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Modeling the response to exogenous shocks:
The capital uplift rate in petroleum taxation

by*

Magnus Berg[a] Øyvind Bøhren[bc] Erik Vassnes[d]

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Abstract
We show how a recent drop in the Norwegian capital uplift rate by two percentage points changes optimal field design and reduces field value for shareholders. Although optimal design changes considerably and value drops by 12%, the ability to reoptimize design after the shock is worth only 1.5% of field value. This evidence suggests that large behavioral effects of a shock do not necessarily imply large value effects, making it less important to always account for the taxpayers' response. The valuation error in such cases may be moderate if one instead uses the simplifying and widespread assumption of unresponsive taxpayers.

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[a] Arctic Securities, Haakon VIIs gate 5, N0161 Oslo, Norway. Email: magnus.asbjorn.berg@gmail.com.
[b] BI Norwegian Business School, Nydalsveien 37, N0442 Oslo, Norway.
[c] Corresponding author. Telephone: +4746410503. Email: oyvind.bohren@bi.no.
[d] Norwegian Ministry of Finance, P.O. Box 8008 Dep, N0030 Oslo, Norway. Email: erik.vassnes@gmail.com.

1. Introduction

Firms are exposed to exogenous shocks, such as sudden shifts in exchange rates, input and output prices, corporate law, and the tax system. Regulators, financial analysts, and researchers who want to estimate how such shocks affect the value of the firm must make a fundamental methodological choice: Can they just assume the firm's behavior does not respond to the shock (unresponsive firm), or should they instead assume that behavior changes (responsive firm)? This choice involves a tradeoff between simplicity and realism. Assuming an unresponsive firm is the simpler and easier approach, because assuming a responsive firm requires a specific model of how the firm will react. Such responsive models may be difficult to build and even harder to implement. On the other hand, responsive models may better predict what the firm will eventually do when the shock occurs (Auerbach 2005, Boehm et al. 2014).

Studying a recent tax shock in Norway, we compare the responsive modeling approach to the unresponsive approach when estimating the effect of shocks on the taxpayer's behavior and on the value of the taxpayer's claim. We find that both effects are quite large if we assume the taxpayer responds optimally. However, the value effect is quite similar if we instead assume the taxpayer does not change behavior after the tax shock. Therefore, the improved insight gained by modeling a responsive rather than unresponsive taxpayer may not be worth the effort if the primary concern is to quantify value effects rather than behavioral effects. This is the main result of our paper.

In 2013, the Norwegian Parliament increased the level of petroleum taxation by reducing the annual capital uplift rate from 7.5% to 5.5% of capital investment (capex) per year over the first four years of the field's life. Capital uplift is extra depreciation deducted from taxable income in order to protect normal returns (taxed at 28%) from being taxed as abnormal returns (taxed at 78%). The tax change we study is large. For instance, the tax shield from capital uplift used to be 30% (i.e., 4 times 7.5%) of capex in all planned fields on the Norwegian continental shelf and about 35% of shareholder value in the fields we consider in this paper.

We analyze how this tax shock interacts with design characteristics (e.g., capital investment, extraction rate, and production period) and with shareholder value (i.e., net present value of the owners' residual claim after taxes) in a wide range of petroleum fields. We alternatively assume shareholders respond vs. do not respond to the shock by modifying vs. not modifying the field's design after the shock. No response (i.e., exogenous design) or only limited response is by far the most common assumption (Smith 2013). Nevertheless, Poterba (2010) advocates models that assume response (i.e., endogenous design), stating, "In any analysis of tax policy and tax reform, it is essential to recognize that taxpayers respond to taxation."[1] Similarly, Smith (2013) says, "let tax policies for extractive resources be founded on the basis of models and methods that admit the broadest range of behavioral response."

Our paper makes two contributions to the literature. The first is to provide new evidence about the effect of taxes on taxpayers. We use the responsive approach to estimate how the reduced capital uplift rate affects the field's optimal design and maximum shareholder value. As far as we know, this is the first study of how the capital uplift rate in petroleum taxation interacts with the behavior and the value of the firm.[2]

The second and major contribution is to clarify the importance of assuming responsive vs. unresponsive taxpayer behavior. We compare two very different approaches. What we call *the unresponsive model* assumes the firm does not change the field's design after the tax shock, meaning the design data are identical before and after the regulatory change. Using data from 2 stylized fields and 68 actual fields, we calculate the shareholder value of the field with unaltered design under the new tax regime, compare this value to the field's value under the old tax regime, and use the difference to assess the sensitivity of the value to the tax shock. This assumption of unresponsive design is often called "the scenario approach" in petroleum tax research (Smith 2014). Examples of this widespread method are found in Bøhren and Schilbred (1980), Kemp (1987, 1992, 1994), Smith (1995, 1997), Tordo (2007), Bacon and Kojima (2008), and Hogan and Goldsworthy (2010). According to Smith (2013), the unresponsive approach is basically an accounting exercise.[3]

The alternative approach is what we call *the responsive model*, which assumes shareholders react to the tax shock by changing the field's design. Given the new tax regime, shareholders may find it optimal for tax-minimizing reasons to change design characteristics. Hence, the responsive model measures the effect of the tax shock in ways that account for the

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[1] The public economics setting Poterba refers to uses the effect of taxes on cash flow before taxes to analyze the tax system's efficiency (neutrality, non-distortive) property. Although we will not address efficiency, any such effect must be driven by decisions related to the after-tax cash flow we use to determine how the tax change affects shareholder wealth and behavior. Nystad (1985) is an early example of efficiency studies in petroleum taxation, estimating the distortive effect on design characteristics in general and on recovery rates in particular.

[2] Lund (1992) uses contingent claims valuation and Monte Carlo simulation to compare the Norwegian petroleum tax systems in 1980 and 1987. He considers design effects and value effects, but studies efficiency properties of the two tax systems rather than the assumption of response vs. no response. The 1987 tax reform changed the uplift rate, royalty rate, production allowance, starting date of depreciation, and the tax rate, but Lund does not analyze the efficiency effect of the uplift rate separately.

[3] "In effect, only the initial decision to undertake the project (if after-tax cash flows meet the break-even conditions) or terminate production (when marginal after-tax returns become negative) are under the investor's control. Thus, it is possible to estimate how a given regime will affect the break-even price required for investment, or the minimum economic field size (assuming there are economies of scale), or the minimum required cost of capital, or the terminal flow rate that would trigger abandonment. It is not possible, however, to gauge the effect of the tax system on the intensity of initial development, the speed of production and/or subsequent decline rate, or the timing and magnitude of any secondary investments undertaken to enhance recovery—because these factors are all pre-determined" (Smith, 2013).

shareholders' effort to avoid taxes by developing the field differently. For instance, the reduced capital uplift rate may induce the firm to recover less of the reservoir, avoid the most capital-intensive fields, extract the petroleum less aggressively, and prolong the field's life.

We compare the unresponsive model to a rich responsive model across a variety of fields. While both models allow for optimal field design in the old tax regime, only the responsive model has this property in the new tax regime. The question is whether the two models produce significantly different shareholder values after the tax shock. If they do, the unresponsive model is seriously biased, and the more complicated, costlier, and less common responsive model may be the better alternative. If instead the shareholder values are similar, the unresponsive model may be superior because it requires less insight, takes less effort, and is widely known.

Very few papers in petroleum tax research use truly responsive models (Smith 2013, Table 2). This fact is probably due to the difficulty of building economic models that capture the field's physical production process in a realistic, comprehensive, and analytically tractable way. We implement the responsive approach using a model recently developed by Smith (2014), which seems particularly well suited for our purpose. The model reflects a field's design characteristics quite accurately, transforms them into cash flows and net present values, applies to any tax system, is straightforward to build and solve in a spreadsheet, and generates field designs that are close to those observed in the industry (Smith 2014, p. 149).

Specifically, the shareholders in our responsive model choose the combination of a recovery rate, extraction rate, and enhanced recovery (i.e., design effects) that generates the expected after-tax cash flow having the highest net present value (i.e., value effects). This menu of design variables seems richer than what other models can offer. For instance, Zhang (1997) allows the firm to choose the starting date of production (i.e., timing), but not the investment (i.e., scale) and not the shape of production (i.e., profile). The EMTR/EATR approach to measuring tax system efficiency (Daniel et al. 2010, Chen and Perry 2015) assumes the firm responds by investing more or less capital (i.e., changing scale) rather than reoptimizing the use of capital across different design characteristics (i.e., changing timing, profile, and scale).

We report four results. Using the responsive model, our first result is that the taxpayer responds to the lower uplift rate by reducing capex, reducing the extraction rate, and by postponing the startup of enhanced production. The typical magnitude of these design effects of the tax shock is 15%, while cumulated production volume (reserves) drops by only 3%. The latter response is moderate because the reduced tax benefit of investing for early extraction induces the firm to move production to later years and to prolong the production period.

Our second result is that the design effects are larger in more capital-intensive fields. This finding confirms the intuition that optimal field design responds more strongly to capex-related tax shields such as uplift the higher the capex needed to produce a certain volume.

The third result is that the shareholders' value loss is about 12% regardless of capital intensity. This finding suggests that the value loss caused by the reduced capital uplift rate is considerable, but also that this loss is robust to field design.

Our fourth result is that, despite the large design effects (typically 15%), the ability to reoptimize design rather than not respond after the tax shock is worth only about 1.5% of shareholder value. This minimal effect of re-optimized design on shareholder value happens because the value loss is similar in both the responsive model and the unresponsive model (typically 12%), making the difference between the losses correspondingly small. Therefore, assuming no behavioral response does not seriously bias the estimated value effect of the tax shock. This impression is confirmed when we assume exogenous design in the 68 planned fields that cover a wide range of field types. The average loss of shareholder value is close to the 12% loss we find when assuming responsive design in the two stylized fields. This consistency supports the impression that the general structure and the specific parameters of the responsive model jointly capture reality quite well.

