North Sea Decommissioning
Valuing the Options

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ABSTRACT

This paper develops a model of the decision to decommission an oil platform offshore the UK, using elementary options valuation. It contrasts the choice of decommissioning date under expected or certain-equivalent value with the dates that would be optimal if options values for continuing production were developed with respect to uncertain prices, decommissioning costs, fixed operating costs, and quantities. The problem of combining uncertain parameters is discussed and the effect is shown of UK and Norwegian tax, in very simple representation.

1. OVERVIEW

What is Decommissioning?

The decommissioning of an oil platform is an important action. Large capital sums are spent on removing all or part of the platform, sealing the wells, and disposing of debris and waste without damaging the environment. Because of the complexity of decommissioning, there is a lead time, as with investment decisions. The plans must be agreed in detail with the Government; their execution is of concern to environmental protection interest groups and may profoundly affect the firm's reputation. Once decommissioning has taken place it cannot be reversed if conditions change. These characteristics are shared by decommissioning of nuclear and chemical plants and to some extent by any decision irrevocably to close a manufacturing plant in jurisdictions where such a decision triggers serious obligations to clean or restore the site.

Economic Issues

Decommissioning decisions are strictly part of the initial decision to invest, whenever that carries with it an obligation to decommission. Such decommissioning costs are in an economic sense "sunk costs" before they are incurred, since decommissioning is inevitable: oil reservoirs will deplete and nuclear reactors will deteriorate to the point where safe operation is impossible. But before that point the timing of decommissioning is a separate decision: the firm has some freedom to decide when to decommission near the end of the asset's productive life. There may also be some choice, at that stage, over the precise method of decommissioning (though sometimes that choice is exercised by the Government, or by environmentally driven public opinion, rather than by the firm). It is this late-stage decision which is the subject of this paper.

Delaying decommissioning has an economic value for the firm: it defers expenditure which will not produce future revenue and allows the deferred funds to be invested in productive activities while "waiting". This can be regarded as the "opportunity cost" of decommissioning.

Decisions about timing and method of decommissioning oil platforms are made under uncertainty. The expected economic benefits of continuing operation depend on net revenues and therefore on the price of oil or gas as well as the quantities produced and the cost of production. The costs of decommissioning depend on advances in technology as well as on constraints determined by the Government or public opinion. Government policy and public opinion, like price, may change, even within the lead-time between the decision when and how to decommission and the carrying out of the decision.

The case for decommissioning "now" rather than "later" can be evaluated under uncertainty by conventional cash flow analysis, discounting the *expected* values of cash flows at the firm's cost of capital or a relevant opportunity cost of capital.

Options in Timing of Decommissioning

"Waiting" has another possible value. The options approach to investment decisions, as described by Dixit and Pindyck (1993),[1] and others, suggests that the conventional cash flow analysis described above is flawed because it does not recognize the value of waiting for new information which may reduce some of the critical uncertainties. In this view, a firm with the opportunity to make an investment decision, which is irreversible, is in a position analogous to the holder of a call option who has the right (but not the obligation) to acquire an asset. Making an investment is analogous to exercising a "call" option. Making a disinvestment decision is like exercising a "put" option for discharging the decommissioning liability at a known cost. The methodology for evaluating options places the question of timing and uncertainty at the centre of the analysis: making a particular investment now excludes the possibility of making it later. The probability that a later action might be more profitable, its "option value", should be taken into account.

The cost of decommissioning now rather than later thus consists of three components: the loss of expected future revenues from the operation, if positive, the loss of opportunity to earn income by temporarily investing the decommissioning capital elsewhere, represented by the discount rate on the capital, and the loss of information which might result in a different and more profitable timing decision, represented by the option value.

[1] A. Dixit and R. Pindyck *Investment Under Uncertainty*, Princeton, 1993

The focus on timing in the options approach to investment decisions makes it particularly useful for evaluation of decommissioning decisions, and where timing is the central issue. However, unlike a decision to invest in a new platform, investment in decommissioning an existing oil platform is *inevitable*, and the capital expenditure is incurred at the end of the project's life rather than the beginning. Unlike many divestment projects the scrap or resale value of the platform is often exceeded by the cost of decommissioning and environmental protection. The mechanics of the options approach to decommissioning are therefore somewhat different from the mechanics of the options approach to new investment. In this paper we spell out the mechanics of analysing decommissioning decisions, first under the conventional NPV approach based on expected values, then, by contrast, using options valuation in an extremely simple decision model.

Our Model

Sections 2-8 of this paper contrast the conventional NPV and options approaches to changes and uncertainties in key variables: oil prices and quantities (and therefore revenues), operating costs, and the cost of decommissioning - which could also reflect uncertainty about decommissioning policy. This, the main part of the paper, looks at decisions on a pre-tax basis, as if for public policy. Section 9 has a very simplified representation of features of the offshore taxation systems in the UK and Norway which may influence the decommissioning decision. Section 10 presents conclusions and Section 11 discusses the scope for further work.

In real life, decisions are likely to be more constrained than we have assumed. There would be the usual difficulties of specifying probability distributions of the uncertain parameters. A numerical model could be developed, using our methodology, to incorporate these. However, the analytical model is useful as it stands. We have demonstrated in what direction changes in various parameters, and in the volatility of these parameters, will affect the timing of decommissioning and the value of the ongoing project. For most of the key parameters the directional effect is unambiguous for the parameter taken in isolation. To deal with combinations of uncertainties in different variables a simulation approach would be necessary, but we show how its results could be incorporated into the basic model.

Suggestive Results

The directional effects which are revealed in our model are strong enough to be suggestive for policy purposes, and show that there would be commercial value in constructing numerical models for real-life cases. For example:-

- Production is likely to continue even if oil prices are so low that operating costs exceed revenue, because of the benefit of deferring capital expenditure on decommissioning and the value of having the option to produce later. The "break-even" price level for continuing UK production is therefore significantly below the current cash cost of production. Using the option valuation with uncertain future prices leads to later decommissioning than conventional NPV. The more volatile prices are expected to be, the later the decommissioning date.
- A firm's best date for decommissioning will be deferred if there is an immediate, once-for-all increase in decommissioning costs. The threat of future increases in cost may however accelerate decommissioning. Technical change leading to cost reduction will have the opposite effect: when it occurs, it will accelerate decommissioning. While it is expected in the future, it will delay it.
- Uncertainties about future operating costs and production qualities increase option values and tend to defer decommissioning, compared to conventional NPV analysis.
- The more decommissioning costs are relieved against tax, and the higher the tax rate, the earlier the firm is likely to decommission (and vice versa).
- Ring fencing fields for tax purposes, and limiting the carry-back of losses, leads to earlier decommissioning than would otherwise be the case.
- A simple conceptual comparison between the different UK and Norwegian treatment of decommissioning costs suggests that, other things being equal, platforms in Norway will tend to be decommissioned earlier than in the UK, and that the Norwegian approach may be more tax-neutral.

2. CONVENTIONAL NPV ANALYSIS: TIMING & DEPLETION

In a conventional analysis of a decommissioning decision, the firm considers:

The discount rate	r
Decommissioning cost	D
Fixed operating cost	C
Operating revenue	R = p * q
Operating cash profit	π = R-C

Where p is the expected price of output and q is the quantity expected to be produced.

Suppose the decision is taken at the beginning of time period t whether to decommission at the beginning of period t or to continue operations in time period t and therefore delay decommissioning to the beginning of time period t+1.

The Net Present Value of decommissioning in time period t is

$$NPV1 = -D$$

The Net Present Value of decommissioning in time period t + 1 is

$$NPV2 = \frac{-D}{(1+r)} + \pi$$

The decision rule is to defer decommissioning to period t + 1 , if

$$NPV2 > NPV1$$

$$= \pi + \frac{-D}{1+r} - (-D) > 0$$

$$= \pi + rD > 0$$

$$= R - C + rD > 0 \qquad (1)$$

This holds even when cash profits are negative, with operating costs exceeding revenues. The rule of thumb in words is that the firm will tolerate an annual operating loss up to the level of the income it can earn on the capital required to decommission.

However, for oil reservoirs, decommissioning is inevitable: the reservoir will deplete and when production ceases regulation will require decommissioning. The model of a twoperiod decision applies directly if decommissioning is inevitable in period three. It can be graphically represented in Figure 1.

In this figure,

T represents the time of physical depletion.

D represents the capital cost of decommissioning whenever production ceases.

C the annual value of fixed costs, assumed constant through time.

R represents the annual value of revenue, pq, where p is the unit price and q the quantity produced and sold.

