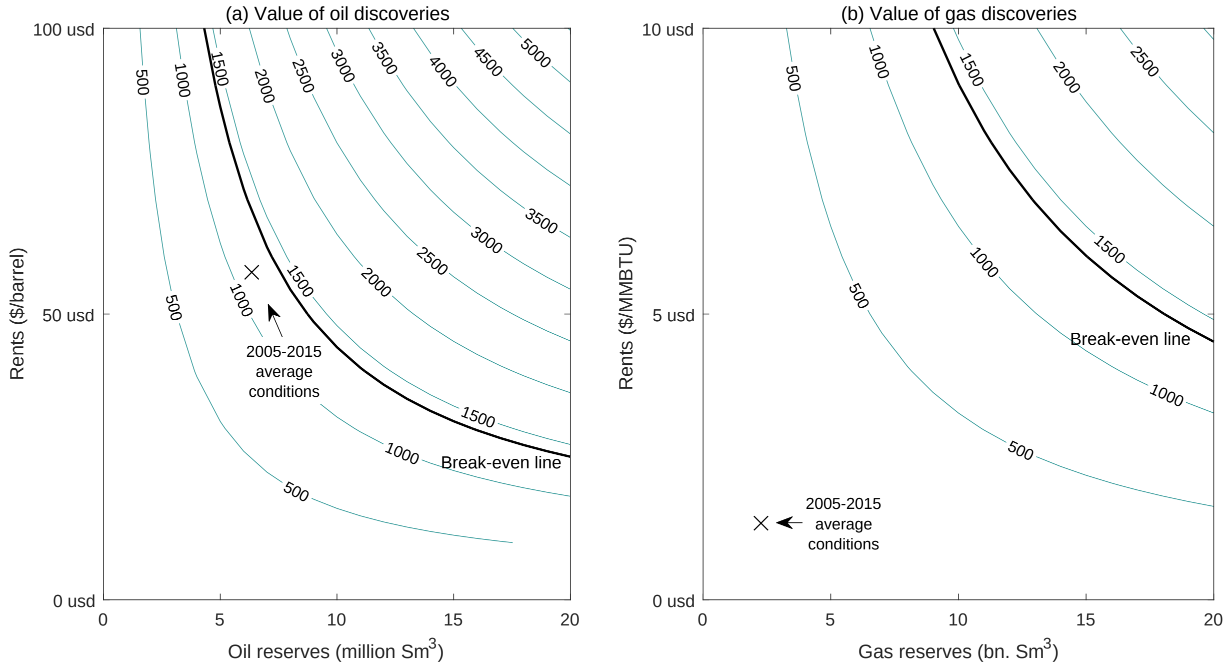

Figure 6: Value of oil and gas discoveries.

Notes: The figure is a contour plot of values of oil and gas discoveries of a given size, and with a given rents (price minus production costs) based on the estimated production profiles and 4% discount rate. The solid black line marks the break-even of the policy (the benefit is equal to the cost of $1382 million per discovery), given the assumption that a discovery contains only oil (left panel) or gas (right panel). We also plot the average discovery size across all companies as well as the rents following from the average oil price over the period 2005-2015.

the benefits are exactly equal to the cost of $1382 million. The average rents and discovery rates are plotted in the figure, to the left of the break even line both for oil and gas, implying a negative value of the policy. However, the figure also makes clear that other (also plausible) assumptions could tip the net benefits in both positive and negative directions. The results in our specific sample is not sufficient to conclude strongly in either direction regarding the welfare effects of the policy.

6 Concluding remarks

Cash-flow corporation taxes allow governments to collect revenues without distorting firms' investment decisions. However, negative taxes to loss-making firms are rarely practiced, which may distort firm entry and exit. A natural experiment of introducing cash refunds to loss-making firms in the Norwegian petroleum sector in 2005, together with detailed Norwegian and UK data, allows us to provide evidence on the size of such extensive margin distortions.

We find that the refund program led to a large increase in investments by new entrants. In total, 37 per cent of all new wells in Norway in 2005-2015 can be attributed to the policy. The evidence suggests that this investment is additional, rather than displacing investments of the incumbent firms. The fact that entry may lead to additional drilling is consistent with a common value model where firms disagree on the likelihood of finding oil. While entry increases drilling, the model also predicts that the effect is larger on dry than non-dry tracts. It follows that discovery rates are endogenous to the policy and should fall when more firms enter. This is in accordance with our empirical findings: we find that the discovery rate of the new wells was as low as 8 per cent, or 70% lower than the counterfactual discovery rate. The optimal entry balances the social value of new discoveries against the increased costs of drilling dry wells, and the net welfare effect of entry is thus ambiguous. Our back-of-the-envelope cost-benefit analysis suggests that the increased benefits of the additional discoveries are at par with the increased costs of drilling in our sample.

Our results should be helpful for policy makers. We find that tax distortions related to entry, as emphasized in the theoretical literature, are also empirically relevant. This paper further rationalizes the Norwegian refund policy by showing both theoretically and empirically that entry-inducing policies may lead to additional drilling and discoveries, rather than just wasteful competition over fixed petroleum resources. At the same time, this paper also shows that there can be too much of a good thing, as increased entry also leads to a drop in the discovery rate. In fact, undistorted entry may generate too much drilling of dry wells. This complicates the design of optimal taxes, as policy makers cannot simply trust that undistorted firm decisions will maximize social welfare. Any tax-reform that affects firm entry needs to account for, on one hand, the positive effects on investments and, on the other hand, that new entrants both may crowd out investments of incumbent firms and that more firms can result in wasteful efforts where prospects for success are small.

Our findings are based on the petroleum sector in Norway and the UK, which is characterized by large upfront investments, high risk related to geology and prices, long lags between investments in exploration and cash flows from production and high marginal tax rates. Still, the same logic calls for negative taxes for loss-making firms in other sectors. This is particularly true in any high-risk activities, where the potential entrants cannot guarantee to be in a positive tax-flow position in the future, for example investments in R&D or infant industries. On top of the arguments presented in this paper, cash refunds may help by providing liquidity to credit constrained firms or by acting as insurance for risk-averse firms. Future theoretical work on these themes as well as empirical evaluations of tax policies in other high-risk sectors, may help to generalize our results.