This fourth result is our major finding. It suggests that although the responsive and unresponsive approaches make opposite assumptions about taxpayer behavior, the estimated effect on shareholder wealth may be quite similar, meaning that the value function is rather flat around the optimal design vector. Therefore, it may not always be critical to account for taxpayers' behavioral response when estimating the value effect of a tax shock. Because even forceful design changes may have only moderate value effects, the unresponsive model may not seriously underestimate field value.

The intuition of this result may perhaps be derived from the envelope theorem (Milgrom and Segal 2002). We find that the objective function at optimum design is quite flat with respect to modified design (changing endogenous variables), but rather steep with respect to modified uplift (changing exogenous variables). That is, the tax shock more strongly affects shareholder value through what used to be optimal design under the old tax regime (unresponsive model) than through the redesign made to minimize taxes under the new tax regime (responsive model). Provided the design is reasonably optimal before the tax shock, the envelope theorem predicts that the first-order condition for optimal design ensures that changing exogenous variables like the uplift rate will have no value effect through optimal redesign. In contrast, there may be a value effect through the pre-shock design. Because the exogenous shock we study is not marginal, however, the envelope theorem does not directly apply. This non-marginal change is why the value effect of modified design is not zero, but still only a small part of the total value effect of the shock.

Our findings continue to hold when we consider larger shocks to the uplift rate than the one observed in 2013, and when we use alternative costs of capital. However, we do use a theoretical responsive model rather than real-world observations. Although the responsive model we use is rich and tractable compared to the alternatives, it is still just a model. Moreover, the model ignores a potentially important real-world characteristic, which is the value of flexibility offered by real options throughout the field's life. We also assume the cost of capital is unaffected by the tax shock. Thus, although regulators considering a tax change and shareholders considering a behavioral response must work with modeled rather than actual behavior, any model will be a simplification, including ours.[4]

There are at least two further reasons why our findings cannot be generalized to how real-world taxpayers respond to any shock to any tax system. First, Norwegian petroleum taxation mimics a neutral cash flow tax system, while most other countries use production sharing systems where tax rates are highly non-linear in the pre-tax cash flow. Smith (2014) analyzed several idealized tax regimes, finding that investor response had large effects on effective tax rates in some regimes, but minimal effects in others. Such results may serve to caution against broad extrapolation of our results to dissimilar fiscal regimes. Second, we have analyzed only one component of the Norwegian tax system.

Nevertheless, we do think there is one general lesson from our analysis that is worth considering in any setting that involves external shocks to the firm: A shock having large effects on firm behavior does not imply that this response has large effects on shareholder value. Therefore, the simplifying and very common modeling assumption of no or just limited behavioral response may be less problematic than it appears.

Finally, our findings do not imply that value effects are more important than design effects for any stakeholder in the empirical setting we study. Information about large changes in design may be very useful for stakeholders who primarily care about outcomes like the extraction rate, project duration, produced volume, employment, time to first production, and

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[4] The empirical validity of our theoretical model may in principle be tested by comparing the model's predicted design effects and value effects to what actually happened. However, the 2013 tax shock we study was followed by an even larger shock when the petroleum price dropped by more than 50% in 2014. Hence, it would be very difficult to separate the effect of the tax shock from the effect of the price shock. Moreover, it is difficult to argue that the increased taxation in 2013 reflects bad regulatory timing because of the large price shock. The prospective price shock was not obvious when the tax shock occurred.

time to first tax revenue. Nevertheless, such information is less relevant for stakeholders who primarily care about consequences for firm value, which may be a quite different story. The major such stakeholder is the owner.

We present the tax system in Section 2 and the two models in Section 3. We estimate the response to the tax shock in Section 4, while summarizing and concluding in Section 5.

2. The tax system

The Norwegian petroleum tax system has two components. The first is the regular corporate tax and the deduction for capex through regular depreciation. The second component is the special tax and the capital uplift. The capital uplift allows for extra deduction of capex in taxable income for the special tax, on top of deduction of regular depreciation. Unused uplift can be carried forward at the riskless interest rate, can be transferred if the firm is sold or merged, and the tax benefit of unused uplift is refunded if the firm is liquidated. A ring fence system ensures that these uplift benefits cannot be transferred to entities outside the offshore petroleum industry.

The role of the special tax is to capture the abnormal return on the petroleum resource, while the role of the uplift is to shield the normal return from the special tax (Garnaut and Clunies Ross 1975). Hence, the uplift is supposed to ensure that the normal return is not taxed twice, and only at the regular rate. This system is used because petroleum licenses are granted with almost zero up-front payment. Instead, the government tries to capture the abnormal return through the special tax and through direct state participation in select fields. This system of trying to capture rents through taxation is much more common internationally than the auction system used in the United States (Smith 2014).

In principle, the Norwegian petroleum tax system mimics a pure cash flow tax, which produces neutral taxation (Brown 1948, Boadway and Keen 2010). That is, the special tax and the uplift are supposed to jointly ensure that fields considered profitable before tax are also profitable after tax, and that the ranking of profitable fields is identical before and after tax. However, neutrality requires that the present value of regular depreciation and uplift equal the present value of capex, which may not be the case under the specific uplift rate and the interest rate on unused uplift. For instance, a critical condition is that the interest rate on unused uplift granted by the government reflect the risk of the associated tax saving (Lund 2009, IMF 2012).

Most petroleum tax systems in the world are not of the pure cash flow type. Rather, capex must be depreciated over time rather than expensed immediately, and taxable losses must be carried forward to later years. Unless compensated for, these features will produce distortions relative to a neutral Brown tax. Notice, however, that the Norwegian tax system allows carry-forward with interest of taxable losses and unused uplift. The system also ensures that the shareholder receives the value of taxable losses and unused uplift, as the government guarantees a payout if necessary. These properties suggest that one may validly assume that any deduction in taxable income becomes effective when the deduction occurs. This effect is also the government's justification for using the riskless interest rate to carry forward unused losses and uplift. Taken together, these characteristics make the Norwegian petroleum tax system quite unique, as most other countries capture rents with production sharing systems that make the tax rate highly non-linear in the field's cash flow.

Before the tax change in 2013, the corporate tax rate was 28%, and there was linear depreciation of capex over six years. The special tax rate was 50%, and the uplift rate was 7.5% of capex per year over four years. Hence, the tax rate on corporate profits after regular depreciation and extra depreciation through uplift was 78% (28 + 50), while the total depreciation rate (regular plus uplift) over the years was 130% (100 + (7.5 times 4)).

The tax change reduced the annual uplift rate from 7.5% to 5.5%, leaving everything else in the tax system unaltered. Therefore, the tax base and the regular tax rate on corporate profits remained unchanged, while the tax base for the special tax was changed:

$$\begin{aligned}\textit{Base for corporate tax} = {} & \textit{Operating income-Operating expenses-Depreciation} \\ & \textit{-Net financial costs-Deficits from earlier years}\end{aligned} \tag{1}$$

$$\textit{Base for special tax} = \textit{Base for corporate tax-Uplift-Unused uplift from earlier years} \tag{2}$$

Thus, (1) remained unaltered after the tax shock, while (2) changed. Depreciation in (1) is zero after six years, while Uplift in (2) is zero after four years. The uplift rate underlying Uplift in (2) is 7.5% before the tax change and 5.5% afterwards. The economic question we analyze is how the change in (2) changes the incentives to develop a petroleum field.

Summarizing this section, we have outlined the Norwegian petroleum tax system, where the capital uplift rate for the special tax is the crucial feature in our setting. For the special tax, capital uplift allows for deduction, beyond regular depreciation, of capex in taxable income. The special tax is supposed to capture the abnormal profit, while the capital uplift is supposed to shield the normal profit from the special tax. The tax change we study reduced the annual capital uplift rate from 7.5% to 5.5%, leaving the rest of the tax system unaltered.

3. Measures and models

We explain how we measure the effect of the tax shock in Section 3.1, followed by a description of the responsive model in Section 3.2.

3.1 Measuring the effects of the tax shock

The response to the tax shock can be measured as change in design and change in value. Change in design is irrelevant in the unresponsive model, which assumes the firm does not react to the tax shock by modifying field characteristics. Accordingly, design effects can be studied only in the responsive model, where we analyze the impact on field characteristics like capex, extraction rate, and investment timing.

We measure the value effect of the tax change in *the unresponsive model* (*U*) as:

$$\Delta V^U \equiv V(T_A,D_B) - V(T_B,D_B) \tag{3}$$

V is the valuation operator, *T* is the tax system, *D* is field design, *A* is after the tax change, and *B* is before. As shown by (3), the principal feature of the unresponsive model is the assumption that what used to be optimal design before the tax change (D_B) is also optimal afterwards. This approach differs from that of *the responsive model* (*R*), where we measure the value effect as:

$$\Delta V^R \equiv V(T_A,D_A) - V(T_B,D_B) \tag{4}$$

According to (4), the value effect in the responsive model is the difference in field value before and after the tax change, assuming optimal design in both cases (D_B and D_A, respectively).[5]

Expressions (3) and (4) differ only in the first of their two terms. Comparing the first term in (3) and (4), notice that

$$V(T_A,D_A) \geq V(T_A,D_B) \tag{5}$$

This relationship holds because the value of responding (the option to choose D_A after the tax change if this design is preferred to D_B) cannot be negative (Black and Scholes 1973). The value of responding is included in $V(T_A,D_A)$, but not in $V(T_A,D_B)$. Hence, the value effect of the tax change cannot be larger in the unresponsive model (3) than in the responsive model (4). The tax change in our case reduces the value of the field (i.e., *V* drops). Accordingly, the value drop cannot be larger in the responsive model than in the unresponsive model.

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[5] We assume the valuation operator *V* is the same in the unresponsive model and in the responsive model.

Finally, we want to quantify the value of responding. A comparison of responsive vs. unresponsive design is possible only in the responsive model, which optimizes design conditional on the tax regime. Therefore, we can compare responsive and unresponsive design within the same model by first using a hybrid responsive model *RH*, where we measure the value effect under unresponsive design as:

$$\Delta V^{RH} \equiv V(T_A, D_B) - V(T_B, D_B) \tag{6}$$

D_B in (6) is the optimal design generated by the responsive model before the tax change. Thus, the value effect in (6) uses the same logic as in (3).