For simplicity at this stage in the analysis the price p is assumed constant. q is assumed to decline by a constant amount each period : qt=qt-1-k, subject to qT=0

Valuing Continuing Operations

At time T, q=0, therefore pq=0=R, whatever the value of p. This guarantees the downward slope of R. But with fixed costs, there is economic reason to cease production and decommission at "break-even" time B, rather than T. The break-even is defined from equation (1) as the time when

$$R_B = C - rD \qquad (2)$$

The related decommissioning rule is to decommission at the beginning of period t if

$R_t < C-rD$

This economic decommissioning time at the beginning of period t_B is later than t_N ,which would be decommissioning time if only the reservoir's current profits (current revenues less current costs) were taken into account.

Note that at time B future revenues have diminishing value, $R_{t+1}....R_T < R_B$, so that $(R-C)_{t+1}$ is less than rD. With constant prices and declining volumes, decommissioning at B therefore dominates decommissioning at any later time. At times before B, future revenues have value, because $R_t..R_{B-1} > R_B$. Equation (2) must be expanded to take this into account.

Let V be the value of future profits from continuing operations at time 0<t<B-1 where

$$V = \int_{t}^{B} \frac{R-(C-rD)}{(1+r)^{T-t}}. \quad (3)$$

Note that the cost of decommissioning enters the equation only through the term rD. The total value of the project (continuing operations plus decommissioning costs) would be

$$VP= V-D \quad (4)$$

But decommissioning is inevitable; the only thing to be decided is when to decommission. The condition for break-even revenue at the beginning of period t can now be written as

$$R_B = C-rD- V \quad (5)$$

The related decommissioning rule is to decommission at the beginning of period t if, in period t

$$R_t= C-rD-V_t$$

The NPV of the continuing operations can be measured at any time t by

$$NPV= R_t-(C-rD-V_t). \quad (6)$$

This is illustrated in Figure 2.

At the break-even point V goes to 0, so with R=p*q the *break-even price* p* in any period is given from equation 5 by

$$p^* = \frac{C-rD}{q} \quad (7)$$

The break-even price p* will rise rapidly over time, since volumes are assumed to decline while fixed costs C and the opportunity cost of deferring decommissioning expenditure rD are constant.

Price Uncertainty

In the previous paragraphs future values were assumed to be known with certainty. Alternatively, the expected value of each variable - a probability weighted estimate - could be used as a certainty equivalent to give the same result ($p=Ep$). However, this is not the best treatment of uncertainty. It does not allow for the possibility of changing a decision as a result of new information.

3. OPTIONS EVALUATION WITH UNCERTAIN PRICES

Assume that:

1) The price p in each future period has a probability distribution e and that there is no correlation between prices at different periods.

2) Although there is price uncertainty, the price is known one time period in advance.

3) Decommissioning decisions are taken, and are effective, at the beginning of each time period.

4) Decommissioning is irreversible. (The option of "mothballing" with no production but a lower fixed cost can be analysed separately by the same method).

Thus the firm which defers decommissioning from the beginning of period t (even if period t operation only breaks even) has the option to decommission or not at the beginning of period t+1 depending on the price of oil in the next period, t+1. Decommissioning at the beginning of period t would "kill" this "option".

For illustration, Figure 3 shows the situation where the price will be either:

p+h with probability z

OR

p-h with probability 1-z

so that the expected price E(p) = p if z=0.5.

If the firm works from expected values (as in section 2 of this paper) the optimal time to decommission will be at the beginning of period t when, as in equation (2), R=C-rD , and R=pq with p = E(p). In words, expected revenues in period t do not exceed the cost of current operations (reduced by the income earned from investing temporarily the capital required for later decommissioning).

However, if the firm were to defer decommissioning to the beginning of time period t+1, it would (under these assumptions) discover whether the price in time period t+1 was high (p_t=p+h) or low (p_t=p-h).

If the price discovered for t+1 were high, revenues in period t+1 would exceed costs (reduced by the income earned from investing temporarily the capital required for later decommissioning). Their discounted value at the beginning of time t would be positive.

The firm would therefore continue operations in period t+1, and defer decommissioning again from the beginning of period t+1 to the beginning of period t +2.

If the price discovered at the beginning of t+1 were low, the firm would decommission immediately, and avoid the loss which would occur if it continued production.

This decision rule can be expressed as:

Max [R_{t+1}-(C-rD); 0].

The break-even price for period t+1 is still

$$p^* = \frac{(C - rD)}{q_{t+1}}$$

but for the decision at the beginning of time period t there is a value A for continuing operations through period t (which generate neither profit or loss), because it provides the option to produce in t+1 if the price for t+1 turns out to be "high". Let A be the continuation value with respect to price. Then

$$A_t = \frac{z(P+h).q_{t+1} - (C - rd)}{1+r} \qquad (8)$$

This can be written more generally for a distribution E of prices for one period ahead as

$$A_t = \frac{E(p_{t+1}.q_{t+1}) - (C - rD)}{1+r}, \text{ given that } p>p^* \qquad (9)$$

The value in period t of the option to continue production in period t+1, which is conferred by deferring decommissioning, is then the probability-weighted sum of revenues, less costs, discounted, for *that part of the probability distribution of prices where the price exceeds the break-even price.* This value is greater than the zero *expected* value of future revenues in period t+1 based on probability-weighted prices which include price below the break-even price. The firm can avoid these downside prices by decommissioning at the beginning of time t+1.

The condition for break-even at time t (Equation 5) should therefore be rewritten as

$$R = C - rD - V - A \tag{10}$$

The related decision rule is to decommission at the end of period t if for period t+1

$R_t < C - rd - V_t - A_t$

This is illustrated graphically in figure 4. A firm looking at expected values would decommission at period B_e. Certain information that the price would be high would lead it to decommission in period B_h. The optimal decommissioning date is at the beginning of period B_A . This is the key result of incorporating the options concept: the possibility to adjust future actions in response to new information affects the decision taken today.

Extension to More than one Time Period

In the preceding example, deferring decommissioning provided information about the price for one extra period ahead. Only the value of the "option" to produce in "tomorrow's" period t+1 was considered in the decision whether or not to decommission " today" at the beginning of period t. The use of the concept of break-even meant that "tomorrow" was by definition the last possible economic period of production. This procedure could be followed every period in deciding whether or not to decommission. The problem is how to represent the value of the project, including the option value, throughout the life of the project as was illustrated in Figure 2 for the "conventional NPV" analysis. There are three possibilities:

1) The value of continuing operation, shown in figure 2 from the expected future prices, would be increased in every period by the option value of the next period. From Equations (3) and (8) we can write

$$NPV = R_t - (C - rD - V_t - A_t), \tag{11}$$

This is represented in Figure 4. The curve A lies to right of curve V, the shift representing the value each period of the option to produce the following period. The shift is larger in the earlier periods because the quantities involved are higher (by assumption).

The intuitive justification for the two-part valuation is that the firm can be certain of avoiding the downsides only for one period. Because decommissioning is irreversible, there is no option to switch back and forth in future periods (this is not a mothballing decision). The value of periods beyond t+1 for which information will be revealed by deferring decommissioning must be captured somehow. Deferring decommissioning through periods when prices are below break-even would incur costs which are captured in V_t, the discounted value of revenues at probability-weighted expected prices.

2) A more complicated, and strictly more accurate representation would allow joint probability of a sequence of periods in which there was a probability of the price exceeding the break-even price. The value of this sequence is given where:

$$A_t = \frac{E(p_{t+1}.q_{t+1}) - (C - rD)}{1+r}, \text{ given that } p_1 > p^*$$

$$+ \frac{E(p_{t+2}.q_{t+2}) - (C - rD)}{(1+r)^2}, \text{ given that } p_1 > p^* \ \& \ p_2 > p^*$$

and so on until

$$+ \frac{E(p_T.q_{tT}) - (C - rD)}{(1+r)^{T-t}}, \text{ given that } p > p^* \& \ p_{t-1} > p_{t-1}^* \dots p_T \qquad (12)$$

where p* is the break-even price for each period.

A_t then includes all the future expected sequences of positive values so that equation (11) can be written

$$NPV = R_t - (C - rD - A_t), \qquad (13)$$

As was noted earlier, the breakeven price p* will rise rapidly through time because of the interaction of fixed costs with declining volumes. The combination of probabilities, as well as the discounting, will also rapidly shrink the contribution of the distant periods to the value of A, so that the extra complexity of this calculation would have little practical effect. This shrinkage might be offset if the trend of future increases in price were expected to outweigh the effects of declining volumes and/or the uncertainty about future price was greater the further ahead prices were projected.

3) A different situation would arise if deferring decommissioning for one period would reveal prices for all future periods. This might be an unlikely assumption for oil prices but could be more realistic for gas prices on term contracts, or for costs (which are discussed later in this section). The evaluation of A_t is then more simple.