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APPENDIX FOR ONLINE PUBLICATION

A Appendix: Technical appendix for Section 3

Preliminaries. Firm i's ex-post payoff under neutral taxation is given by (2): $\pi_i = (1-\tau)(v_\omega x_i - c)$, where $x_i = 1$ if firm i drills in that deposit. The game proceeds as follows. In the first stage of the game firms decide whether to pay c to receive a signal s_i. In the second stage, firms decide whether or not apply for a license (and drill if receive one), based on their signal s_i. Throughout, we assume that the strategies of the $n-1$ other firms are taken as given, and they are assumed to be symmetric and in cut-off strategies: apply for a license (and drill if get one) if: $s_{-i} \geq s^*_{-i}$, and do not apply otherwise. We solve the game by backward induction and begin by focusing on the second stage. After receiving signal s_i, and taking cut-off strategies s^*_{-i} of the competitors as given, a company's expected profits of applying for a license is:

$$\mathbb{E}[\pi_i] = (1-\tau)\sum_{k=1}^{n}\binom{n-1}{k-1}\Big[p(s)(1-F(s^*_{-i}))^{k-1}F(s^*_{-i})^{n-k}\frac{v_H}{k}+(1-p(s))(1-G(s^*_{-i}))^{k-1}G(s^*_{-i})^{n-k}\frac{v_L}{k}\Big] \tag{A.1}$$

where the first term in the sum gives the binomial probability that $k-1$ other firms receive a signal above the cut-off and also apply for the license. If a company does not apply, it receives zero payoffs (apart from the sunk cost c paid in the first stage). Here, the first term in brackets is the probability that exactly k rivals receive a signal above their cut-off, s^*_{-i}, if the true type is $\omega = H$. In this case the expected value of the deposit is v_H/k. Respectively, the second term is the probability that exactly k rivals receive a signal above s^*_{-i} when the true type is $\omega = L$. In this case the expected value of the deposit is v_L/k. To simplify equation (A.1), we can use the binomial theorem:

$$\sum_{j=0}^{m}\binom{m}{j}x^j y^{m-j} = (x+y)^m$$

Integrate both sides of the binomial theorem with respect to x:

$$\sum_{j=0}^{m}\binom{m}{j}\frac{1}{j+1}x^{j+1}y^{m-j} = \frac{1}{1+m}(x+y)^{m+1} + C$$

Plug in $x = 0$ to solve the constant: $C = -y^{m+1}/(1+m)$ and use $x = 1 - y$ to get:

$$\sum_{j=0}^{m} \binom{m}{j} \frac{1}{1+j} y^{j+1}(1-y)^{m-j} = \frac{1-y^{m+1}}{1+m} \tag{A.2}$$

With a change of variables $k = j+1$, $n = m+1$ we can apply rule (A.2) to simplify equation (A.1):

$$\mathbb{E}[\pi_i] = (1-\tau)p(s_i)\frac{1-F(s^*_{-i})^n}{n(1-F(s^*_{-i}))}v_H + (1-\tau)(1-p(s_i))\frac{1-G(s^*_{-i})^n}{n(1-G(s^*_{-i}))}v_L \tag{A.3}$$

Best-response. It is optimal for the company to apply for a license (and drill) whenever the expression (A.3) is non-negative:

$$p(s_i)\frac{1-F(s^*_{-i})^n}{n(1-F(s^*_{-i}))}v_H \geq -(1-p(s_i))\frac{1-G(s^*_{-i})^n}{n(1-G(s^*_{-i}))}v_L$$

Note, that the tax rate τ does not show up in the condition; we refer this as intensive margin tax neutrality. Plug in the definition of $p(s_i)$ from Bayes' rule (2) and simplify:

$$q\frac{f(s_i)}{1-F(s^*_{-i})}\big(1-F(s^*_{-i})^n\big)v_H \geq -(1-q)\frac{g(s_i)}{1-G(s^*_{-i})}\big(1-G(s^*_{-i})^n\big)v_L$$

The best response for firm i to others' symmetric cut-off policy s^*_{-i} is to follow a cut-off policy of its own: apply for a license (and drill) if $s_i \geq s^*_i$, where the cut-off s^*_i is given by:

$$\frac{f(s^*_i)}{g(s^*_i)} = -\frac{1-F(s^*_{-i})}{1-G(s^*_{-i})}\frac{1-G(s^*_{-i})^n}{1-F(s^*_{-i})^n}\frac{1-q}{q}\frac{v_L}{v_H} \tag{A.4}$$

This cut-off is illustrated in Figure A.1. By the monotone likelihood ratio, the left-hand side is strictly increasing in s^*_i while the right-hand side is constant. Thus, the best-response to others' cut-off policy s^*_{-i} is unique.

Also, the right hand side of equation (A.4) is increasing in n because the monotone likelihood ratio implies $F(s) < G(s)$ for all s. As the left-hand side is also increasing in s^*_i, a larger n always increases the optimal cut-off strategy s^*_i. Intuitively, with more competition, a firm is more likely to split a discovery (at least one rival receives a signal above s^*_{-i} when $\omega = H$) than a dry well (at least one rival receives $s_{-i} \geq s^*_{-i}$ when $\omega = L$).

Equilibrium. In symmetric Bayes-Nash equilibria of the game all firms use the same cut-off $s^*_{-i} = s^*_i = s^*_n$:

$$q\frac{f(s^*_n)}{1 - F(s^*_n)}\Big(1 - F(s^*_n)^n\Big)v_H = -(1-q)\frac{g(s^*_n)}{1 - G(s^*_n)}\Big(1 - G(s^*_n)^n\Big)v_L \tag{A.5}$$

Or, by denoting the hazard rate by $H_f(s) = f(s)/(1 - F(s))$ and respectively for $g(s)$, we can rewrite equation (A.5) as:

$$\frac{H_f(s^*_n)}{H_g(s^*_n)} = -\frac{1-q}{q}\frac{1 - G(s^*_n)^n}{1 - F(s^*_n)^n}\frac{v_L}{v_H} \tag{A.6}$$

For uniqueness of the symmetric equilibrium, we need condition (A.6) to hold for at most one s^*_n. On one hand, the left-hand side of (A.6) is increasing in s^*_n if $H'_f(s^*_n)/H_f(s^*_n) > H_g(s^*_n)/H_g(s^*_n)$. Since we have assumed that signals follow $s_i \sim \mathcal{N}(s_\omega, \sigma^2)$, $s_H > s_L$ (implying $H_g(s_1) = H_f(s_2), s_1 < s_2$) this condition is equivalent to assuming a log-concave hazard rate. Unfortunately, this condition does not follow from the commonly used monotone likelihood ratio property and to guarantee uniqueness, we need to use a stronger assumption that signals are normally distributed, which is known to have this property (see e.g. Baricz 2010). On the other hand, the right-hand side of condition (A.6) is decreasing in s^*_n for any given n, because the monotone likelihood rate implies $F(s) < G(s)$. This guarantees the uniqueness of the symmetric equilibrium.