We can now measure the value of responding as the difference between (4) and (6), where (4) allows for a response while (6) does not:

$$\Delta V^{R} - \Delta V^{RH} = V(T_A, D_A) - V(T_A, D_B) \tag{7}$$

The closer to zero the non-negative difference in (7), the less important it is to use a model with responsive design. Given (7), the most important economic question for the taxpayer is not the change in design, but how changed design translates into a changed value. The smaller the value effect in (7) compared to the design effect as measured by, for instance, changes in the extraction rate or capex, the more robust the field's value to the field's design, and the lower the relative merit of the responsive model vs. the unresponsive model.

This relationship means that if a small design change generates a large value change, the value function is steep around the optimal design vector. If instead the value change is small, the value function is flat around the optimum. Using a responsive model to estimate the value effect of the tax change is important in the first case, but not in the second.

3.2 The responsive model

We choose the recently developed model by Smith (2014) as our responsive model. The shareholder maximizes the net present value (*NPV*) of the field's cash flow by optimizing the combination of three decision variables. These decision variables are the recovery rate of the primary reservoir (*s*), the extraction rate of the reserves to be recovered (*a*), and the starting date of enhanced (secondary) production (*T*):

$$Max\ NPV(s,a,T) = \int_0^T P_t \cdot Q_t \cdot e^{-r\cdot t} dt - I(s,a) + \int_T^\infty P_t \cdot Q_t^E \cdot e^{-r\cdot t} dt - \frac{e^{-(a+r)\cdot T}}{1-e^{-a\cdot T}} \cdot \lambda \cdot I(a,\lambda;T) \tag{8}$$

P is expected price minus expected operating costs per unit of production, Q is primary production, Q^E is enhanced production, I is investment (capex), λ is the enhanced recovery factor, and r is the weighted average cost of capital (WACC).[6]

The first two terms of (8) reflect primary production, while the third and fourth terms reflect enhanced production. We next explain these four terms, initially ignoring taxes.[7]

3.2.1 Primary production

The *primary production* happens from time *0* to time *T* and is assumed to decline exponentially at the chosen rate *a* from the initial level Q_0:

$$Q_t = Q_0 \cdot e^{-a \cdot t} \tag{9}$$

Uhler (1979) argues that this production process reflects the natural loss of reservoir pressure as the petroleum is gradually depleted. This model of the production process is quite common in the literature (Smith and Paddock 1984, Adelman 1990, Smith 1995, 2014).

The production process in (9) allows us to relate *primary reserves* R_0 (primary volume to be extracted) to primary volume produced over the field's life (primary volume extracted):

$$\begin{aligned} R_0 &= \int_0^{\infty} Q_t \cdot dt \\ &= \frac{Q_0}{a} \\ &= s \cdot PIP \end{aligned} \tag{10}$$

The second line of (10) follows from (9), and the third line relates the primary reserves R_0 to the primary recovery rate *s* and the petroleum in place *PIP* (reservoir). Because industry estimates suggest *s* is typically 1/3 (Total Exploration and Production 2009), Smith (2014) assumes that s > 1/3 requires capex beyond the normal level. To account for this assumption, he introduces a cost index function for capex relative to the capex needed for a recovery level of s = 1/3:

$$C(s) = (3s)^c \quad for \ \mathrm{s} \geq 1/3, \tag{11}$$

where *c* is the elasticity of the index function with respect to the recovery rate.

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[6] The WACC is supposed to reflect the riskiness of the after-tax cash flow from operations in (8). Any side effects of financing, such as tax benefits and financial distress costs, are included in the cost of capital. There are no debt financing effects in the cash flow, such as interest and amortization (Berk and DeMarzo 2014).

[7] The Smith model also includes an exploration component. Because we will analyze only fields that have already been explored, we ignore the exploration component of the model. It is worth noting, however, that Smith (2014) found that redesigned exploration had major effects on field value in some tax regimes and minor effects in others.

Expressions (9) and (10) imply that *the decline rate* (percentage drop in reserves) equals *the extraction rate* (production as a percentage of remaining reserves) at any time. The remaining reserves at t are:

$$\begin{aligned} R_t &= \frac{Q_t}{a} \\ &= R_0 \cdot e^{-a \cdot t} \end{aligned} \tag{12}$$

The second term of the objective function (8) is the *capex* required to ensure a certain recovery rate s and a certain extraction rate a. The optimal capex reflects the value-maximizing tradeoff between the benefit of faster extraction and the cost of the higher capacity required. The capex function can be specified as:

$$I(a,s) = C(s) \cdot A \cdot s \cdot PIP \cdot a^d, \tag{13}$$

where d is the elasticity of capex relative to the extraction rate. Instead of using d, we can alternatively specify capex through the *capital intensity CI*, which we define as capex per unit initial daily production:

$$CI(a,s) \equiv \frac{I(a,s)}{Q_0/365} \tag{14}$$

Substituting for *I(a, s)* from (13) and for Q_0 from (10), we can solve for A and substitute back into (13), which transforms into:

$$I(a,s) = \frac{CI}{365} \cdot s \cdot PIP \cdot a \tag{15}$$

Thus, capex is proportional to the capital intensity and the extraction rate. We want to compare the tax sensitivity of fields with different capital intensity specified as required monetary investment per unit of production. Accordingly, we will use (15) rather than (13) to find the extraction rate a that maximizes shareholders' NPV in (8) through the optimal capex I. We set s = 1/3 using estimates in Total Exploration and Production (2009).

3.2.2 Enhanced (secondary) production

According to (8), the investor can increase the remaining reserves at time T by the factor λ > 1. At any time after this enhancement E, the *enhanced production* Q_t^E is:

$$Q_t^E = \lambda \cdot Q_t, \quad t > T \tag{16}$$

Because Q_t in (16) is what production would have been without enhancement ($\lambda = 1$), we implicitly assume that the extraction rate a also applies to the enhanced reservoir.

The fraction of primary reserves depleted at time t is:

$$\begin{aligned} d_t &= 1 - \frac{R_t}{R_0} \\ &= 1 - e^{-at} \end{aligned} \tag{17}$$

Using (17), we can specify the *capex in enhanced production* at time T as

$$I(a,T) = \frac{a^d \cdot \lambda \cdot R_T}{d_T} \tag{18}$$

This is basically the same investment function as for investment in primary production in (13) except for the adjustment for depletion at time T. The relationship in (18) reflects that if the enhanced investment occurs late in the field's life (small R_T and large d_T), the investment needed to obtain a given enhanced recovery will be low. The idea is that, unlike when investment is made early, a larger part of the technology needed for enhanced recovery can use idle infrastructure. Thus, choosing a high T (the decision variable for enhanced production) has the advantage of lower investment, but also the disadvantage of relatively more petroleum sold late in the field's life. The investor trades off these two opposing effects in (8) to set the optimal T.

Given (8)–(18), (8) has a closed-form solution with first-order conditions that ensure a unique maximum (Smith and Paddock 1984). However, we must also account for taxes, which are paid only at discrete points in time. We implement a discrete version of (8)–(18), expand it by Norwegian tax rules, and solve the model with the DataTable function in Excel.

3.2.3 Taxes

Augmenting (8)–(18) by the tax system described in Section 2 is straightforward. To avoid excessive repetition, we only specify the value of the tax shield from regular depreciation and from capital uplift, respectively. Moreover, we study how the tax change influences shareholder value rather than each separate component of shareholder value. Therefore, we use the same cost of capital r for the two tax shields as for any other component of the cash flow from operations after taxes.[8]

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[8] We may alternatively use the adjusted present value (APV) approach, which values each cash flow component separately according to its risk (Myers 1974, Lessard 1979). This approach means the cost of capital may differ across the components. APV is particularly useful if it is important to value tax shields correctly (Fane 1987, Summers 1987, Bond and Devereux 1995, Graham and Harvey 2001, Lund 2002). However, it is difficult to determine the correct cost of capital for each cash flow component. Moreover, there is always a WACC that

The depreciation amount is the depreciation rate η times the capex. The depreciation period is six years, and the depreciation amount is constant and deductible for both corporate and special taxes. Denoting the corporate tax rate ζ_c and the special tax rate ζ_s, the present value (*PV*) of the depreciation tax shield is:

$$\begin{aligned} PV(\mathit{Depreciation\ tax\ shield}) &= \frac{R_0 \cdot a^{1.68} \cdot \eta \cdot (\zeta_c + \zeta_s)}{1+r} + \frac{R_0 \cdot a^{1.68} \cdot \eta \cdot (\zeta_c + \zeta_s)}{(1+r)^2} + \ldots + \frac{R_0 \cdot a^{1.68} \cdot \eta \cdot (\zeta_c + \zeta_s)}{(1+r)^6} \\ &= R_0 \cdot a^{1.68} \cdot \eta \cdot (\zeta_c + \zeta_s) \cdot A(r,6), \end{aligned} \qquad (19)$$

where *A(r,6)* is the present value of an annuity of one unit over six years at the discount rate *r*. The annual tax payment saved is $R_0 \cdot a^{1.68} \cdot \eta \cdot (\zeta_c + \zeta_s)$. It follows from (19) that the value of the depreciation tax shield increases in initial reserves (and hence in the recovery rate), the extraction rate, the elasticity of capex to the extraction rate, the depreciation rate, the corporate tax rate, and in the special tax rate, while decreasing in the discount rate.

The uplift equals the uplift rate μ times the capex. The deduction is granted for four years, and it applies only to the special tax. The present value of the uplift tax shield is:

$$\begin{aligned} PV(\mathit{Uplift\ tax\ shield}) &= \frac{R_0 \cdot a^{1.68} \cdot \mu \cdot \zeta_s}{1+r} + \frac{R_0 \cdot a^{1.68} \cdot \mu \cdot \zeta_s}{(1+r)^2} + \frac{R_0 \cdot a^{1.68} \cdot \mu \cdot \zeta_s}{(1+r)^3} + \frac{R_0 \cdot a^{1.68} \cdot \mu \cdot \zeta_s}{(1+r)^4} \\ &= R_0 \cdot a^{1.68} \cdot \mu \cdot \zeta_s \cdot A(r,4), \end{aligned} \qquad (20)$$

where *A(r,4)* is the present value of an annuity of one unit over four years at the discount rate *r*, while $R_0 \cdot a^{1.68} \cdot \mu \cdot \zeta_s$ is the tax saved per year. Expression (20) shows that the tax shield from the uplift is worth more the larger the reserves, the extraction rate, the elasticity of capex to the extraction rate, the uplift rate, the special tax rate, and the smaller the discount rate.