Let A_{pt} be the value at time t of knowing all prices from time t+1 onwards (Prices at time t are known by assumption in our model at the beginning of time t). Then

$$A_{pt} = \int_{t}^{T} \frac{Z(p_{t+1} \cdot q_{t+1}) - (C - rD)}{1 + r^{T-t}}, \; p > p^* \qquad (14)$$

This implies that by one decision, deferring decommissioning for one period, all the downsides of the probability weighting for all future periods can be avoided. The maximising decision rule applied to the price information of period t+1 will apply to all future periods. V is eliminated from the valuation and replaced entirely by A. This is illustrated in Figure 5. For simplicity, in the remainder of this paper, the third treatment is used unless otherwise stated.

Summary, Valuing Decommissioning Options for Uncertain Prices

We have so far derived a simple model which evaluates the value A_p of the firm's option to decommission its oil platform under the conditions of price uncertainty. The model shows that a firm may be willing to defer decommissioning even when current revenue falls short of current total cost (including the opportunity cost of capital required for decommissioning and the present value of future revenues based on expected prices). This is because it is willing to "pay for an option" not to decommission if it believes that waiting will reveal information which will justify continuing operations later. The model shows how the option can be valued, and the optimal time of decommissioning determined, in a simple case where the price of oil is uncertain.

4. OPTIONS VALUES FOR UNCERTAIN DECOMMISSIONING COSTS

Towards the end of a platform's economic life, as the volume of production falls, uncertainty about costs becomes more important - possibly even more important than uncertainty about revenues, if decommissioning costs are high.

In this section all assumptions are the same as in the previous section except that revenue is assumed known with certainty throughout (this assumption will be relaxed later) and the notation is the same. It is helpful to rearrange the basic equation for break-even (equation 2) in terms of decommissioning costs. In this equation, D enters the timing of the break-even decision through rD (alternative use of deferred capital). R= C-rD (equation 2) generates the break-even decommissioning cost.

$$D^* = \frac{C-R}{r} \tag{15}$$

So, when the excess of current costs over current revenues equals the decommissioning cost divided by the discount rate, the time for decommissioning has come.

One-off Immediate Changes in Decommissioning Costs

It is now easy to show how changes in decommissioning costs work through the model.

If there is a once-for-all change X in decommissioning costs D *before* the timing of decommissioning is decided, the effect is simple : given the assumption of falling revenues due to falling volumes, higher costs will defer the optimal decommissioning period B. D+X > X so r(D+X)>rD and the greater the acceptable operating loss (R-C) in equation (3) and the later the optimal decommissioning. Lower costs will have the opposite effect. This counter-intuitive result is because the opportunity cost of higher capital is greater: more can be earned on the larger sum whose inevitable expenditure is deferred. The assumption of falling revenues (and eventually of total depletion), ensures that decommissioning eventually takes place (R=pq goes to zero when q goes to zero) and the only decision is about timing.

Future Changes in Decommissioning Cost

The formulation above leaves a puzzle. If the decommissioning cost changes before the decision is taken it enters the operating calculations only through the opportunity cost of the capital required for decommissioning. But when decommissioning costs are expected to change in *future* these changes must also affect the timing decision. If the future decommissioning costs are known with certainty to be higher this can be handled by introducing an extra term into the break-even equation for period t to represent the cost of this change.

Let $X= D_{t+1}-D$ represent a future one-period change in decommissioning costs.

The total value VP of the project, including operations and decommissioning is

$VP= - D$ for decommissioning immediately (beginning of period t) and

$VP_X =R_t-C+rD -D + rX-X$ for decommissioning one period later,

so $VP_X-VP= R_t-C +r(D+X) - X$ (16)

It is optimal to defer decommissioning if $VP_x>VP$, i.e. if

$X< R_t-C +r(D+X)$.

The break-even condition still holds: the maximum acceptable decommissioning cost D* is

$D_t* =\frac{R-C}{r}$ for period t and

$D_{t+1}* = \frac{R_{t+1}-C}{r}$ for period t+1

Since $R_{t+1} < R$ by assumption in the example (declining volumes, constant prices), $D*_{t+1}< D*_t$. Deferring decommissioning will be optimal only if the cost change is negative (decommissioning costs fall): If a rise in decommissioning costs is expected, the optimal decommissioning date will be earlier. Including the change in the future decommissioning *capital* cost therefore works in the opposite direction from including the opportunity cost of income earned on the changes in the capital cost (which was all that counted in the previous case, where the change in cost was known before the decommissioning decision was made).

Figure 6 shows the contrasting effect of a future increase in decommissioning cost on the optimal decommissioning date: B_X is the optimal date, taking account of both the higher rate of operating return from deferring higher decommissioning costs and the higher cost when decommissioning takes place, B_D is the break-even for unchanged decommissioning costs, and B_{rX} is the date which would result, under increasing costs, from looking only at the change in the rate of return on the deferred capital.

Uncertainty about Decommissioning Costs

In this example the assumptions are the same as in the previous section, except that

1) Decommissioning costs are uncertain.
2) Uncertainty about decommissioning costs will be eliminated within one period (for example by signing a contract or obtaining a government consent).
3) Prices are known with certainty. (This assumption will be relaxed later in the discussion of combinations of uncertainty). Future operating profits are therefore represented by V (expected future value) rather than A_p (their option value).

The decision rule is still to decommission at the beginning of period t if

$R_t < C+X-rd-V$

where V_t represents the expected profits from future periods .

From the previous example we can specify $X^* = D_t^* - D_{t+1}^* = \frac{R - R_{t+1}}{r}$ (17)

where X* represents the breakeven change in future decommissioning costs. For a future change in decommissioning costs, the optimal date will be deferred if X<X* and advanced if X>X*. This breakeven can now be used in the evaluation of the option to delay decommissioning when its cost is uncertain.

Suppose that the expected cost of decommissioning in period t+1 may be higher or lower than the cost in period t by X, so that

$D_{t+1} = D_t - X_h$, a fall in cost, with probability z

and $D_{t+1} = D_t + X_l$, a rise in cost, with probability 1-z.

and that deferring decommissioning to the end of period t will reveal the actual cost.

If a higher cost is revealed decommissioning can take place at the beginning of period t+1 to avoid further losses. But if a lower cost is revealed decommissioning can be deferred beyond t+1.

Reworking equation (9) for the option value A_D of knowing the decommissioning cost therefore gives

$$A_D = E\left\{\int_t^T \frac{R - C + r(D+X)}{1+r} - X\right\} \text{when } X<X^* \text{ (cost falls more than break-even)}$$

$$+\ E(rX - X), \text{ when } X \geq X^* \qquad (18)$$

The first term gives the upside of continuing production and saving decommissioning cost at some future time if the future cost turns out to be lower than the break-even fall in cost. The second term gives the cost of decommissioning one period later if the cost turns out to be higher than the break-even fall in cost.

Equation 11 for the value of the operation through time, given known prices and revenues and uncertain decommissioning costs becomes therefore

$$NPV = R_t - (C - rD - V_t - A_D). \qquad (19)$$

This is illustrated in Figure 7.

5) OPERATING COSTS

Different operating costs in the model and the example work in the same way as uncertainty about prices. When volumes are declining, an *immediate* increase in operating costs, known before decision time means earlier decommissioning, and an immediate fall in operating costs mean later decommissioning. Figure 8 shows this effect.

Changes in *future* operating costs are more complicated. The procedure in our model is similar to that for future changes in decommissioning costs, except that (unlike decommissioning costs) operating costs cannot be deferred.

Assume for simplicity that future revenues and decommissioning costs are known (this assumption will be relaxed later), then from equation (5) the optimal time for decommissioning is at the beginning of period t when

R_t=C-rD- V_t) and V_t=0.

A change in future operating costs will enter the decision through a change in V. Let Y= C- C_{t+1} represent a known once-for-all change, effective one period ahead, in future operating costs. (Y positive means a fall in costs). Then

$$dV = \int_{t}^{T} \frac{Y}{(1+r)^{T-t}} \tag{20}$$

If Y is negative (an increase in future operating costs), dV will fall below zero, the right hand side of the break-even equation will increase, requiring an increase in revenue, which is (under the assumptions) only available at an earlier period. If Y is positive (operating cost will fall), dV >0 and the reverse applies; later and smaller revenues will do.

The model can now be applied to estimate the option value of knowing uncertain operating costs one period in advance. Deciding in period t to defer decommissioning can be regarded as buying an option to continue producing if operating costs fall.

Let z be the probability that Y> 0 and

(1-z) be the probability that Y ≤0.

Let A_{ct} be the value of discovering future operation costs by deferring decommissioning in period t,

then $A_{ct} = \int_{t}^{T} \frac{E(R - C + Y)}{(1+r)^{T-t}}$, given Y>0. (21)

In the event that Y≤0, decommissioning will take place at the beginning of period t+1: the higher operating cost in period t+1 will not be incurred. The decision rule can be expressed as before

Max R_t-(C_t-rD-V_t-A_D), 0.