Discoveries and dry wells. The expected number of discoveries, $Y_{disc}(n)$, is given by the probability that the state is h and at least one of the firms receives a signal above the equilibrium cut-off value and wants to drill:

$$Y_{disc}(n) = q\big(1 - F(s^*_n)^n\big) \tag{A.7}$$

Similarly, the expected number of dry wells, $Y_{dry}(n)$, is the probability that the state is l and at least one of the firms receives a signal above the equilibrium cut-off:

$$Y_{dry}(n) = (1-q)(1 - G(s^*_n)^n) \tag{A.8}$$

As established above, the left-hand side of (A.6) is increasing in n through s^*_n. To maintain the equality, also the right-hand side of (A.6) msut be increasing in n. However, by using the definitions (A.7) and (A.8), this requires that $Y_{dry}(n)/Y_{disc}(n)$ is increasing in n. This directly implies that the equilibrium discovery rate:

$$Y_{dr}(n) = \frac{Y_{disc}(n)}{Y_{disc}(n) + Y_{dry}(n)} = \frac{1}{1 + \frac{Y_{dry}(n)}{Y_{disc}(n)}}$$

is decreasing in n.

Next, we will show that $Y_{disc}(n)$ is always non-decreasing in n. First, note that this follows immediately if the cut-off is not updated, $s^*_{n+1} = s^*_n$, because $1 - F(s_n)^{n+1} > 1 - F(s_n)^n$ follows from $F(s) < 1$. We are left to show that the increase in s^*_n cannot be so large that the total number of discoveries (weakly) decreases. The proof is by contradiction: assume that $Y_{disc}(n+1) \leq Y_{disc}(n)$, implying $F(s^*_{n+1})^{n+1} \geq F(s^*_n)^n$, or alternatively, $F(s_{n+1})^{n+1} = kF(s_n)^n$, with $k \geq 1$. As the left-hand side of equation (A.5) is strictly increasing in n through s^*_n, also the right-hand side must be increasing in n. The first part of the following inequality must therefore hold:

$$\frac{1 - G(s^*_{n+1})^{n+1}}{1 - F(s^*_{n+1})^{n+1}} > \frac{1 - G(s^*_n)^n}{1 - F(s^*_n)^n} > \frac{1 - kG(s^*_n)^n}{1 - kF(s^*_n)^n} \tag{A.9}$$

where the second inequality follows from $k \geq 1$ and $F(s) < G(s)$. The assumption $F(s^*_{n+1})^{n+1} = kF(s^*_n)^n$ necessitates that, for inequality (A.9) to hold, we must have $G(s^*_{n+1})^{n+1} \leq kG(s^*_n)^n$. However, since we have $F(s) < G(s) \leq 1$, $F(s^*_{n+1})^{n+1} = kF(s^*_n)^n$ implies that $G(s^*_{n+1})^{n+1} > kG(s^*_n)^n$. This contradiction proves that $Y_{disc}(n+1) > Y_{disc}(n)$.

A similar argument can be used to show that the number of dry wells is strictly increasing. Proof is again by contradiction: $Y_{dry}(n) \leq Y_{dry} \Rightarrow G(s_{n+1})^{n+1} = kG(s^*_n)$, $k \geq 1$. This condition and inequality (A.9) together require that $F(s_{n+1}) \geq kF(s_n)^n$. However, from $F(s) < G(s) \leq 1$ it follows that $G(s^*_{n+1})^{n+1} = kG(s^*_n)^n$ implies that $F(s^*_{n+1})^{n+1} < kF(s^*_n)^n$. This contradiction proves that $Y_{dry}(n)$ is increasing in n.

Private entry incentives. Next, we will focus on the first stage. A firm enters if the profits from the second period equilibrium (where the equilibrium cut-off strategies are determined by condition A.5) exceed the sunk cost of entry, c:

$$\mathbb{E}[\pi_i] = (1-\tau)\sum_{k=1}^{n}\binom{n-1}{k-1}\left[q(1-F(s^*_n))^k F(s^*_n)^{n-k}\frac{v_H}{k} + (1-q)(1-G(s^*_n))^k G(s^*_n)^{n-k}\frac{v_L}{k}\right] \geq (1-\tau)c \tag{A.10}$$

While equation (A.1) gives the expected welfare *after* paying and c and receiving the signal s_i, equation (A.10) is the equation *before* that. Equation (A.2) proves helpful in simplifying equation (A.10), which can be written as:

$$\frac{q\big(1-F(s_n^*)^n\big)v_H}{n}+\frac{(1-q)\big(1-G(s_n^*)^n\big)v_L}{n}\geq c$$

Or, to rewrite, n:th firm enters if

$$q\big(1-F(s_n^*)^n\big)v_H+(1-q)\big(1-G(s_n^*)^n\big)v_L-cn\geq 0 \tag{A.11}$$

Note, that taxes do not show up in the optimal entry condition, meaning that taxation is neutral on the extensive margin. How do incentives to enter change if taxation is not neutral on the extensive margin? Consider the payoffs under asymmetric treatment of revenues and costs as given by expression (1). Consider a firm in weak tax position, whose benefits from entry are now:

$$\mathbb{E}[\pi_i]=\sum_{k=1}^{n}\binom{n-1}{k-1}\Big[(1-\tau)q(1-F(s_{-i}^*))^kF(s_{-i}^*)^{n-k}\frac{v_H}{k}+(1-q)(1-G(s_{-i}^*))^kG(s_{-i}^*)^{n-k}\frac{v_L}{k}\Big]$$

Taxation is no longer neutral on the extensive margin. The firm now faces a positive tax rate τ if a discovery is made (the first term in the brackets), but faces the full cost incidence in case of no discovery (the second term in the brackets). This discourages entry.