The only economic effect of the tax shock in the unresponsive model comes through the shift in μ in (20). The effect is radically different in the responsive model. First, (20) may change not just because of a shift in μ, but also because of a shift in the design variables R_0 and a. Second, and for the same reason, (19) may change as well. Third, changes in any other design variable that matters for taxable income may influence field value, such as cash flow from operations and length of the production period.

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corresponds to a given set of component-specific costs of capital. Therefore, we will analyze the sensitivity of our conclusions to the cost of capital in Section 4.3.2, using alternative levels of WACC in (8)–(18).

3.2.4 Risk

There are three potential concerns regarding the way our model handles risk. First, the objective function in (8) includes the expected oil price. The cost of capital is supposed to reflect the inherent risk in this price and in the other exogenous variables. However, the after-tax cash flow is a non-linear function of taxable income if there is imperfect compensation for taxable losses. Therefore, using an expected price ignores the possibility that the tax shock may change the allocation of risk between the firm and the government (Jacoby and Laughton 1992, Lund 1992, Bradley 1998). As pointed out in Section 2, however, the tax system we study allows carry-forward with interest of taxable losses and unused uplift, and shareholders are compensated for the value of unused taxable losses and uplift. Thus, as in neutral tax systems using cash flows rather than earnings, it is reasonable in our case to assume that deductions in taxable income become effective when the related cash flow occurs, making taxable income a linear function of the cash flow.

Second, our models do not allow for the fact that it may be profitable to change field design later if the observed exogenous variables such as the petroleum price deviate from what was expected when the field was planned. Thus, the models ignore the possibility that different designs have different real-option properties (i.e., the flexibility to modify design as risk gradually disappears). The value of flexibility can be captured by the real-option approach (Paddock et al. 1988, Dixit and Pindyck 1994). However, implementing this approach is infeasible if there is path dependence, which is often the case in after-tax settings. For instance, the effective tax rate may depend on past taxable deficits and unused uplift. Therefore, we choose to accept the simplifications of (8)–(18) because the model’s realism and tractability seem superior to what alternative models can offer.

The third potential concern is that risk may change after the tax shock. Such change may happen because it may be optimal to redesign not just cash flow from operations (influencing operating risk), but also financial leverage (influencing financial risk). Moreover, the risk of the after-tax cash flow in a tax system that fully refunds unused uplift and taxable income may change even if pre-tax cash flow and financial leverage remain unchanged (Lund 2014). Thus, while we use the same WACC before and after the uplift change, the true WACC may differ in the two settings. However, our focus is not the level of shareholder value, but the difference in reduced shareholder value between the responsive and the unresponsive model. Because the possible change in WACC applies to both models, using the same WACC before and after should not be a serious problem in our case.

Summarizing Section 3, we have established measures of how a lower capital uplift rate reduces shareholder value. Using responsive rather than unresponsive models to estimate this value loss is particularly important if even small design effects produce large value effects. If instead the value effect is small even under large design effects, the much simpler unresponsive model may be the better alternative. The crucial element of making this judgment is to quantify the value of optimizing design after the tax shock rather than keeping the pre-shock design.

The taxpayer in the responsive model we use reacts to the reduced capital uplift rate by changing the optimal combination of three basic field design parameters, which are the recovery rate of petroleum in the ground, the extraction rate of recovered reserves, and the startup date of enhanced production. We specify this responsive model and tailor it to the Norwegian tax system. Unlike in the responsive model, the only economic effect of the tax shock in the unresponsive model comes through the reduced capital uplift rate and the resulting increase in taxable income for the special tax. Field design remains unaltered. Finally, because our main concern is to compare the value drop after the tax shock in the two models, we ignore the possibility that the tax shock may change the cost of capital.

4. Data and estimates

We estimate the effect of the tax shock using the responsive model and stylized field data in Section 4.1, analyzing the effect on design, value, and the value of responding. We use actual field data and the unresponsive model in Section 4.2. Robustness results follow in Section 4.3.

4.1 The responsive model

Table 1 shows the data we will be using in the responsive model. Except for assumptions about the tax system, variable costs, and capex, we copy every parameter value from Smith (2014, Table 2). This choice ensures that we can estimate the effect of the tax shock under assumptions we know are internally consistent, produce economically meaningful results, and generate optimal production profiles that are well in line with industry practice.[9]

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[9] Smith (2014) argues: “A more rigorous test of how the various pieces of the model interact is to see whether it provides solutions (in terms of primary recovery rates, initial production flow, subsequent decline rates, field life, and total resource recovery factors) that are consistent with industry experience. By all these measures, the model performs reasonably well. Simulated extraction rates over the scenarios presented in Tables 4 and 5 range between 2% and 12% with an average of 7%. According to PIW (2013), the fifty largest international oil companies in 2013 experienced an average extraction rate of 6.5% for oil operations and 5.9% for gas. Separately, Hőők et al. (2009) report that the average extraction rate for the world's 261 largest oil fields averages 6.5% (with 4.9% for onshore fields and 9.4% for offshore). They also report that the individual extraction rates for 78% of these fields fall between 2% and 12% -which corresponds to the range of our simulated extraction rates. Regarding extraction rates, then, the model seems consistent with industry behavior. In terms of the primary recovery factor (i.e., percentage of total-oil-in place produced prior to EOR), the model also seems consistent with industry practice. The simulated

Table 1

The parameters of the tax system follow from Section 2, where the parameter of interest is the drop in the capital uplift rate for the special tax from 7.5% to 5.5% per year over the first four years of production. This reduced uplift rate implies that the tax shield will drop more in monetary terms the more capital intensive the field. That is, more tax benefits of the uplift will be lost the higher the capex per unit of initial production. However, the effect on field value may be mitigated by the taxpayer's response. This mitigation happens because (8)–(18) allow the firm to react to the tax change by re-optimizing design, for instance by reducing both the recovery rate and the extraction rate and hence the required capex.

To analyze the resulting effect on optimal field design and maximum field value, we study two fields where the capital intensity is high (called High) and low (called Low), respectively. Low has \$40,000 of capex per initial daily barrel produced and \$20 of variable costs per barrel. We choose \$60,000 as capex per unit of initial production in High to ensure a large difference in capital intensity between High and Low. These capital intensities are in line with reports from Petroleum Intelligence Weekly (2009). Moreover, we choose \$4 as variable cost per barrel in High in order to capture the endogenous relationship between fixed costs, variable costs, and capital intensity. The variable cost of \$4 also ensures that the responsive model produces optimal field designs in Low and High with practically the same shareholder value before the tax shock. For simplicity, we assume inflation is zero, which means the prices of inputs and outputs in Table 1 are in real terms at any point of the field's life.

Given these assumptions about technology, prices, and the tax system, the responsive model optimizes field design by choosing a combination of the extraction rate and enhanced recovery that maximizes the value of the field for its owners.[10] Table 2 shows the results, which we report separately for the old tax regime (7.5%), the new tax regime (5.5%), the difference between the two regimes, and for the fields with low and high capital intensity.

Table 2

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primary recovery factor ranges between 33% and 37% across our scenarios. This compares well with U.S. DOE (2006) estimates based on 1581 oil fields located in ten U.S. oil basins for which the primary recovery factor averages 34% (with a range extending from 27% to 44%). The DOE study also projects that EOR will raise the overall recovery factor from these same fields to roughly 48%, which is consistent with technical effectiveness (λ) somewhere between our presumed values of 2.0 and 2.5."

[10] As specified in Section 3, we choose 1/3 as an exogenous parameter value of the primary recovery rate s in (8) (the fraction of petroleum in the ground to be extracted as primary production).

4.1.1 Design

The extraction section of the table shows that the firm responds to the lower uplift rate by reducing extraction intensity and delaying startup of enhanced production. The annual extraction rate drops by 8% in Low and by 9% in High, while the startup time of investment in enhanced production is delayed by 14% in Low and by 22% in High.

The investment section shows that both initial (time *0*) and subsequent (time *T*) capex are reduced when the uplift rate drops. For instance, total capex in present value terms is reduced by 15% in Low and by 20% in High. In contrast, the production section of the table shows that total primary production remains unaltered, and that total recovered reserves (primary plus secondary) drop by 2% in Low and by 4% in High. Therefore, total production is considerably less sensitive to the tax change than is any other design characteristic. This lesser sensitivity happens because the reduced tax benefit of investing for early extraction induces the firm to invest less and to extract less intensively, which in turn moves more production to later stages of the field's life. Also, both fields produce for a longer period. For instance, field life increases from 37 to 41 years in High.

Every design effect of the tax change is stronger in High than in Low. This result supports the intuition that optimal field design is more sensitive to shocks in capex-related tax shields the higher the capex needed to achieve a given extraction rate.

4.1.2 Value

We report the value effects of the tax shock in the bottom section of Table 2, using the definition in (4). Three features stand out.[11] First, the value of the cash flow after taxes drops by 11% in Low and by 12% in High. Thus, reducing the capital uplift rate reduces the value of the field for its owners by 11–12%, quite independently of the field's capital intensity.

Second, this reduced field value is not due to just the smaller tax shield from uplift, which would be the only story told by unresponsive models. As argued in Section 3.2.3, the multiple effects in the responsive model happen because the firm redesigns the field after the tax shock to minimize the adverse tax effect of reduced uplift. The bottom four rows of Table 2 quantify this property by splitting the field value into four components. These components

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[11] The value of the cash flow before taxes drops by 1% regardless of capital intensity. Thus, reducing the uplift rate apparently makes the tax system less neutral. However, this effect may be due to the specific discount rate we have chosen. Therefore, to make a proper judgement about neutrality, we would need to use the adjusted present value logic with alternative sets of component-specific discount rates or a series of alternative WACCs that differ from the 8% we have chosen. We will use the latter approach in section 4.3. Because the tax system's efficiency property is not an issue in our paper, however, we will not pursue the neutrality question.

are the value of (i) the investment, (ii) the operating cash flow after tax assuming no depreciation or uplift, (iii) the tax shield from depreciation, and (iv) the tax shield from uplift.