The result, as is typical with options decisions, will be different from that which would result from taking the expected value of operating costs (for example, if z=0.5, in the example, the probability-weighted expected operation cost in period t+1 would be C +Y with Y=0, so that dV=0 and decommissioning would result at the beginning of period t when V_t=0). The effect is shown in Figure 9. The option value of learning about uncertain future operating costs enhances the expected value and shifts the optimal decommissioning time to the future.

6. CHANGES AND UNCERTAINTY IN VOLUMES

Changes in the quantity produced enter the model through pq = R. The results under certainty are analogous to changes in prices. High quantities, like higher prices, mean higher revenues. If the change is immediate and before the decommissioning decision, higher prices mean higher revenues and therefore later decommissioning. Lower prices have the reverse effect (see Figure 10).

Options values for uncertain *future* volumes can be treated in the same way as options values for uncertainty about prices.

Let the expected quantities be

$Eq_t = z\,(q+W) + (1-z)\,(q-W)$.

Then R= p.Eq.

From equation 3,

$$V = \int_t^B \frac{R-(C-rD)}{(1+r)^{T-t}}.$$

and, from equation 6,

$$NPV = R_t - (C - rD - V_t). \qquad (22)$$

The break-even quantity is

$$q^* = \frac{C-rD}{p}.$$

Assume, as with price, that the quantity is known in each period one period ahead, then (as with prices) there are three possibilities

1) One period's quantity is known one period ahead, but subsequent quantities are not correlated. An option value A_{qt} for knowing future qualities is calculated on the lines of equation 9.

$$A_{qt} = \frac{E(p_{t+1} \cdot q_{t+1}) - (C-rD)}{(1+r)^{T-t}}, \text{ given that } q>q^*. \qquad (23)$$

The value of operations (from equation 11) is

$$NPV = R_t - (C - rD - V_t - A_{qt}), \qquad (24)$$

2) More strictly, with subsequent quantities not correlated, then on the lines of equation (12)

$$A_{qt}= \frac{E(p_{t+1}.q_{t+1})-(C-rD)}{(1+r)}, q_1 > q_1* + \frac{E(p_{t+2}.q_{t+2})-(C-rD)}{(1+r)^2}, q_1 > q_1 \& q_2 > q_2, \text{etc.}$$

(25)

If, however, waiting one period will reveal all future quantities (for example by proving an extension to the reservoir) then

$$A_{qt}= \int_t^T \frac{Z(p_{t+1}.q_{t+1})-(C-rD)}{(1+r)^{T-t}} \text{ , q>q*} \tag{26}$$

and the value of continuing operations is simply

$$V_t = R_t - (C- rD - Aq_t), \tag{27}$$

7. DISCOUNT RATE

The choice of discount rate r for decommissioning decisions is a problem. Nuclear Electric before privatization, estimated the current provision for future decommissioning costs by discounting the liabilities at 2 per cent.[2] Other candidates might be the firm's expected internal rate of return, or its cost of capital, which would be identical only under rather strong assumptions. Both these rates, however, contain a risk premium which makes them greater than the risk-free rate. While it may seem prudent and conservative to discount future revenues to allow for the possibility that they might not materialize, to discount future liabilities for decommissioning costs by the same rate is the opposite of prudent: The higher discount rate reduces accounting provisions or sinking fund contributions. It increases the "opportunity cost" attributed to the loss of alternate employment of deferred capital expenditure by precisely the amount which would be discounted for risk in calculating present value.

The effect of higher or lower rates on the calculations in our example is simple. The rate r enters through the term rD or rX in the break-even equation.

$R=C-rD$.

Higher r, like higher D, will reduce the revenue required to justify deferring decommissioning, and (given the assumption about declining output) defer decommissioning. Since D is not affected, there is no contrary increase in cost of the kind shown in Figure 6. Lower r will have the opposite effect. The discount rate r also enters the value and option equations for V and A. It is arguable that a higher rate than the risk-free rate should apply. The merits of the choice of rate are discussed in the literature.[3] At least there seems to be a case for the risk-free rate plus the market price for undiversifiable risk. A higher rate will reduce the values of V and A and lower rates will have the opposite effect, advancing or retarding respectively the date at which it is optimal to decommission. Uncertainty about r could be treated in the same way as other uncertainties to calculate an option value. However, these uncertainties might under some assumptions (for example spanning) be regarded as diversifiable risk and ignored.

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[2] "This rate is the real post-tax rate of interest that the Company considers can be earned from long term risk-free investments" *Report and Accounts 1994-1995*, Nuclear Electric. Note, page 33.

[3] There are further possibilities , see Robert S. Pindyck *Investments of Uncertain Cost* MIT Centre for Energy and Environmental Policy Research Paper 109, Elsevier Science Publishers paper 1993.

8. COMBINING UNCERTAINTIES

From equations (14, 19, 21, 27) respectively, we have, for the case where delaying decommissioning by one period reveals information about all future periods,

$$A_{Pt}= \int_t^T \frac{E(p_{t+1}q_{t+1})-(C-rD)}{(1+r)^{T-t}}, \text{ p>p*}$$

$$A_{Dt} = \int_t^T \frac{E[R_t-(C-rD-rX)]}{(1+r)^{T-t}} - X, \text{ given X <X*}$$

$$+E(R-C+rD+rX-X). \text{ given X□ X*}$$

$$A_{Ct}= \int_t^T \frac{E[R-(C-rD]}{(1+r)^{T-t}} \quad \text{, given C<C*}$$

$$A_{Qt}= \int_t^T \frac{E(p_{t+1}q_{t+1})-(C-rD)}{(1+r)^{T-t}}, \text{ given q>q*}$$

However these option values are additive only under restrictive conditions, when there is a joint probability that p>p* & D>D* & C > C* & q> q*. Under other conditions it may still be optimal to defer, if shortfalls against break-even in one variable are offset by excess over break-even in other variables.

Let $\underline{A}$ be the option value of the combined outcome of these uncertain variables.

Then $\underline{A} = \int_t^T \frac{E(p_{t+1}q_{t+1}+rD+rX)}{(1+r)^{T-t}}$, given that pq-C+rd+rX > $\int_0^\infty E(X)$. (28)

In words, it is the combined outcome of uncertain future variables that count on the left hand side of this expression. For all variables except X, the option to defer decommissioning until uncertain information is revealed will yield an additional cost of zero, but where there is a possibility that decommissioning costs will increase there will be a real unavoidable cost (the second term in the equation for A_D). This term therefore appears on the right hand side of the expression for $\underline{A}$, and, since the whole distribution of X is being covered, it is a probability-weighted sum of all the possible cost-increasing values in the distribution.

Simulation appears to be the only practical route to evaluating A or determining its shape. Uncorrelated variations in the different variables may, for example, reduce the overall volatility and therefore the combined options value.

However, there is at least one certain case where A>0, where probabilities combine to make the separate A's additive. All downside has been excluded by the condition to equation (28). It seems therefore that A must exceed V in all cases and the curve will lie to the right of V in Figure 11. Options analysis reveals a value which the conventional NPV analysis will not capture.

9. MODELLING TAX

In this section we use the model of the decommissioning decision to analyse the effects of the tax system on the value of the project and the optimal time for decommissioning. The first part of the section deals with the UK tax system and the second contrasts this with the Norwegian system with respect to decommissioning. Our approach is very simplified indeed and does not attempt to deal with the intricacies and complexities of the tax systems of either country. We simply try to convey the intuition behind the application of the model to the tax system by illustrating its effect in the diagrams generated by our earlier analysis.

Essentials of the UK Tax System

In our analysis "PRT" simply means tax on profits from a field with one production unit (platform) and Corporation Tax means tax on the total upstream business (several production units on different fields).

PRT is calculated on the income for each individual field and is chargeable for each period of six months. Payment is on a more or less "pay as you go" basis. Since June 1993 the rate of PRT was reduced from 75 per cent to 50 per cent. Decommissioning costs are deductible from income before PRT is calculated. Income for the period when decommissioning takes place is unlikely to exceed the cost of decommissioning, so decommissioning will usually create tax losses. The PRT legislation provides for these losses to be carried back so that repayment ("clawback") of PRT paid for earlier periods becomes possible. There is no time limit. Repayment will be at whichever rates are applicable to the periods when the PRT was paid.

Corporation Tax **(CT)** is currently payable at the rate of 33 per cent and is computed not by the individual field but on a company's whole UK oil exploration and production operations, which are "ring fenced" from its other operations: costs losses elsewhere cannot be deducted from oil income "inside the ring fence."