Social entry incentives. As for the social welfare, the planner maximizes

$$W(n)=\underbrace{q\big(1-F(s_n^*)^n\big)}_{Y_{disc}(n)}v_H+\underbrace{(1-q)\big(1-G(s_n^*)^n\big)}_{Y_{dry}(n)}v_L-cn \tag{A.12}$$

The first term represents the value of new discoveries and this term is increasing in n because $Y_{disc}(n)$ is increasing and $v_H>0$. The second term represents the (negative) value of dry wells and this term is decreasing in n because $Y_{dry}(n)$ is increasing and $v_L<0$. The last term denotes the social value of sunk costs, and it is trivially decreasing in n. Note, that $n=0$ always guarantees $W(n)=0$ – therefore the optimal number of firms n^* always satisfies $W(n^*)\geq 0$. The entry is socially desirable if entry by n:th firm ($n>0$) has a positive effect on welfare, $W(n) \geq W(n-1)$:

$$\begin{aligned} q\big(1-F(s_n^*)^n\big)v_H + (1-q)\big(1-G(s_n^*)^n\big)v_L - cn \geq \\ q\big(1-F(s_{n-1}^*)^{n-1}\big)v_H + (1-q)\big(1-G(s_{n-1}^*)^{n-1}\big)v_L - c(n-1) \end{aligned} \tag{A.13}$$

Compare the private entry incentives in equation (A.11) to the social entry incentives (A.13). If $n = 1$, then the right-hand side of (A.13) is zero and the private and social entry incentives align. However, with $n > 0$, the entry incentives no longer align and the free entry condition (A.11) may lead to excessive entry (A.13). It should also be noted that (A.11) means that private entry incentives are positive for as long as $W(n) \geq 0$, while social entry incentives are positive when $W(n) - W(n-1) \geq 0$. Intuitively, entry is socially desirable if it leads to additional discoveries. However, under free entry, firms also take into account non-additional discoveries, that is, drilling in areas where other firms would have drilled.

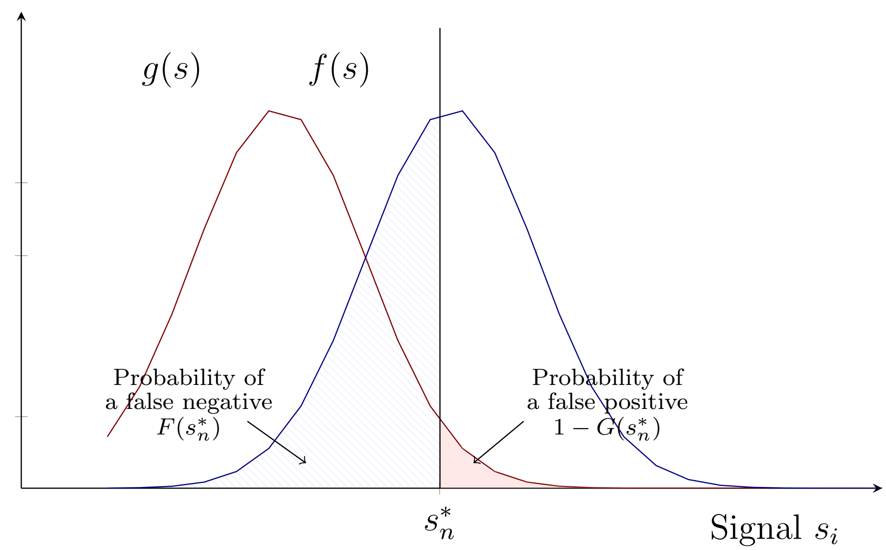

Figure A.1: Illustration of the cut-off equilibrium (s_n^*) and the two types of mistakes that the firms make.

B Appendix: Additional empirical results

Table B.1: The effect of tax refund policy – testing for pre-trends by introducing leads.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treatment effect	1.562	1.562	1.425	1.838	1.493	1.366	1.670	1.381
	(0.631)	(0.631)	(0.626)	(0.758)	(0.766)	(0.819)	(0.955)	(0.832)
2004 x treatment	-0.148	-0.148	-0.206	-0.237	-0.208	-0.235	-0.0614	-0.405
	(0.330)	(0.330)	(0.344)	(0.368)	(0.336)	(0.369)	(0.559)	(0.447)
2003 x treatment	-0.396	-0.396	-0.457	-0.505	-0.459	-0.502	0.712	-0.511
	(0.442)	(0.442)	(0.441)	(0.554)	(0.438)	(0.550)	(1.086)	(0.577)
2002 x treatment	-0.420	-0.420	-0.500	-0.563	-0.503	-0.559	0.965	0.0643
	(0.510)	(0.510)	(0.529)	(0.464)	(0.533)	(0.464)	(0.799)	(0.592)
N	10731	10731	9646	10731	9646	6026	9646	6026
Time FEs	Year	Year	Year Post-company	Year Post-country	Year Post-company Post-country	Company-year Post-country	Country-year Post-company	Country-year Company-year
Company-quadrant FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Quadrant-level controls		Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The table presents the triple-difference estimates together with a test for pre-policy introduction trends (treatment × 2002, treatment × 2003, treatment × 2004), where treatment is a dummy that takes value one for firms who are in weak tax position in Norway.

Table B.2: The effect of tax refund policy – testing for pre-trends by introducing more leads.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
				Panel A - All wells				
Treatment effect	1.599	1.425	1.816	1.492	1.346	1.815	1.281	1.637
	(0.618)	(0.611)	(0.780)	(0.752)	(0.828)	(0.994)	(0.873)	(0.839)
2004 x treatment	-0.383	-0.500	-0.586	-0.504	-0.581	1.134	-0.0348	0.110
	(0.556)	(0.582)	(0.561)	(0.584)	(0.556)	(0.972)	(0.629)	(1.015)
2003 x treatment	-0.359	-0.457	-0.528	-0.460	-0.524	0.830	-0.610	0.743
	(0.593)	(0.587)	(0.680)	(0.586)	(0.674)	(1.093)	(0.666)	(1.169)
2002 x treatment	-0.111	-0.206	-0.260	-0.209	-0.257	0.0651	-0.504	0.0289
	(0.427)	(0.437)	(0.408)	(0.433)	(0.408)	(0.449)	(0.446)	(0.759)
2001 x treatment	0.116	0.0125	-0.0611	0.00981	-0.0572	1.674	-0.465	2.622
	(0.138)	(0.169)	(0.418)	(0.166)	(0.425)	(0.782)	(0.342)	(0.960)
2000 x treatment	0.339	0.267	0.215	0.264	0.219	0.463	0.160	0.756
	(0.304)	(0.299)	(0.467)	(0.299)	(0.467)	(0.278)	(0.492)	(0.572)
1999 x treatment	-0.111	-0.204	-0.267	-0.206	-0.264	-0.163	-0.672	-1.059
	(0.290)	(0.294)	(0.469)	(0.293)	(0.459)	(0.583)	(0.423)	(0.762)
1998 x treatment	-0.0955	-0.178	-0.204	-0.180	-0.203	-0.433	0.0261	-0.281
	(0.239)	(0.241)	(0.450)	(0.243)	(0.450)	(0.518)	(0.428)	(0.500)
N	10731	10731	9646	10731	9646	6026	9646	6026
Time FEs	Year	Year	Year Post-company	Year Post-country	Year Post-company Post-country	Company-year Post-country	Country-year Post-company	Country-year Company-year
Company-quadrant FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Quadrant-level controls		Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The table presents the triple-difference estimates together with a test for pre-policy introduction trends (treatment × 1998, ..., treatment × 2004), where treatment is a dummy that takes value one for firms who are in weak tax position in Norway.