The first component shows that the firm invests less after the tax shock, which increases field value per se. The three remaining components all drop, which reduces field value. This drop happens because of reduced uplift rate, reduced investment, reduced extraction intensity, and reduced enhanced production. Although the largest percentage value drop occurs for the uplift tax shield, the monetary drop is considerably larger for the depreciation tax shield. For instance, the relative (absolute) value drop under high capital intensity is 41% (176 mill. USD) for the uplift tax shield and 20% (411 mill. USD) for the depreciation tax shield. Thus, focusing only on the value loss from the uplift in expression (20) is highly misleading if the taxpayer behaves according to the responsive model. In contrast, the unresponsive model would report only this effect and would assume the only thing that happens in (20) is a drop in the uplift rate.

Even though the sensitivity of field design to the shock differs considerably in Low and High, the sensitivity of value is very similar. For instance, while enhanced production drops by 22% in Low and by 35% in High, value drops by 11% and 12%, respectively. This small value difference between High and Low suggests that the objective function in (8) is rather insensitive to field design as specified in (9)–(18), at least when implemented with the assumptions from Table 1. That is, the NPV may be a quite flat function of the project design vector around the optimum. We return to this robustness property several times in the following.

4.1.3 The value of response

As defined in (7), the value of the ability to respond is the value of the field under the new design minus the value under the old design, given the new uplift rate in both cases. The responsive alternative uses (8)–(18) to generate the new, optimal field design and the resulting maximum value under the 5.5% reduced uplift rate. In contrast, the unresponsive alternative computes the value under the 5.5% uplift rate using the design that used to be optimal under the 7.5% uplift rate. The results are shown in Table 3.

Table 3

Panel A documents that the responsive design is worth 1.0% of field value in Low and 1.7% in High. These figures may appear surprisingly small, considering the much larger change in design documented in Table 2 (typically 10–15%). As we also showed in Table 2, however, fields with different capital intensity have large differences in design effects, but very similar value effects under responsive design. Hence, this insensitivity of shareholder value to design from Table 2 reappears in Table 3: The insensitivity concerns fields with different capital intensity under responsive design in Table 2, while it concerns responsive vs. unresponsive design under given capital intensity in Table 3.

Using the logic from Table 2, we split the field value from Panel A into four components in Panel B to show why the value of responsive design is so moderate. Because the effects are qualitatively equal regardless of capital intensity, we focus on the field Low, which is worth 788 mill. USD with responsive design and 780 mill. USD with unresponsive design. Because the unresponsive alternative uses the design after the shock that used to be optimal before the shock, there is no effect on either the value of the investment, the value of the operating cash flow after tax without depreciation and uplift, or the value of the depreciation tax shield. The only effect comes from the value of the uplift tax shield, which drops from 384 mill. USD in Table 2 to 281 mill. USD in Table 3. As is evident from (20), this drop is due to only the lower uplift rate and not to the base the uplift rate is multiplied by.

Allowing for responsive rather than unresponsive design, the firm invests less (2,437 mill. USD instead of 2,862), which increases field value correspondingly (i.e., by 425 mill. USD). Because this lower investment also reduces extraction intensity and total production, however, there is also a drop in the value of the operating cash flow (102 mill. USD), the depreciation tax shield (274 mill. USD), and the uplift tax shield (41 mill. USD). Accordingly, the gain from the reduced investment per se is almost fully neutralized by the loss on the operating cash flow and the two tax shields. Moreover, the major source of value loss on tax shields is not reduced uplift, but reduced depreciation, which is driven by reduced investment.[12]

These findings show, once more, that although the responsive model produces rather large design effects of a tax shock, they do not translate into large value effects. This result suggests that assuming unresponsive design may not seriously underestimate shareholder value and hence overestimate the value loss of the tax shock. That is, the design may be far off, but the NPV may not be. We next explore this relationship further using the unresponsive model and actual field data.

4.2 The unresponsive model

We first present the field data and the major design characteristics, subsequently analyzing the effect of the reduced uplift rate on field value.

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[12] As already pointed out, the two tax shields are less risky than the other components of the cash flow are. Applying a lower discount rate to the tax shields would strengthen the conclusion that because capex falls, considerably more tax shield is lost through regular depreciation than through uplift.

4.2.1 Field data

We use the unresponsive approach with actual field data for two reasons. First, findings from this approach are useful for validating the findings from Section 4.1, which uses a theoretical model and stylized field data. The closer the estimated value loss in the two approaches, the more valid the findings from Section 4.1. Second, unresponsive design is the dominating approach in practice. This model may be the only feasible option when theoretical models are missing. It may also be the preferred model by shareholders who want to challenge the regulator, as using unresponsive design maximizes the shareholders' estimated loss from the tax shock.

We use planning data for 68 actual fields exposed to the Norwegian tax system. These fields have been designed by Rystad Energy (www.rystadenergy.com), which is arguably Norway's most reputable provider of field data. Rystad Energy keeps complete records of historical data for every field on the Norwegian continental shelf and delivers data for all planned fields. Rystad Energy states upon our request that, although produced by them, the data for planned fields are always developed in close contact with the operating firms.

Table 4 gives an overview of design characteristics for each field. We use these characteristics to calculate the PV of capex and opex per boe total production, NPV of the after-tax cash flow at the 7.5% and the 5.5% uplift rates, and the difference between these two NPVs. In line with the unresponsive approach, we assume field design is identical before and after the tax change.

Table 4

The table shows that the fields differ regarding product (oil, gas, gas-condensate), main technological facility (fixed, subsea, floater), and province (North Sea, Norwegian Sea, Barents Sea). Planned startup varies between year 2017 and 2025, field life varies between 12 and 39 years, while recovered reserves vary between 10 and 1,845 Mboe. Capital intensity as measured by the present value of capex per boe total production varies between 6 and 29 USD.

4.2.2 Value effects

Section 3.2.2 shows that the only economic effect of the tax shock in the unresponsive model comes through a lower uplift rate, because nothing happens to field design. Specifically, the pre-shock capex is multiplied by a lower, post-shock capital uplift rate, producing a lower tax shield for the special tax. The three rightmost columns of Table 4 show the effect of the tax shock on field value. To demonstrate how this value drop differs across fields, Table 5 groups the fields according to field characteristics that may matter for the sensitivity of the field's value to the tax shock.

Table 5

The bottom row of the table shows that the aggregate shareholder value of the 68 fields falls from 29,387 to 26,601 mill. USD. This is a 9% drop, which is quite close to what we found under the responsive model and stylized field data in Table 2 (11% for the field with low capital intensity and 12% for the field with high capital intensity).

Table 5 suggests that the shareholder value's sensitivity to the tax change varies with field characteristics. For instance, small fields tend to be less sensitive than large, gas-condensate fields are more sensitive than oil fields and gas fields are, and the sensitivity increases with capital intensity. However, these field characteristics may be correlated, the value effect is measured only at the grouped field level, and the number of fields is often very different across field types under a given classification. Therefore, we estimate a regression model in Table 6, using the log of the absolute value of the percentage value drop as the dependent variable and design characteristics as independent variables. "Oil field," "Fixed installation," and "North Sea" are dummy variables, "Capital intensity" is the present value of capex per daily boe total production, while "Size" is the log of the number of million boe extracted.[13] The *p*-value of a coefficient's *t*-value is reported in parentheses.

Table 6

Models I–V show the univariate relationships, while VI combines the five independent variables into one multivariate model. Because size is never significant and is rather strongly correlated with fixed installation and capital intensity (the correlation coefficients being 0.46 and -0.31, respectively), we prefer model VIII, which excludes size. This model shows that at conventional confidence levels, the sensitivity of NPV to the uplift rate is significantly smaller for oil fields than for gas fields and gas-condensate fields, larger for fields with fixed installations than with floater or subsea installations, and larger the more capital intensive the field. The latter result for capital intensity is consistent with what we found using the responsive model and the two stylized fields.

Regarding economic significance, the standard deviations (not reported) and the estimated coefficients of the statistically significant variables in VIII suggest that the strongest value effect comes from the field's capital intensity, while the weakest effect comes from production technology. Specifically, a one standard deviation increase in capital intensity and

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[13] Using the distribution of field characteristics in Table 5, we classify gas fields and oil-condensate fields into one group, such that oil fields is the only other group. Similarly, we classify floater and subsea fields into one group, which means fixed installation fields are the only other group. Finally, we group fields from the Norwegian Sea and the Barents Sea into one group, such that North Sea fields constitute the only other group. We do this reclassification to avoid excessive correlation between the dummy variables in the model.

production technology increases the expected value drop by 1.7 and 1.1 percentage points, respectively.

Summarizing this section, we have found that the taxpayer in the responsive model reacts to the lower uplift rate by reducing capex and extraction intensity, and by delaying the start of enhanced production. While these changes are typically 10%, total production drops by only 3%. This lower sensitivity of total production happens because the reduced tax benefit of investing for early extraction induces the firm to invest less, reduce extraction intensity, move production to later years, and to prolong the production period.

These design effects are larger in the more capital-intensive fields, reflecting that optimal field design responds more strongly to capex-related tax shields the higher the capex needed to achieve a given extraction rate. In contrast, shareholders lose about 12% regardless of capital intensity, suggesting that the value reaped by the taxpayer is robust to field design.

Despite the large change in project design after the tax shock in the responsive model, the ability to respond is worth only about 1.5% of field value. This finding suggests that the exogenous field design assumed by the unresponsive model may not seriously overestimate the value loss of a tax increase. That impression is confirmed when we use the unresponsive model on actual field plans. We find that the average value loss is very close to what it is with stylized data in the responsive model. Hence, although the two models make opposite assumptions about taxpayer response, the effect of the tax change on field value is quite similar.