The cost of decommissioning an offshore oil platform is relievable against this ring-fenced corporation tax in the same way as any other trading expenses or losses within the "ring fence". Losses can be carried forward against profits of the same trade indefinitely; they can be offset against any profit in the same period or can be carried back against any profits for a period of up to three years. This three year carry back was introduced as a special concession to the oil industry to cope with the problem of decommissioning and was then subsequently extended to all other trading companies. The effect of the three-year limit means that the refund of PRT more than three years old generates a higher CT liability which is not reduced by the carrying back of current losses against CT.

The Effect of Petroleum Revenue Tax

In our model the Petroleum Revenue Tax (PRT) simply means the firm pays tax on its profits for that field. As Figure 12 shows (omitting corporation tax), the PRT lowers the part of the revenue curve where R>C (the platform is producing a current cash profit: details of oil allowance, royalties, uplift and other deductions are omitted). In conventional NPV analysis, PRT only affects the revenue curve above the point where expected revenue R=C and V=0 (under the assumptions about declining volumes). The optimal decommissioning period (t_B in the figure) would not be affected by PRT. However, PRT does bring the time of decommissioning forward under options valuation, just as a reduction in revenue due to lower prices or quantities would. This is because PRT reduces the firm's future revenue in the event that p>p* or q>q*. PRT thus reduces the value of A, pushing it up and to the left, which means that the time to decommissioning is earlier : t_{TAX} (in Figure 12) rather than t_A.

This result is intuitive since if a firm is paying taxes on its profit, the profit is worth less to the firm and thus the firm would pay less for the option to keep the project alive.

However, there is an opposite effect as a result of the possibility of clawing back past PRT when operating losses are incurred. Inevitably (since interest is not accumulated and the allowance is in nominal, not real terms) there is a loss in value. The effect is as shown in Figure 13. The heavy broken line represents the after-tax revenue, taking account of PRT paid up to the point where R=C, and of refund of past PRT payments after that point. The graph also shows opportunity cost of deferring decommissioning costs (C-rD) and the option value A_t (as reduced by possible future PRT liabilities).

The break-even tB period, with K representing the amount of clawback available, is when

$$C=R_t + K_t + A_t + rD$$

The Combined Effect of PRT and CT (Corporation Tax)

If the company owned just one platform there is no separate effect of corporation tax since there is no other operation to offset costs against. The position will be as represented in Figure 13, except that the TAX function will be the combined effect of PRT and CT (against which PRT is a deduction). If the company owns platforms in other fields which continue producing then the losses in one platform can be offset against profits in another when CT is calculated. In effect, revenue from the loss-making platform is enhanced. This is represented in Figure 14 by the lower part of the heavy broken line RS. The effect of increasing revenue is, of course, to shift the optimal decommissioning time to a later period. This effect could be picked up by conventional NPV analysis - except to the extent that future revenue from other fields is itself the subject of option values which would tend to reflect the possibility of higher profits elsewhere being available.

The optimal decommissioning time for the first field will be the t_{TAX} in Figure 14, and (as in the pure PRT case) will be later than would be reckoned by conventional NPV analysis because of the remaining option value A.

Decommissioning Tax Allowances: UK versus Norway

In the UK decommissioning costs are treated as part of the PRT and Corporation Tax systems but in Norway decommissioning costs are separated from the petroleum tax system. By the 1975 Petroleum Act, decommissioning costs are not deductible and set offs for future removal costs are not tax deductible. When an installation is removed, the company can apply for a state grant to share between the state and the licensee in accordance with the 1986 Cost Sharing Act.

The State's share of the company's cost is calculated separately for each licensee and is based on the average government share of pre tax profits for that particular licensee for the years during which the licensee used the installation. If a licensee's average tax rate during the relevant period is the maximum tax rate of 78 per cent, the State's share of his removal costs is 78 per cent. The objective of this system is that the licensees should be left in the same position as if yearly provisions for future removal costs had been recognized as deductible expenses and to protect the tax base from all the uncertainties that surround decommissioning. (There is a school of thought in the UK oil industry which advocates the deductibility of provisions as a better policy for the UK.)

The effect of the tax deductions in the UK and the grants in Norway is to reduce the final cost of decommissioning. In the UK case the reduction is constrained by the limits to the carry-back provisions: the firm will claw back past PRT payments on operating losses first, before decommissioning, since (in the absence of indexation and interest) they will be worth more: they may therefore be exhausted, or at least diminished, by the time the decommissioning cost has to be paid. At the Corporation tax level in the UK, the deduction will be limited by the three-year limit to carrying losses back and there may be no effective deduction at all. The Norwegian system is not subject to those restrictions. The absence of indexation or interest is to some extent compensated for by the fact that the shares are calculated as they occur for both State and firm indexation or interest. In general, therefore, the State will bear a larger share of the decommissioning cost in Norway than in the UK.

The effect of this can be shown in our model through the effect on the decommissioning cost D and through that will therefore work through the term rD in the basic break-even equations (4) and (11) (see Figure 15). With some possible nuances around the complexities of the UK system (in the event that clawbacks have not been fully used prior to decommissioning), the reduction will be independent of the timing of decommissioning.

The effect of the deductions in the UK, and the State contributions in Norway will be to advance the time of decommissioning, compared with the situation in which no deduction from tax or contribution from the State is available. Because larger contributions from the State tend to be available in Norway, otherwise similar production units would (if there were no other difference in taxation) tend to be decommissioned earlier in Norway than in the UK.

10. CONCLUSIONS

We have constructed a simple analytical model which applies the options approach to the timing of investment in the decommissioning of oil platforms. Unlike a new investment, decommissioning of an existing platform cannot be avoided, but a firm has choice over its timing. When key parameters are uncertain the option value is the value of continued production until tomorrow when circumstances might be more favourable. It is thus part of the ongoing value of the project. It is thus also the opportunity cost of decommissioning today and can be used to determine the optimum time to decommission.

The options approach facilitates/enables the contribution of each uncertain parameter to the value of the project and to the timing of decommissioning. We have demonstrated how the model can be used to determine the directional effect, on the timing of decommissioning and the value of the ongoing project, of changes in various parameters and their volatility. For most of the key parameters the effect is unambiguous for the parameter taken in isolation.

While the contribution can be evaluated, given the probability distribution of the uncertain parameter, it remains a problem for real-life applications to specify the probability distribution. Some of these probabilities are amenable to action by the firm during the period while decommissioning is deferred. Contracts may reduce uncertainty about prices or costs (either operating or decommissioning); additional drilling or technical development may reduce uncertainties about costs and quantities. The calculation of the options values for price, decommissioning cost, operating cost, and quantity in equations 14, 18, 21 and 27 will give some indication of how much such actions would be worth to the firm.

It is difficult to say analytically whether the combined options values, with uncorrelated uncertainties will be greater or less than the sum of the individual options values. Simulation is probably necessary: the value of actions (or waiting) to mitigate a particular uncertainty may be changed when that is considered incrementally to others. The effect of combinations of changes would depend on their magnitudes and there is a case for constructing numerical simulation models.

The effect of taxation on the decommissioning decision is complex: but we have shown that, because of its effect on option values, the decommissioning decision is not neutral to tax. Tax reduces future revenues and accelerates decommissioning when options values are taken into account. Allowance for deduction of operating losses will tend to defer decommissioning; allowances for deduction of decommissioning costs (or State contributions to those costs) will tend to advance it. The outcome, compared to the before-tax position, will depend on the numbers and the details.

Nevertheless, the directional effects which can be shown from our simple model could have sufficiently strong policy implications to suggest that numerical models could be worth constructing. For example:

- Production is likely to continue even when operating costs exceed revenue, because of the benefit of deferring capital expenditure on decommissioning and the value of continuing to have the option to produce later. The "break-even" price level for continuing North Sea production is therefore probably significantly below the current cost of production because decommissioning costs are high.
- Increasing uncertainty about future prices would increase the option value and tend to defer decommissioning.
- Future increases in decommissioning costs will tend to defer the firm's preferred decommissioning date, but increasing uncertainty about future increases will increase the value of deferring decommissioning if deferral may reduce the uncertainties.
- The existence of tax advances the timing of decommissioning through its effect on the option value of future revenues under uncertainty about prices, costs and quantities, but the optimal decommissioning date will still be later, when options values are taken into account, than when only expected values are considered.
- The firm will choose to decommission earlier, the more the decommissioning cost is relieved against tax, and the higher the tax rate, and vice versa. A simple conceptual comparison of the different UK and Norwegian tax treatments of decommissioning costs suggests that, other things being equal, platforms in Norway will be decommissioned earlier than in the UK sector of the North Sea, but the Norwegian approach may in principle be more tax-neutral.