Table B.3: The effect of the tax refund policy on exploration effort and outcomes without controls.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A - All wells								
Treatment effect	1.619	1.619	2.239	1.447	1.444	1.444	1.444	1.401
	(0.573)	(0.573)	(0.668)	(0.747)	(0.757)	(0.728)	(0.768)	(0.710)
Effect size (wells)	16.2	16.2	33.5	13.0	13.0	13.0	13.0	12.2
N	10731	10731	9646	10731	9646	6026	9646	6026
Panel B - Discoveries								
Treatment effect	1.401	1.401	1.396	1.266	0.800	0.800	0.800	0.727
	(0.712)	(0.712)	(1.153)	(0.827)	(1.366)	(1.238)	(1.396)	(0.895)
Effect size (wells)	3.4	3.4	3.3	2.8	1.3	1.3	1.3	1.2
N	4851	4851	4277	4851	4277	2132	4277	4336
Panel C - Dry wells								
Treatment effect	1.762	1.762	2.483	1.720	1.595	1.595	1.595	1.628
	(0.530)	(0.530)	(0.636)	(0.763)	(0.749)	(0.725)	(0.764)	(0.910)
Effect size (wells)	14.0	14.0	31.8	13.3	11.4	11.4	11.4	11.9
N	8988	8988	8083	8988	8083	4336	8083	4348
Marginal discovery rate	20.8%	20.8%	10.0%	21.5%	10.4%	10.4%	10.4%	9.6%
Change in discovery rate	-24.4%	-27.8%	-63.5%	-21.7%	-62.1%	-62.1%	-62.1%	-65.1%
Time FEs	Year	Year	Year Post-company	Year Post-country	Year Post-company Post-country	Company-year Post-country	Country-year Post-company	Country-year Company-year
Company-quadrant FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Quadrant-level controls	No	No	No	No	No	No	No	No

Notes: The table presents Poisson coefficients for the time period 1995-2015. The effect on new wells is calculated by $\overline{y}_j(e^{\beta_j} - 1)$ where $\overline{y}$ is the pre-policy annual average of (j = total wells/discoveries/dry wells) and β is the estimated Poisson parameter. The change in discovery rate is given by $(e^{\beta_k} - 1)/(e^{\beta_j} - 1) - 1$ with k=non-dry wells and j=total wells. Fixed effects (FE) and controls included as indicated in the bottom rows. The controls are historical exploratory drilling, historical discovery rates and the presence of processing, offloading, storage, quarter, or other facilities, all measured at the quadrant level. Robust standard errors in parentheses clustered on the company and country-by-year level.

Table B.4: The effect of the tax refund policy on exploration outcomes with broader definition of discoveries, based on the content of the well.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A - Discoveries (alternative specification)								
Treatment effect	1.550	1.427	1.655	1.272	1.024	0.878	1.063	1.233
	(0.708)	(0.716)	(1.120)	(0.788)	(1.347)	(1.206)	(1.411)	(1.054)
Effect size (wells)	5.2	4.4	5.9	3.6	2.5	2.0	2.7	3.4
N	5292	5292	4718	5292	4718	2497	4718	2497
Panel B - Dry wells (alternative specification)								
Treatment effect	1.692	1.607	1.875	1.966	1.358	1.360	1.362	1.716
	(0.526)	(0.514)	(0.687)	(0.748)	(0.786)	(0.860)	(0.819)	(1.192)
Effect size (wells)	11.5	10.4	14.4	16.0	7.5	7.5	7.6	11.9
N	8526	8526	7413	8526	7413	3874	7413	3874
Marginal discovery rate	32.1%	32.0%	25.2%	23.8%	19.0%	14.9%	20.6%	28.2%
Change in discovery rate	-8.3%	-8.7%	-28.0%	-32.1%	-45.6%	-57.4%	-41.2%	-19.5%
Time FEs	Year	Year	Year Post-company	Year Post-country	Year Post-company Post-country	Company-year Post-country	Country-year Post-company	Country-year Company-year
Company-quadrant FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Quadrant-level controls		Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The table presents Poisson coefficients for the time period 1995-2015 with alternative specification of discoveries. Now, the set of discoveries also includes all wells that have oil or gas content. The effect on new wells is calculated by $\overline{y}_j(e^{\beta_j}-1)$ where $\overline{y}$ is the pre-policy annual average of (j = total wells/discoveries/dry wells) and β is the estimated Poisson parameter. The change in discovery rate is given by $(e^{\beta_k}-1)/(e^{\beta_j}-1)-1$ with k=non-dry wells and j=total wells. Fixed effects (FE) and controls included as indicated in the bottom rows. The controls are historical exploratory drilling, historical discovery rates and the presence of processing, offloading, storage, quarter, or other facilities, all measured at the quadrant level. Robust standard errors in parentheses clustered on the company and country-by-year level.