4.3 Robustness

In Section 4.3.1 we analyze whether our conclusions are valid for larger tax shocks than the one we have studied so far. In Section 4.3.2 we use a wide set of alternative costs of capital to explore whether our conclusions depend on the specific risk premium used in the valuation.

4.3.1 The uplift rate

We have so far analyzed the firm’s response to just one shock in the uplift rate. To clarify what would happen if the regulator reduces the uplift rate more aggressively, Table 7 shows the relationship between the maximized NPV from (8) and uplift rates that vary between 7.5% and 0%. We assume the starting level is 7.5% and that the uplift period is four years. We show the results for the responsive model with stylized field data from Table 1 in Panel A and for the unresponsive model with actual field data from Table 4 in Panel B.

Table 7

Panel A shows that the sensitivity of field value to the uplift rate is almost independent of capital intensity. For instance, value drops by 32% in Low and by 34% in High if deduction for uplift is completely eliminated (i.e., if the uplift rate falls from 7.5% to 0%). Moreover, the relationship between reduced uplift rate and reduced field value is close to proportional: Value drops by about 5% per unit of decreased uplift rate regardless of the starting level of the uplift rate.

The results in Panel B are very similar to those in Panel A. For instance, reducing the uplift rate from 7.5% to 3.5% produces a decline in NPV of 19% in the unresponsive model and either 20% (low capital intensity) or 21% (high capital intensity) in the responsive model. Hence, we once more find that although the two models make opposite assumptions about taxpayer behavior, the effect of the tax shock on shareholder value is very similar. This finding holds even for very large changes in the tax system.

4.3.2 The cost of capital

We have so far used the same cost of capital as in Smith (2014), which is a real WACC of 8%. Because we assume the taxpayer's objective is to maximize NPV, which is determined by the after-tax cash flow and the cost of capital, we want to explore the robustness of our findings to the cost of capital. Specifically, we vary the WACC between 4% and 12%.

A real riskless interest rate of 1% and a risk premium of 5% are in line with long-run averages in developed capital markets around the world (Dimson et al. 2011). Under the capital asset pricing model, the 4%–12% range we use in the WACC corresponds to a 0.6–2.2 range in the asset (i.e., unlevered) beta. The average asset beta in the petroleum industry was 0.9 as of January 2016, using estimates from 351 individual firms (Damodaran 2016). Thus, the alternative costs of capital we use seem to cover a sufficiently wide range of risk levels observed in the petroleum industry. We report the results in Table 8.

Table 8

Panel A shows how the choice of WACC influences investment, field value, and the value of response. We report the effects separately for the field with low and with high capital intensity. Three features stand out. First, a higher cost of capital makes the optimal capex less sensitive to the uplift rate. For instance, investment in the most capital-intensive field drops by 28.6% after the tax shock if the WACC is 4%, while the drop is only 16.4% if the WACC is 12%. This difference happens because a higher cost of capital makes distant cash flows less valuable, inducing the firm to reduce its investment less in order to ensure a high extraction rate and hence early cash inflows, including tax savings from the uplift.

Second, the drop in field value is insensitive to the cost of capital. The percentage value drop is 10–12% regardless of WACC. Hence, as we found earlier under the baseline assumptions in Table 3, a larger design effect measured as percentage drop in capex is not accompanied by a larger value effect measured as percentage drop in value. The relative value effect remains considerably smaller than the relative design effect.

Third, the value of response is 1–3% regardless of the cost of capital. Again, this magnitude is small compared to the design effect and very similar to what we found in Table 3.

Panel B shows that the percentage value effect of the tax shock in the unresponsive model increases with the cost of capital. For instance, the value drop is 6.8% when WACC is 4%, increasing to 15.3% when WACC is 12%. This inverse relationship is as expected, because NPV necessarily falls when a given cash flow is discounted at gradually higher rates.

Overall, the robustness tests show that the value drop is about 5% per unit of reduced capital uplift rate regardless of whether the reduction of the rate is small or large. This uniform effect is true in both the responsive model and the unresponsive model. We also find that the relationship between design effects and value effects, as well as the value of responsive vs. unresponsive design, is rather insensitive to the cost of capital. Finally, the value effect of the tax shock in the unresponsive model increases with the cost of capital.

5. Summary and conclusions

This paper provides new evidence about the effect of shocks on the firm's behavior and value. Using both stylized and actual data for petroleum fields exposed to Norwegian tax law, we analyze how higher taxation through reduced capital uplift influences a field's design and shareholder value through lower tax shields on the invested capital. We use two alternative approaches to evaluate the importance of assuming unresponsive vs. responsive taxpayer behavior. The unresponsive approach assumes the firm does not react to the tax shock by changing behavior. Existing petroleum tax research very often uses this assumption of exogenous design or assumes only a limited ability to change design. The alternative is the responsive approach, where the taxpayer reacts to the tax shock by re-optimizing field design in order to maximize shareholder value. We implement the responsive approach using the model by Smith (2014), which has an unusually rich menu of behavioral responses. Studying the tax sensitivity of design and value, we compare the unresponsive and the responsive models across a wide variety of petroleum fields.

We find that the taxpayer in the responsive model reacts to the lower uplift rate by reducing capex, reducing extraction intensity, and postponing startup of enhanced production.

As expected from a tax change that reduces the tax shield of capex, these design effects are stronger in more capital-intensive fields.

The value of the field for shareholders drops by about 12% regardless of capital intensity, but the ability to redesign optimally is worth only about 1.5% of the field value. This is our main result, suggesting that the assumption of exogenous design may not seriously overestimate the value loss caused by a tax shock. That impression is confirmed when we apply the unresponsive model to actual field data.

Overall, this evidence suggests it is not always critical to account for the taxpayers' response to even large tax shocks. Rather, the bias may be modest if one instead assumes that optimal design is unresponsive to the shock and remains unaltered. The intuition of this result seems roughly in line with the envelope theorem. A potential policy implication is that shareholders and regulators estimating the value effect of a proposed tax change may make modest errors by simply applying the proposed tax rates to existing shareholder behavior.

We do not claim that these findings hold for the modeling of taxpayer response to shocks in general. Nor do we claim that our findings carry over to other countries' petroleum tax systems or even to other components of the specific petroleum tax system we analyze. Therefore, an interesting topic for future research is whether other tax systems have relationships between design effects and value effects resembling what we found. Moreover, we recognize that while value effects are of primary interest to shareholders, which is our focus, design effects may be the more important concern for other stakeholders, such as employees, suppliers, and regulators.

Despite these limitations, we think there is one general and important insight from our analysis: A tax change with large effects on behavior does not imply that the behavioral effect has large effects on value. The widespread, simplifying modeling assumption of no behavioral response to tax shocks is sometimes more innocent than it appears.

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Table 1: Assumptions used in the responsive model

	Field	
Parameter	Low	High
Petroleum price (USD/boe)	100	100
Variable cost per unit (USD/boe)	*20*	*4*
Capex per initial daily barrel of production (USD)	*40,000*	*60,000*
Fixed annual operating cost (% of initial capex)	2%	2%
Petroleum in place (Mboe)	300	300
Primary recovery (Mboe)	100	100
Enhanced recovery factor	2.5	2.5
Cost of capital (%)	8%	8%
Corporate tax rate (%)	27%	27%
Special tax rate (%)	51%	51%
Uplift rate (annually for four years, %)		
Old tax regime	7.5 %	7.5 %
New tax regime	5.5 %	5.5 %
Linear depreciation of capex (years)	6	6

This table shows the parameter values used in the responsive model as specified in equations (8) – (18) of the main text. Field "Low" has lower capex per barrel of initial production and higher variable costs per unit than field "High". Both fields have the same NPV (net present value) for shareholders in the old tax regime according to the responsive model. "Boe" is barrel of oil equivalents, and "Capex" is capital expenditures (investments). All monetary values refer to the price level at time 0, and all prices and costs are assumed to follow the general inflation. The cost of capital is the weighted average cost of capital in real terms after taxes. The firm is assumed to be in full tax position. Assumptions that differ across the two fields are in italics. Except for variable costs, capex, and assumptions about the tax system, every parameter value is taken from Smith (2014, Table 2).

Table 2: The optimal response to the tax shock according to the responsive model

	Old regime: 7.5% uplift rate		New regime: 5.5% uplift rate		New - Old, %	
Characteristic	Field Low	Field High	Field Low	Field High	Field Low	Field High
Extraction						
Extraction rate per year (%)	13%	11%	12%	10%	-8%	-9%
Start of enhanced oil recovery period (year)	7	9	8	11	14%	22%
Investment						
Initial investment (mill. USD)	1,397	1,808	1,288	1,644	-8%	-9%
PV of investment in enhanced oil recovery (mill. USD)	1,462	1,370	1,147	896	-22%	-35%
PV of all investments (mill. USD)	2,862	3,179	2,437	2,539	-15%	-20%
PV of all investments per boe (USD)	18	20	15	17	-13%	-17%
Production						
Primary production (Mboe)	99	99	99	99	0	0
Enhanced production (Mboe)	65	57	61	50	-6%	-12%
Recovered reserves (Mboe)	164	156	160	149	-2%	-4%
Total recovery rate (%)	55%	52%	53%	50%	-2%	-4%
Field life (years)	34	37	37	41	9%	11%
Plateau rate (boe)	38,420	30,137	33,550	27,397	-13%	-9%
Valuation						
NPV before taxes (mill. USD)	3,774	3,716	3,751	3,685	-1%	-1%
NPV government take (mill. USD)	2,892	2,846	2,964	2,916	2%	2%
NPV after taxes (mill. USD)	882	870	788	769	-11%	-12%
NPV of investment	-2,862	-3,179	-2,437	-2,539	-15%	-20%
NPV of operating cash flow	1,526	1,586	1,424	1,432	-7%	-10%
NPV of depreciation tax shield	1,834	2,037	1,561	1,626	-15%	-20%
NPV of uplift tax shield	384	426	240	250	-38%	-41%

This table shows the optimal field design and the resulting maximum field value for shareholders under the responsive model as specified in equations (8)–(18) of the main text when using the assumptions in Table 1. Field "Low" has lower capex per barrel of initial production and higher variable costs per unit than field "High". "Mboe" is million barrels of oil equivalents. "Plateau rate" is the highest production volume per day over the field's life. "Total recovery rate" is the sum of primary and secondary production (recovered reserves) divided by petroleum in place (300 Mboe). "PV" is present value and "NPV" is net present value, which are both calculated at a 8% real weighted average cost of capital. "Goverment take" is corporate tax plus special tax. "Operating cash flow" is cash flow from operations after tax , but before investment, and assuming no depreciation or uplift. "Depreciation tax shield" is tax saved due to ordinary depreciation , while "Uplift tax shield" is tax saved due to capital uplift.