11) FUTURE APPLICATIONS

Simulation

The generalized basic model derived in this paper is presented as a piece of applied theory which could be adapted very easily to run with real numbers. In the case of the North Sea, the Wood Mackenzie data could be used for a numerical model, derived either on an individual field basis which could prove useful internally for a company, or to the North Sea as a whole, which should prove useful to government policy-makers for taxation purposes. Simulation with realistic numbers and considered judgements about probability distributions would also focus on the relative importance of information to reduce price, cost, or quantity uncertainty.

Mothballing

Our basic decommissioning model suggests that typically a firm will operate a platform at a current operating loss for some period of time, so long as it is recovering at least part of its fixed costs. Eventually, as losses continue to be incurred - if there is no sign of a price improvement to recover profit - the firm will decommission/abandon the oil platform. However, there is an alternative choice at this stage, often considered by firms when they start to incur losses, which is to mothball (at some cost). Mothballing avoids the decommissioning costs and should the price of oil recover, the firm could de-mothball and begin to produce the resource again. This is not an option when the firm has fully decommissioned (without incurring substantial investment costs).

Our basic model could be extended to include mothballing. Instead of the option value being attached to the choice of production versus decommissioning, the decision analysis could be expanded to include an option value for production compared to mothballing and then mothballing compared to decommissioning at a later stage.

Other Examples of Decommissioning e.g. Nuclear Power Stations

Although the model and analysis in this paper has been applied (theoretically) to the decommissioning of a North Sea oil platform, the model can easily be generalized and applied to other areas of decommissioning, such as Nuclear Power Stations or Oil Refinery Sites.

Environmental Damage

Environmental externalities are not represented in the model. In principle, environmental damage caused by continued operation, and by the decommissioning act itself, and uncertainties in these functions could be treated by the options methods to illustrate the environmental value (or cost) of waiting. Parameterization would be a major problem, as would the formulation of a single decision rule.