Table B.5: The effect of the tax refund policy on exploration effort and outcomes – with 2007 as the treatment year.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A - All wells								
Treatment effect	1.894	1.796	2.555	1.695	1.479	1.565	1.487	1.899
	(0.570)	(0.557)	(0.809)	(0.718)	(0.832)	(0.880)	(0.865)	(0.859)
Effect size (wells)	24.8	22.1	52.2	19.6	14.9	16.6	15.1	25.0
N	10731	10731	9646	10731	9646	6026	9646	6026
Panel B - Discoveries								
Treatment effect	1.721	1.600	1.997	1.352	0.493	0.490	0.523	0.973
	(0.753)	(0.759)	(1.247)	(0.824)	(1.314)	(1.181)	(1.340)	(0.861)
Effect size (wells)	5.0	4.3	7 3.2	0.7	0.7	0.8	1.8	
N	4851	4851	4277	4851	4277	2132	4277	4336
Panel C - Dry wells								
Treatment effect	2.056	1.982	2.766	2.209	1.994	2.118	1.992	2.700
	(0.520)	(0.494)	(0.866)	(0.726)	(1.010)	(1.097)	(1.017)	(1.315)
Effect size (wells)	19.8	18.1	43.2	23.5	18.4	21.2	18.4	40.3
N	8988	8988	8083	8988	8083	4336	8083	4348
Marginal discovery rate	20.3%	19.7%	13.4%	16.1%	4.7%	4.2%	5.0%	7.2%
Change in discovery rate	-18.7%	-21.3%	-46.4%	-35.6%	-81.2%	-83.3%	-79.9%	-71.0%
Time FEs	Year	Year	Year Post-company	Year Post-country	Year Post-company Post-country	Company-year Post-country	Country-year Post-company	Country-year Company-year
Company-quadrant FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Quadrant-level controls	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The table presents Poisson coefficients for the time period 1995-2015. The effect on new wells is calculated by $\overline{y}_j(e^{\beta_j}-1)$ where $\overline{y}$ is the pre-policy annual average of (j = total wells/discoveries/dry wells) and β is the estimated Poisson parameter. The change in discovery rate is given by $(e^{\beta_k}-1)/(e^{\beta_j}-1)-1$ with k=non-dry wells and j=total wells. Fixed effects (FE) and controls included as indicated in the bottom rows. The controls are historical exploratory drilling, historical discovery rates and the presence of processing, offloading, storage, quarter, or other facilities, all measured at the quadrant level. Robust standard errors in parentheses clustered on the company and country-by-year level.

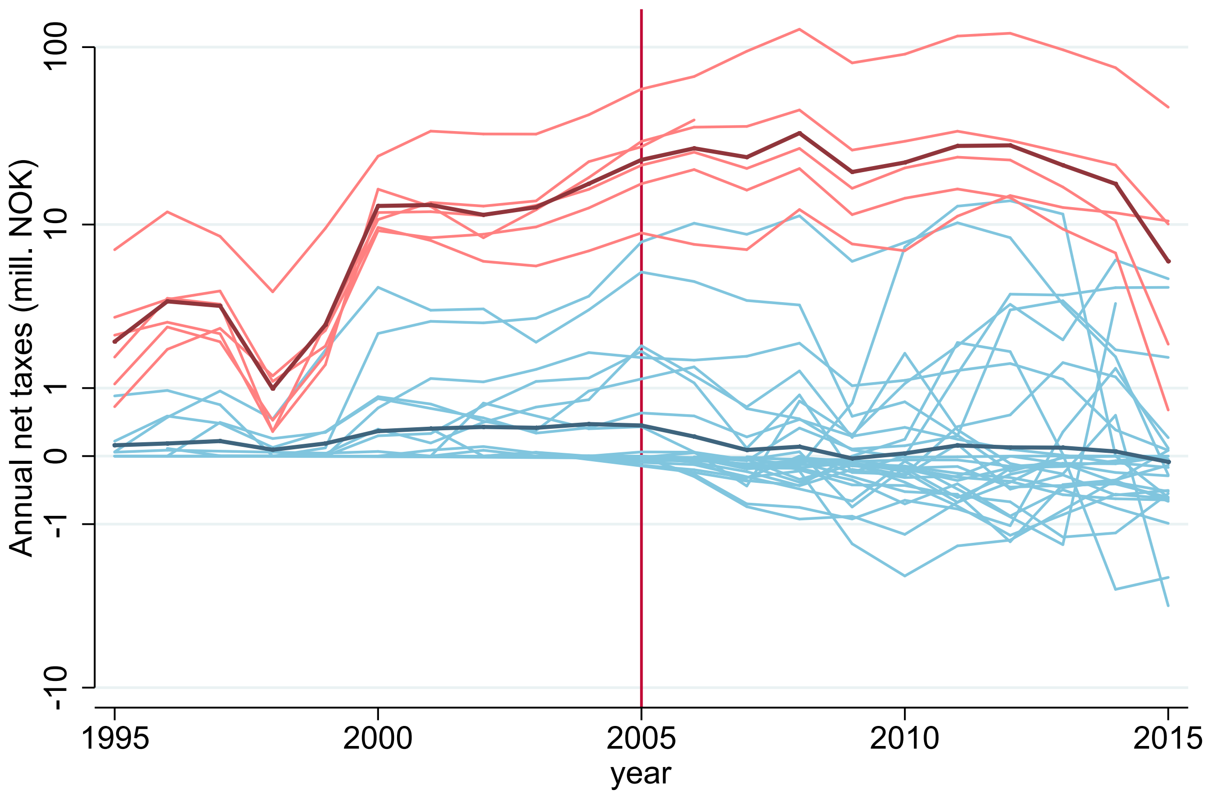

Figure B.1: Tax positions of treatment (blue) and non-treated (red) companies in Norway for 1995-2015. Thick lines represent averages per group, thin lines are the company-specific values.

Notes: The graph shows the paid net taxes per company in Norway for the study period. Negative tax values refer to refunds paid out to the firms. All values given in nominal terms. Note, that the y-axis is in inverse hyperbolic sine -scale. The six companies in the control group are: Equinor, Norsk Hydro, ExxonMobil, Total, ConocoPhillips and Royal Dutch Shell.