Table 3: The value of responsive field design under the tax shock

Panel A: Totals

	Field	
Field design	Low	High
Responsive (NPV)	788	769
Unresponsive (NPV)	780	756
Difference (NPV)	8	13
Difference (%)	1%	2%

Panel B: Components

	Field	
Field design	Low	High
Responsive (NPV)	788	769
Pre-tax value (NPV)	2,964	3,685
Government take (NPV)	2,176	2,916
Investment (PV)	-2,437	-2,539
Operating cash flow (PV)	1,424	1,432
Depreciation tax shield (PV)	1,561	1,626
Uplift tax shield (PV)	240	250
Unresponsive (NPV)	780	756
Pre-tax value (NPV)	2,994	3,716
Government take (NPV)	2,214	2,960
Investment (PV)	-2,862	-3,179
Operating cash flow (PV)	1,526	1,586
Depreciation tax shield (PV)	1,835	2,036
Uplift tax shield (PV)	281	313

This table shows the value of the field for shareholders under alternative assumptions about the ability to redesign the field when the uplift rate changes. The starting point is the assumptions in Table 1 under the old tax regime (7.5% uplift rate). The responsive model uses (8–(18) of the main text and the assumptions in Table 1 in order to find the optimal field design and the resulting maximum value for shareholders under the new tax regime (5.5% uplift rate). The unresponsive model uses the optimal design under the 7.5% uplift rate to compute field value under the 5.5% uplift rate, assuming no design changes. "PV" is present value, while "NPV" is net present value. "Operating cash flow" is cash flow after tax from operations, but before investment, and assuming no depreciation or uplift. "Investments" is all investments over the field's life. "Depreciation tax shield" is tax saved due to ordinary depreciation, while "Uplift tax shield" is tax saved due to capital uplift. The cost of capital is 8% in real terms, and the amounts are in million USD.

Table 4: Assumptions and valuations in 68 planned petroleum fields

#	Name	Product type	Facility type	Pro-vince	Start-up year	Field life (years	Recovered reserves (Mboe)	PV of capex	PV of capex per boe	PV of opex per boe	NPV at 5.5% uplift rate	NPV at 7.5% uplift rate	NPV difference (%)
1	Tor IOR	Oil	Fixed	NS	2024	14	39	767	19	5.7	55	81	-32%
2	25/4-3 (Gekko (Alvheim))	Gas	Subsea	NS	2023	25	33	613	19	3.9	10	31	-68%
3	Hod IOR	Oil	Fixed	NS	2025	39	118	1,021	9	2.9	271	307	-11%
4	Valhall West Flank	Oil	Fixed	NS	2025	16	75	1,005	13	4.8	238	272	-13%
5	Tommeliten Alpha (1/9-1)	Oil	Fixed	NS	2025	24	139	1,334	10	3.5	320	366	-13%
6	Eirin (15/5-2)	G-C	Subsea	NS	2019	34	41	471	11	3.3	21	37	-44%
7	Oseberg (Infill drilling)	Oil	Fixed	NS	2017	27	200	1,354	7	5.3	1,516	1,562	-3%
8	Snorre Late Life	Oil	Floater	NS	2023	21	247	4,562	18	4.3	465	622	-25%
9	24/9-3 (Gamma)	Oil	Subsea	NS	2025	16	20	215	11	4.0	79	86	-9%
10	Sleipner Alpha (15/8-1)	G-C	Subsea	NS	2020	25	30	275	9	4.1	173	183	-5%
11	Sigrun (15/3-4)	Oil	Subsea	NS	2022	17	26	421	16	5.0	92	107	-14%
12	6506/12-3 (Lysing)	Oil	Subsea	NWS	2020	14	10	117	12	6.4	74	78	-5%
13	Trestakk (6406/3-2)	Oil	Subsea	NWS	2019	17	71	1,293	18	6.2	394	438	-10%
14	Freja/Mjolner (2/12-1)	Oil	Subsea	NS	2024	17	25	460	18	4.6	51	67	-24%
15	Froy (redevelop)	Oil	Subsea	NS	2023	18	70	652	9	4.3	394	416	-5%
16	2.2.5	Oil	Subsea	NS	2024	13	17	194	12	4.5	84	90	-7%
17	Lavrans (6406/2-1)	Gas	Subsea	NWS	2022	27	83	832	10	5.6	227	255	-11%
18	34/11-2S (Nokken)	Gas	Subsea	NS	2022	23	44	777	18	5.0	82	109	-25%
19	Ormen Lange LP	Gas	Subsea	NWS	2023	24	198	1,960	10	4.0	386	453	-15%
20	6608/11-2 (Falk)	Oil	Subsea	NWS	2024	20	30	357	12	4.2	114	126	-10%
21	6506/6-1 (Victoria)	Gas	Subsea	NWS	2025	35	168	1,265	8	4.6	98	141	-31%
22	6406/9-1 (Linnorm)	G-C	Subsea	NWS	2025	17	157	1,735	11	6.3	105	165	-36%
23	Astero (35/11-13)	Oil	Subsea	NS	2021	15	28	486	18	4.6	142	158	-11%
24	Peon (35/2-1)	Gas	Subsea	NS	2024	33	122	1,054	9	4.1	99	136	-27%
25	25/11-24 (Midway)	Oil	Subsea	NS	2025	14	21	182	9	4.2	107	113	-6%
26	J1 (PL048C-UK well)	Oil	Subsea	NS	2025	15	15	205	14	4.3	52	59	-12%
27	16/2-3 (Ragnarrock)	Oil	Subsea	NS	2025	14	22	148	7	4.5	117	122	-4%
28	6407/6-6 (Mikkel South)	Gas	Subsea	NWS	2018	23	25	206	8	7.1	170	177	-4%
29	6507/11-9&6 (Natalia&Sigric	Gas	Subsea	NWS	2024	23	19	208	11	5.1	44	51	-14%
30	34/12-1 (Afrodite)	Gas	Subsea	NS	2023	29	90	975	11	4.4	159	193	-17%
31	1/3-11 (Ipswich)	Oil	Subsea	NS	2022	15	15	232	15	5.2	61	69	-12%
32	6407/7-8 (Noatun)	Gas	Subsea	NWS	2023	21	20	261	13	8.7	30	39	-23%
33	30/11-7 (Fulla)	Gas	Subsea	NS	2021	17	41	797	20	5.3	52	80	-34%
34	6705/10-1 (Asterix)	G-C	Subsea	NWS	2022	33	113	1,077	10	3.2	209	247	-15%
35	30/5-3S (Corvus)	Gas	Subsea	NS	2024	27	38	309	8	3.6	83	94	-11%
36	15/12-21 (Grevling)	Oil	Subsea	NS	2025	16	49	487	10	3.9	223	239	-7%
37	34/4-11 (Beta)	Oil	Subsea	NS	2024	18	85	1,203	14	4.1	274	316	-13%
38	34/4-12A (Lower Lunde)	Oil	Subsea	NS	2024	14	22	522	24	4.6	31	49	-37%
39	6506/9-2S (Fogelberg)	Gas	Subsea	NWS	2022	27	66	921	14	5.8	99	131	-24%
40	25/1-11 (Storklakken)	Oil	Subsea	NS	2022	13	11	177	17	5.5	53	59	-10%
41	6507/5-6S (Snadd N)	Oil	Subsea	NWS	2019	18	54	1,411	26	7.5	82	131	-37%
42	6406/3-8 (Maria)	Oil	Subsea	NWS	2019	21	188	2,456	13	5.2	1,271	1,356	-6%
43	6507/7-14S (Zidane)	G-C	Subsea	NWS	2020	24	117	1,798	15	10.9	28	89	-69%
44	16/2-6 (Johan Sverdrup-1)	Oil	Fixed	NS	2020	36	1,845	19,725	11	2.2	10,331	11,024	-6%
45	16/1-14 (Apollo)	Oil	Subsea	NS	2021	14	35	507	15	5.6	209	226	-8%
46	35/9-6 (Titan)	Oil	Subsea	NS	2024	19	74	1,073	14	3.9	199	236	-16%
47	30/11-8S (Krafla)	Oil	Subsea	NS	2022	19	77	769	10	4.6	390	416	-6%
48	16/2-6 (Johan Sverdrup-2)	Oil	Fixed	NS	2023	21	613	6,675	11	3.3	3,143	3,373	-7%
49	30/11-8A (Krafla West)	Oil	Subsea	NS	2024	16	37	209	6	4.3	203	211	-3%
50	6607/12-2S (Alve North)	G-C	Subsea	NS	2019	25	44	925	21	7.7	63	95	-34%
51	8/10-4S (Butch)	Oil	Subsea	NS	2019	16	52	730	14	5.8	369	394	-6%
52	30/6-28S (Crimp)	Oil	Subsea	NS	2019	15	16	291	18	6.2	112	122	-8%
53	35/9-7 (Skarfjell)	Oil	Subsea	NS	2021	20	139	2,348	17	4.7	522	603	-13%
54	6201/11-3 (Albert)	Oil	Subsea	NWS	2022	14	28	741	26	5.3	58	83	-31%
55	16/4-6S (Luno II)	Oil	Fixed	NS	2024	15	52	774	15	5.5	143	170	-16%
56	25/11-27 (Grane F)	Oil	Subsea	NS	2019	14	23	442	19	6.3	148	163	-9%
57	16/2-18S (Cliffhanger North)	Oil	Fixed	NS	2025	12	21	391	19	5.7	34	48	-28%
58	6507/3-10 (Klara)	Oil	Subsea	NWS	2025	14	11	237	22	5.0	9	18	-46%
59	6506/9-3 (Smorbukk North)	G-C	Subsea	NWS	2023	24	33	448	14	5.0	60	75	-21%
60	7324/8-1 (Wisting Central)	Oil	Floater	BS	2025	14	117	1,869	16	5.0	262	327	-20%
61	7120/1-3 (Gohta)	Oil	Subsea	BS	2024	39	154	1,374	9	2.6	317	364	-13%
62	6608/10-15 (Svale North)	Oil	Subsea	NWS	2018	14	18	513	28	7.1	81	99	-18%
63	6407/8-6 (Snilehorn)	Oil	Subsea	NWS	2020	17	59	883	15	6.1	332	362	-8%
64	30/11-9S (Askja West)	G-C	Subsea	NS	2020	26	33	288	9	4.5	149	158	-6%
65	6507/10-2 S (Novus)	Oil	Subsea	NWS	2023	15	11	149	14	6.3	36	41	-13%
66	6406/12-3S (Pil)	Oil	Subsea	NWS	2020	20	116	1,568	13	5.8	617	671	-8%
67	34/10-54 S (Valemon North)	G-C	Subsea	NS	2021	25	39	409	10	6.8	138	152	-9%
68	35/11-17 (F-West)	Oil	Subsea	NS	2019	16	13	321	24	7.4	45	56	-20%