Figure 1

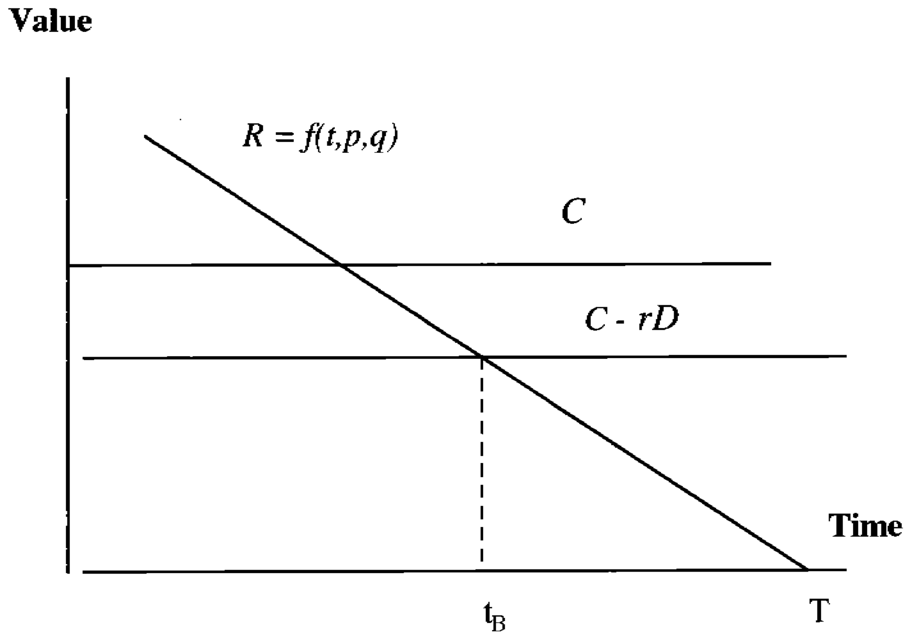


Figure 2

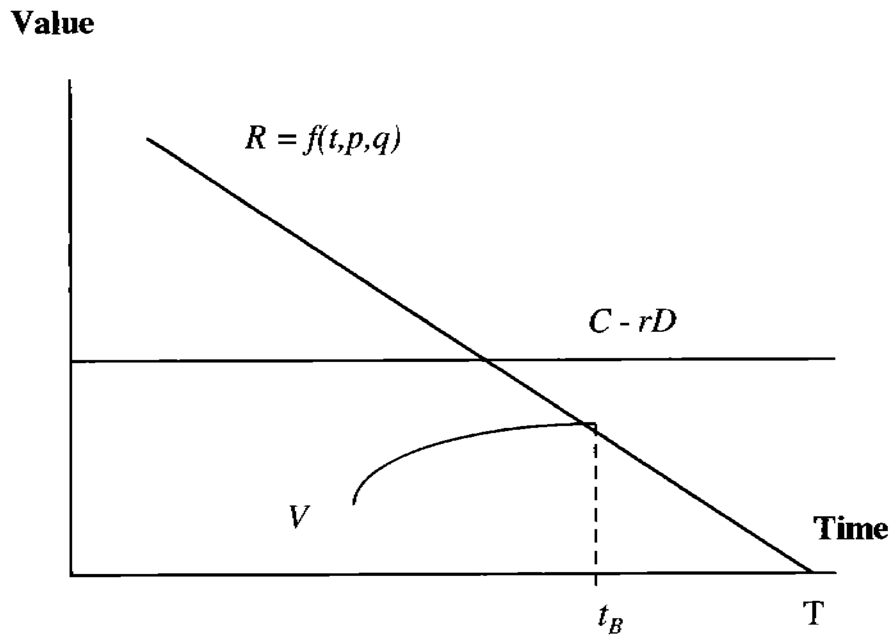


Figure 3

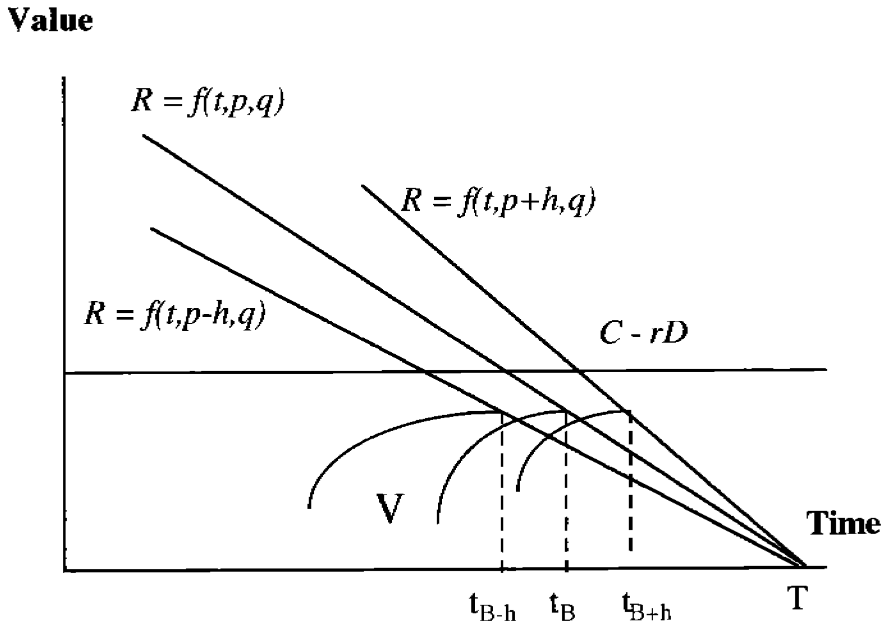


Figure 4

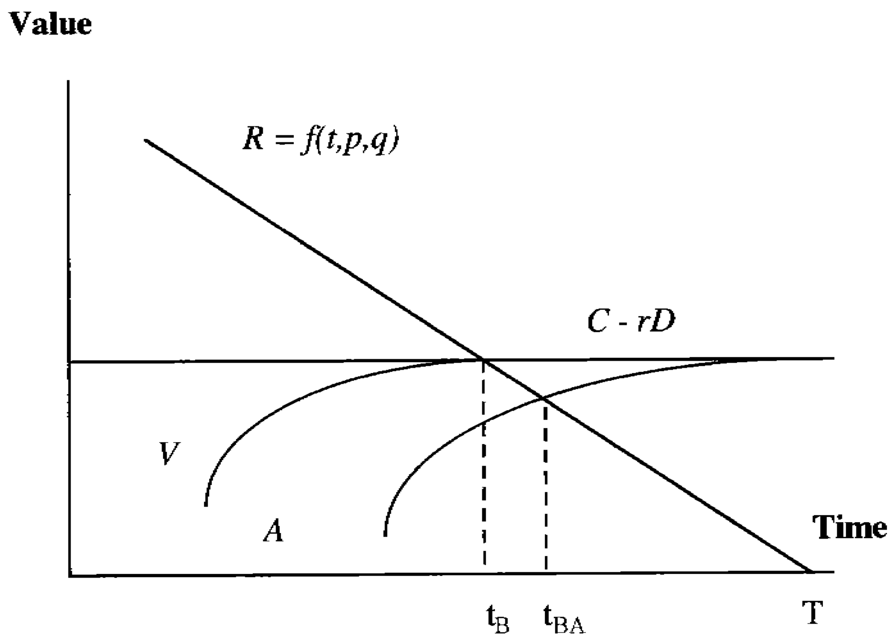


Figure 5

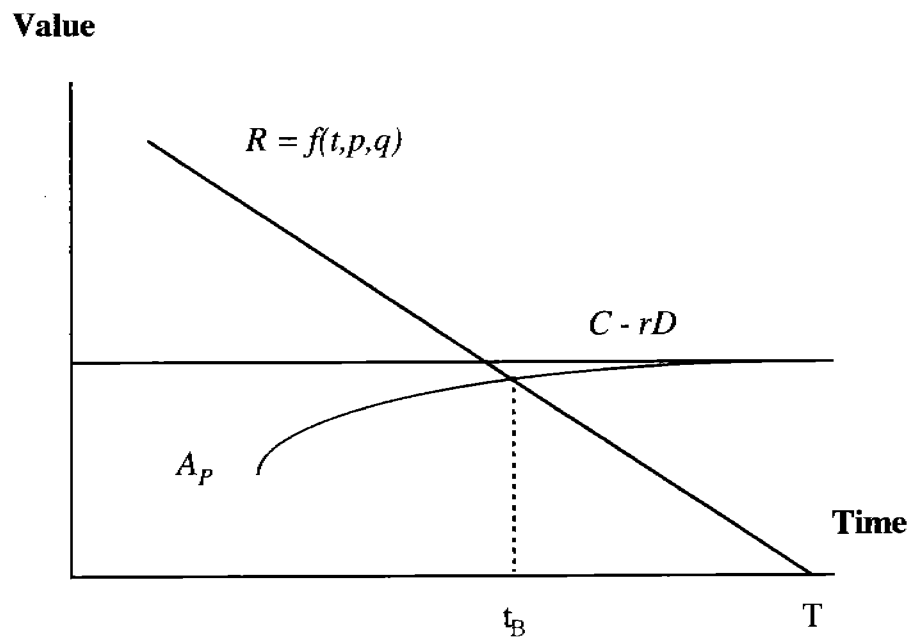


Figure 6

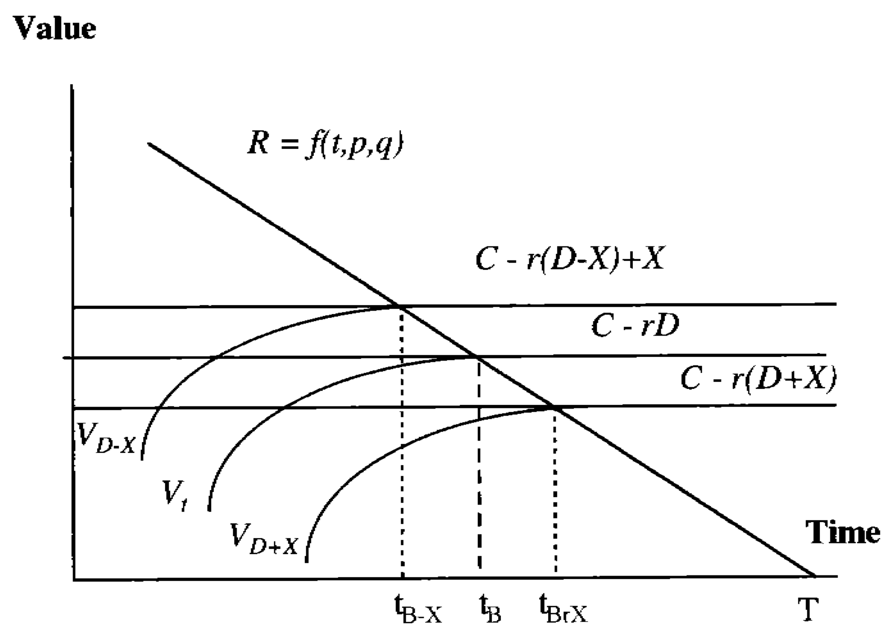


Figure 7

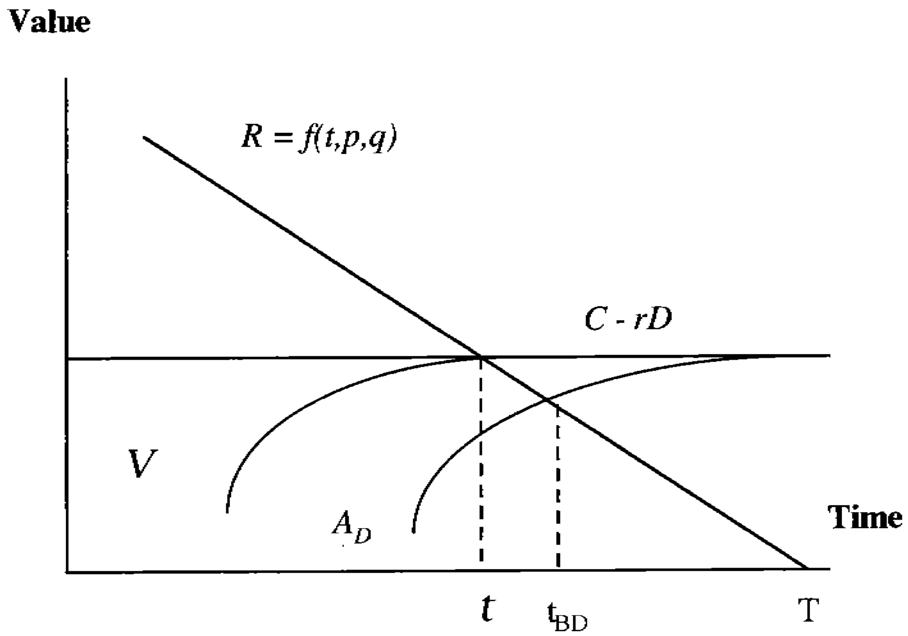