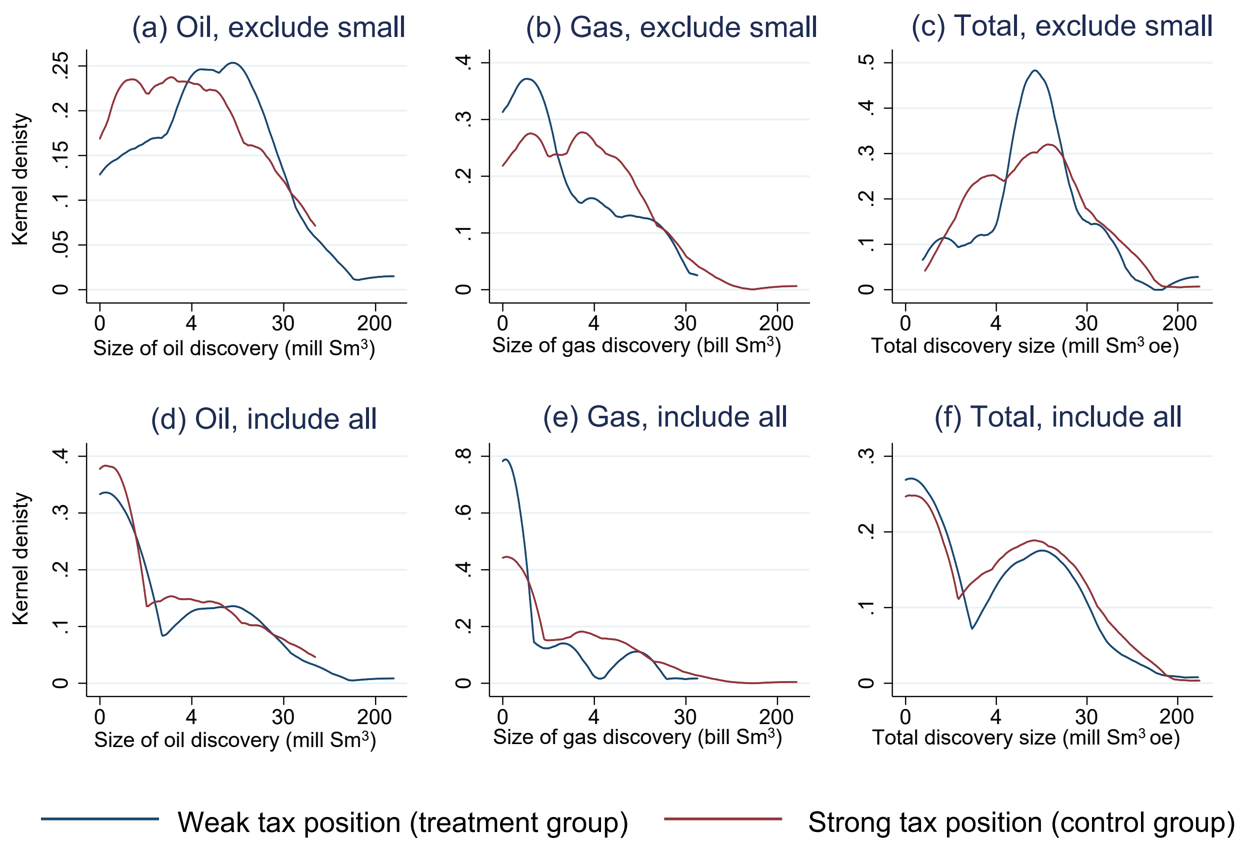

Figure B.2: Discovery sizes.

Notes: The figure plots the distribution of average discovery size (oil, gas and total) for firms in weak tax position (treatment group) and firms in strong tax position (control group). Figures (a)-(c) exclude small discoveries where production is deemed unlikely and Figures (d)-(f) include those discoveries as zeroes.

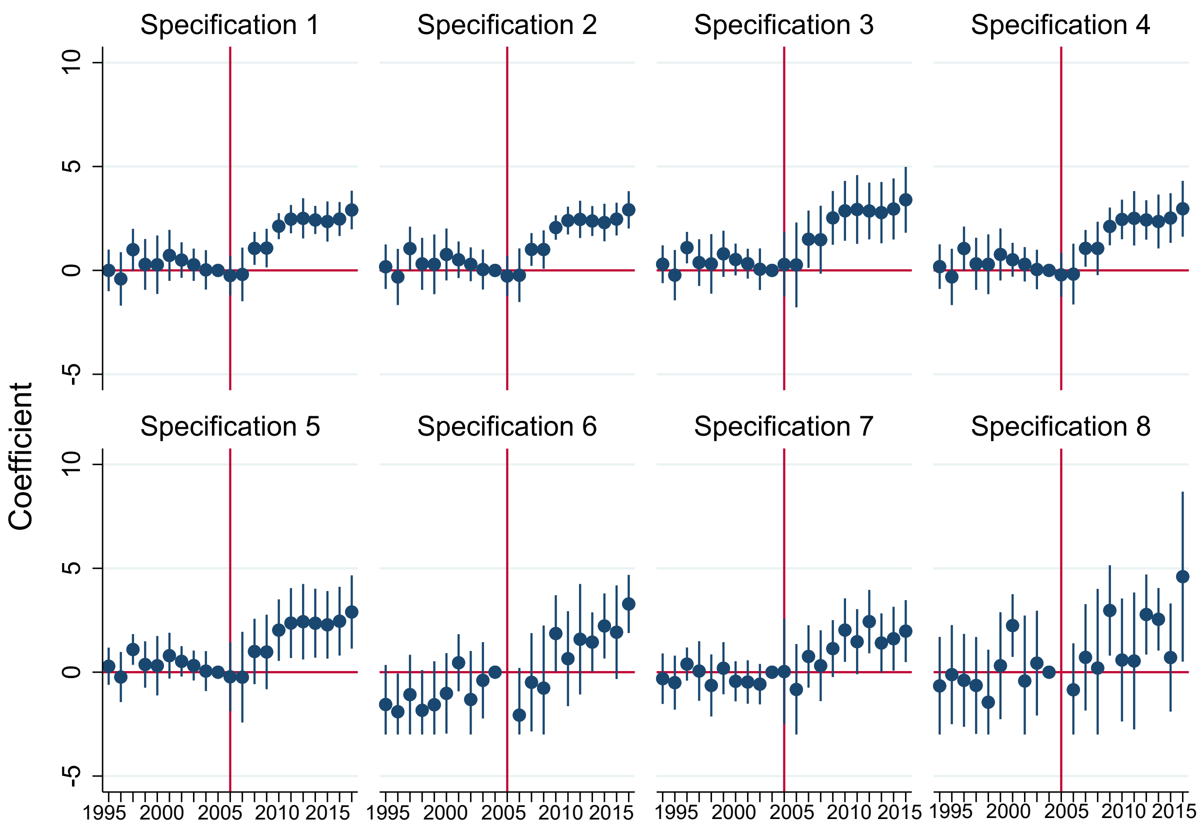

Figure B.3: Event study graphs for all specifications.