This table shows field data and computed field vaues for 68 planned fields exposed to the Norwegian tax system. "Fixed" is fixed installation, "Floater" is floating installation, and "Subsea" is a subsea field developed close to existing infrastructure (tieback). "Mboe" is million barrels of oil equivalents, "Capex" is capital expenditures (investments), and "Opex" is operating expenditures. "G-C" is gas-condensate, "NS" is North Sea, "NWS" is Norwegian Sea, and "BS" is Barents Sea. "PV" is present value, while "NPV" is net present value of the after-tax cash flow from operations. Capex and NPV are in mill. USD. The PV and NPV valuations use a real weighted average cost of capital of 8%. The source for project data is Rystad Energy (www.rystadenergy.com).

Table 5: The value effect of a tax shock by field characteristics in the unresponsive model

					NPV				Change in NPV from 7.5% to 5.5% uplift rate				
Field characteristic	# fields	Recovered reserves (Mboe)	Average PV of capex per boe	Average PV of opex per boe	7.5% uplift rate	5.5% uplift rate	Change	Change, %	Mean	Std.	Median	Min.	Max.
Facility													
Fixed	9	3,103	12	4	17,203	16,050	1,152	-7%	-14%	10%	-13%	-32%	-3%
Subsea	57	3,197	14	5	11,236	9,824	1,412	-13%	-18%	15%	-13%	-69%	-3%
Floater	2	364	17	5	949	727	222	-23%	-22%	4%	-22%	-25%	-20%
Size													
10–30	24	469	16	5	2,080	1,822	258	-12%	-16%	11%	-12%	-46%	-4%
30–100	27	1,443	14	5	5,503	4,821	682	-12%	-18%	15%	-13%	-68%	-3%
100–300	15	2,294	12	5	7,407	6,485	923	-12%	-20%	16%	-15%	-69%	-3%
300–1,000	1	613	11	3	3,373	3,143	231	-7%	-7%	n.m.	-7%	-7%	-7%
1,000–3,000	1	1,845	11	2	11,024	10,331	693	-6%	-6%	n.m.	-6%	-6%	-6%
Product													
Oil	46	5,109	15	5	26,297	24,117	2,179	-8%	-14%	10%	-11%	-46%	-3%
Gas	13	947	12	5	1,890	1,539	351	-19%	-23%	16%	-23%	-68%	-4%
Gas-Condensate	9	608	12	6	1,201	945	256	-21%	-27%	21%	-21%	-69%	-5%
Province													
Norwegian Sea	43	4,754	14	5	23,375	21,437	1,938	-8%	-15%	16%	-15%	-69%	-4%
North Sea	23	1,639	15	6	5,322	4,585	736	-14%	-21%	13%	-11%	-68%	-3%
Barents Sea	2	271	12	4	691	579	112	-16%	-16%	5%	-16%	-20%	-13%
Capital intensity													
High	22	1,073	20	6	3,546	2,844	701	-20%	-25%	14%	-24%	-68%	-8%
Medium	23	1,969	13	5	8,568	7,715	853	-10%	-17%	15%	-13%	-69%	-5%
Low	23	3,622	9	4	17,273	16,042	1,231	-7%	-11%	7%	-9%	-31%	-3%
All	68	6,664	14	5	29,387	26,601	2,786	-9%	-17%	14%	-13%	-69%	-3%

This table shows the value effect on the 68 planned Norwegian petroleum fields by field characteristics when the uplift rate was decreased from 7.5% to 5.5%, assuming no change in project design. "Mboe" is million barrels of oil equivalents, "Capex" is capital expenditures (investments), "Opex" is operating expenditures (operating costs), "PV" is present value, while "NPV" is net present value of the after-tax cash flow from operations. "Capital intensity" is PV of capex per boe. NPV is in million USD, and the cost of capital for PV and NPV is 8% in real terms. The figures reported for "Change in NPV" are equally weighted across the fields. Source for field data: Rystad Energy.

Table 6: The relationship between field characteristics and the effect of the tax shock on field value in the unresponsive model

	Model							
Characteristic	I	II	III	IV	V	VI	VII	VIII
Intercept	-1.650 (0.000)	-2.003 (0.000)	-1.801 (0.000)	-3.140 (0.000)	-1.921 (0.000)	-3.152 (0.000)	-1.029 (0.021)	-2.867 (0.000)
Oil field	-0.533 (0.004)					-0.879 (0.000)	-0.582 (0.004)	-0.895 (0.000)
Fixed installation		-0.043 (0.859)				0.313 (0.107)	0.426 (0.132)	0.396 (0.018)
North Sea			-0.331 (0.068)			-0.450 (0.724)	-0.280 (0.127)	-0.066 (0.594)
Capital intensity				0.081 (0.000)		0.106 (0.000)		0.103 (0.000)
Size					-0.023 (0.798)	0.059 (0.401)	-0.123 (0.210)	
R^2 adjusted	0.107	-0.015	0.035	0.309	-0.014	0.590	0.122	0.591
F	9.058 (0.004)	0.032 (0.859)	3.439 (0.068)	31.018 (0.000)	0.066 (0.798)	20.254 (0.000)	3.326 (0.016)	25.253 (0.000)
n	68	68	68	68	68	68	68	68

This table shows the results of regressing the change in the field's value after the capital uplift shock on field characteristics. The field data are from Table 5, and the value effect assumes the field is not redesigned after the regulatory change (unresponsive model). The dependent variable is the log of the absolute value of the percentage change in net present value of the after-tax cash flow from operations. "Oil field", "Fixed installation", and "North Sea" are 0/1 dummy variables that equal 1 if and only if the field is a gas field, uses fixed installation, and is located in the North Sea, respectively. "Capital intensity" is the present value of capex in USD per boe (barrel of oil equivalents). "Size" is the log of the number of million boe extracted. The cost of capital is 8% in real terms. The *p* -value of a coefficient's *t* -value is reported in parentheses.

Table 7: The sensitivity of field value to the capital uplift rate

Panel A: The responsive model and stylized field data

		Annual uplift rate, %				
Field	Valuation	0	1.5	3.5	5.5	7.5
Low	NPV	603	645	710	788	882
	Change, NPV	-32%	-27%	-20%	-11%	0%
High	NPV	573	616	687	769	870
	Change, NPV	-34%	-29%	-21%	-12%	0%

Panel B: The unresponsive model and actual field data

		Annual uplift rate, %				
Field	Valuation	0	1.5	3.5	5.5	7.5
All	NPV	18,940	21,030	23,815	26,601	29,387
	Change, NPV	-36%	-28%	-19%	-9%	0%

This table shows the sensitivity of the results from Table 2 (responsive model and stylized field data) in Panel A and of the results from Table 5 (unresponsive model and actual field data) in Panel B to alternative shocks in the capital uplift rate. Field "Low" has lower capex per barrel of initial production and higher variable costs per unit than field "High". "NPV" is net present value of the after-tax cash flow from operations, which is shown in million USD. The assumptions behind the results in Panel A are from Table 1 except for the uplift rate, and the maximized NPV for each uplift rate is generated by the model specified in (8)–(18) of the main text. The assumptions behind the results in Panel B are from Table 4.

Table 8: The sensitivity of field design and field value to the cost of capital

Panel A: The responsive model

Cost of capital, %	Reduced capex Field Low	High	Reduced field value Field Low	High	Value of response Field Low	High
4	19.1%	28.6%	10.1%	10.9%	1.4%	2.4%
6	16.9%	25.9%	10.5%	11.3%	0.9%	2.8%
8	14.8%	20.1%	10.7%	11.6%	1.0%	1.7%
10	13.8%	20.1%	10.9%	11.8%	1.3%	1.6%
12	15.7%	16.4%	10.9%	12.5%	1.0%	1.3%

Panel B: The unresponsive model

Cost of capital, %	Reduced field value
4	6.8%
6	7.9%
8	9.5%
10	11.7%
12	15.3%

This table shows how the cost of capital influences the change in the optimal design and the shareholder value of a petroleum field after the capital uplift rate is reduced from 7.5% to 5.5%. The field data for the responsive model in Panel A are from Table 1, while the field data for the unresponsive model in Panel B are from Table 4. Field "Low" has lower capex per barrel of initial production and higher variable costs per unit than field "High". "Capex" is the present value of investment over the field's life, and "Field value" is the net present value of the after-tax cash flow from operations discounted at the specified weighted average cost of capital. "Value of response" is the percentage net present value benefit of reoptimizing field design after the uplift rate is reduced from 7.5% to 5.5%.