Notes: The graph shows the coefficients on a dummy taking one for the treatment group and zero for the control group for the eight specifications, representing the columns of Table 2 with the following time fixed-effects: (1) Year (no controls), (2) Year, (3) Year+post-company, (4) Year+post-country, (5) Year+post-company+post-country (6) Company-year+post-country, (7) Country-year+post-company, (8) Country-year+company-year. Apart from Specification 1, all the specifications include quadrant-level controls. The vertical line indicates the the beginning of the refund policy in 2005.

C Appendix: Estimating the values of discoveries

To estimate the net present value of discoveries of a given size, we build on the approach of Arezki et al. (2016) and estimate the parameters approximating a representative production profile using data from a panel of fields in Norway for years 1971-2016. The approach implicitly assume that the production profile of new discoveries can be reasonably estimated from the previous fields.

The production function captures the typical features of production of $k = \{oil, gas\}$: a production plateau, given by $q_p^k = \alpha_k(URR_k)^{\beta_k}$, followed by an exponentially declining production, with depletion rate $d_m^k = \gamma_k(URR_k)^{\delta_k}$. Here, URR_k denotes the ultimately recoverable reserves and α_k,β_k,γ_k and δ_k are the key parameters to be calibrated. These functional forms can capture the longer production plateau and smaller depletion rates of large fields. Also, we estimate the model separately for oil and gas production (even for the same fields), to capture the lower depletion rates for gas. As in Arezki et al. (2016), production q_t (with $t = 0$ when production starts) is given by:

$$q_t^{oil} = \begin{cases} 0 & \text{for } t \leq T_k^0 \\ q_p^k & \text{for } t \leq T_k^* \\ d_m^k(URR^k - Q_t^k) & \text{for } t > T_k^* \end{cases}$$

for $k = \{oil, gas\}$. Here, $Q_t^k = \sum_{\tau=0}^{t} q_t$ is the cumulative production of oil or gas until t. T_k^0 refers to the beginning of production, we use the average values in the date: 12 years for oil and 13 years for gas. The duration of the production plateau can be derived from the estimated parameters $T_k^* = (URR_k d_m^k - q_p^k)/(q_p^k - d_m^k)$. The calibrated values for oil and gas fields are shown in Table C.1. The production profile is plotted in Figure A1 for selected fields.

In the NPV calculations we also need to define the time between a discovery and the year production begins. We can use the estimate oil and gas production profile to estimate the net present value of a discovery of size with oil and gas (URR_{oil}, URR_{gas}) as follows:

$$v_h = \sum_{t=0}^{\infty} \frac{1}{(1+\delta)^t} \left(q_t^{oil} m_t^{oil} + q_t^{gas} m^{gas} \right)$$

where δ is the discount rate and m_t denotes the "rents" (price minus costs, including the annualized investment costs).

Table C.1: Estimated production function parameters for oil and gas production

	α	β	γ	δ
Oil production	0.265	0.649	0.375	-0.326
Gas production	1.395	0.867	0.168	-0.270

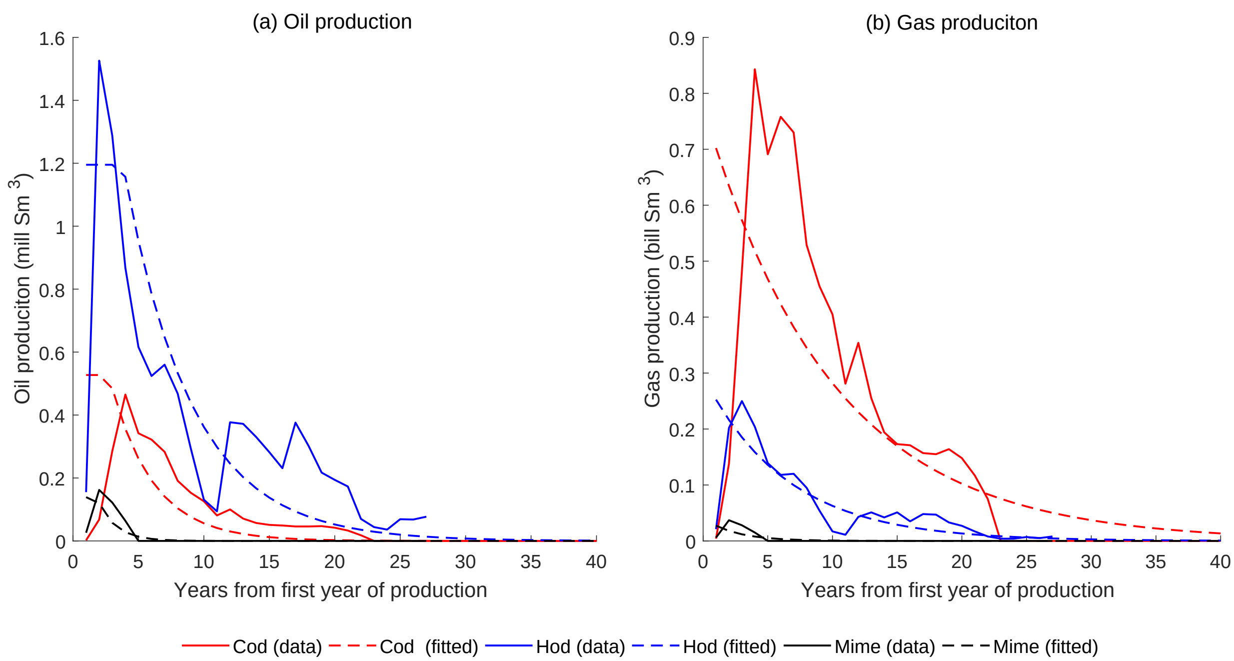

Figure C.1: Estimated production function vs. production data for selected fields

Notes. The selected fields are (1) Cod, discovered in 1968 with 2.88 mill Sm^3 recoverable oil and 7.28 bill Sm^3 recoverable gas, (2) Hod, discovered in 1974 with 10.16 mill Sm^3 recoverable oil and 1.76 bill Sm^3 recoverable gas, (3) Mime, discovered in 1982 with 0.37 mill Sm^3 recoverable oil and 0.08 bill Sm^3 recoverable gas.