Figure 8

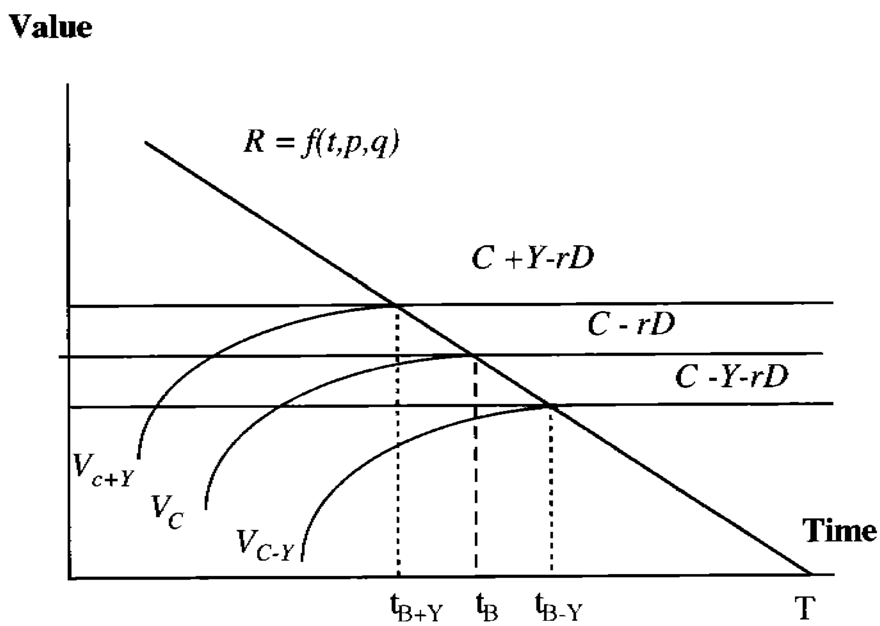


Figure 9

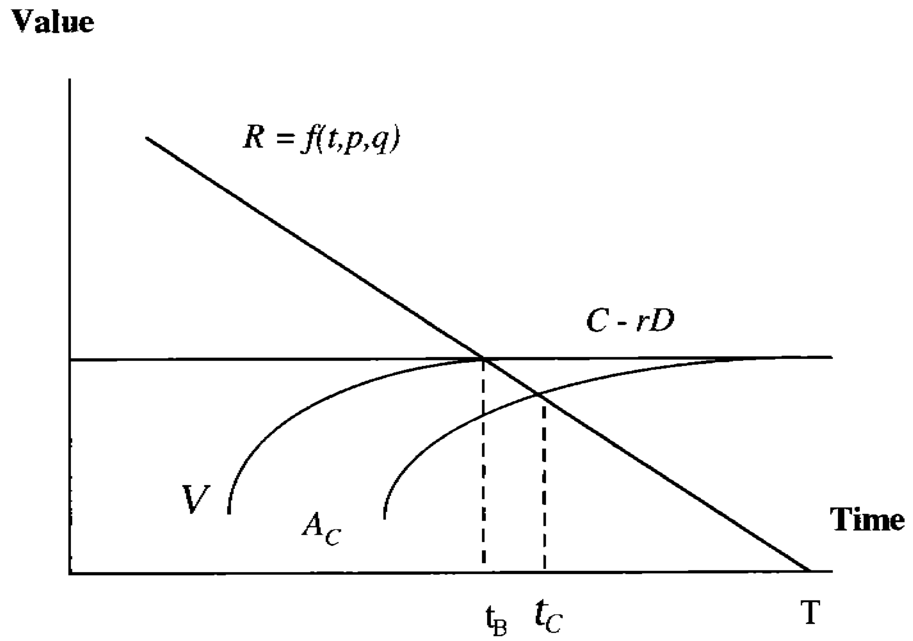


Figure 10

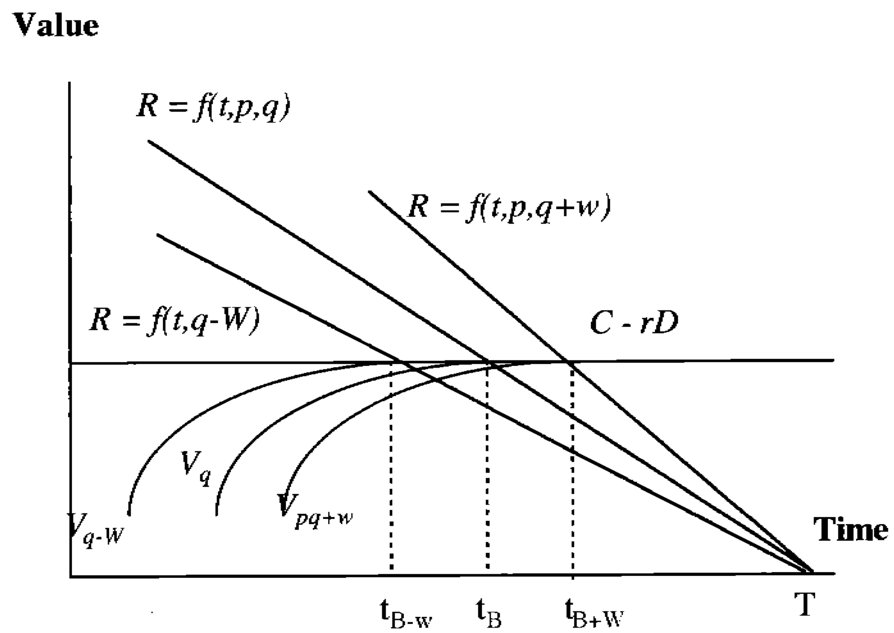


Figure 11

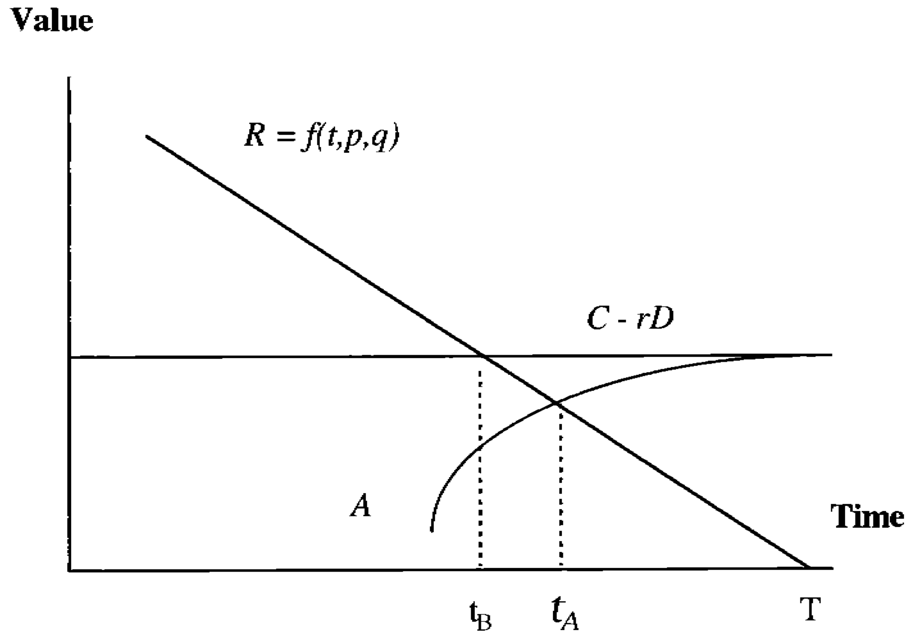


Figure 12

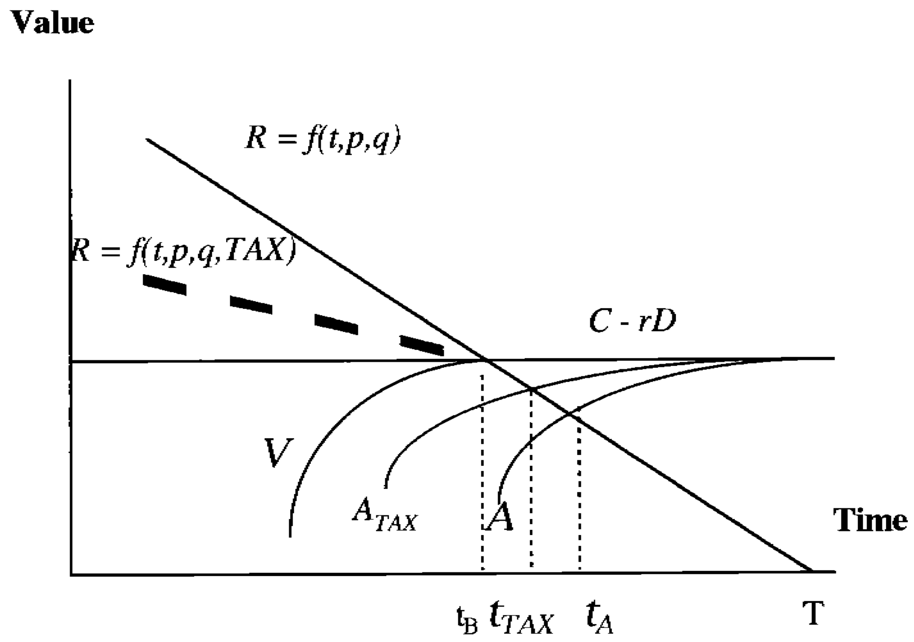


Figure 13

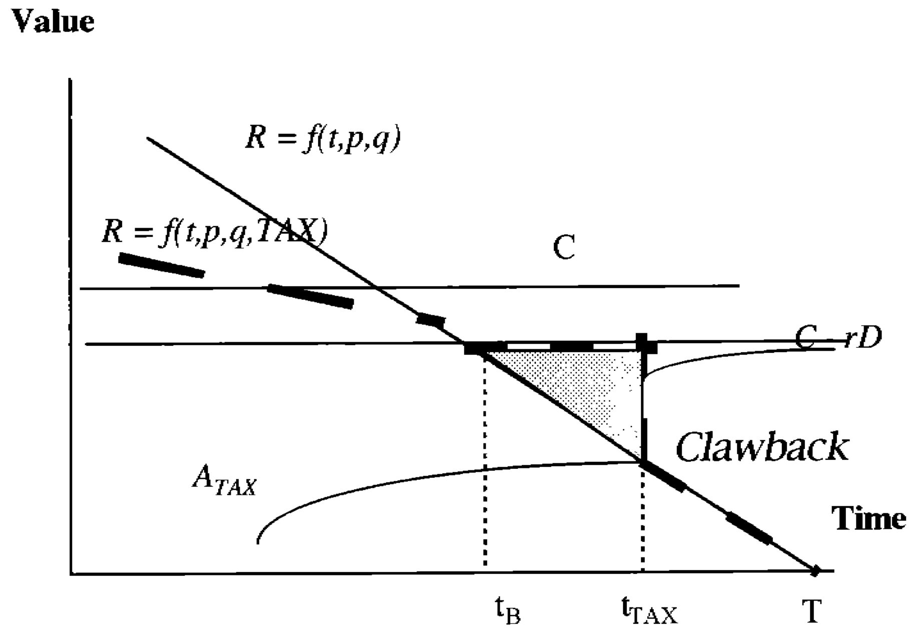


Figure 14

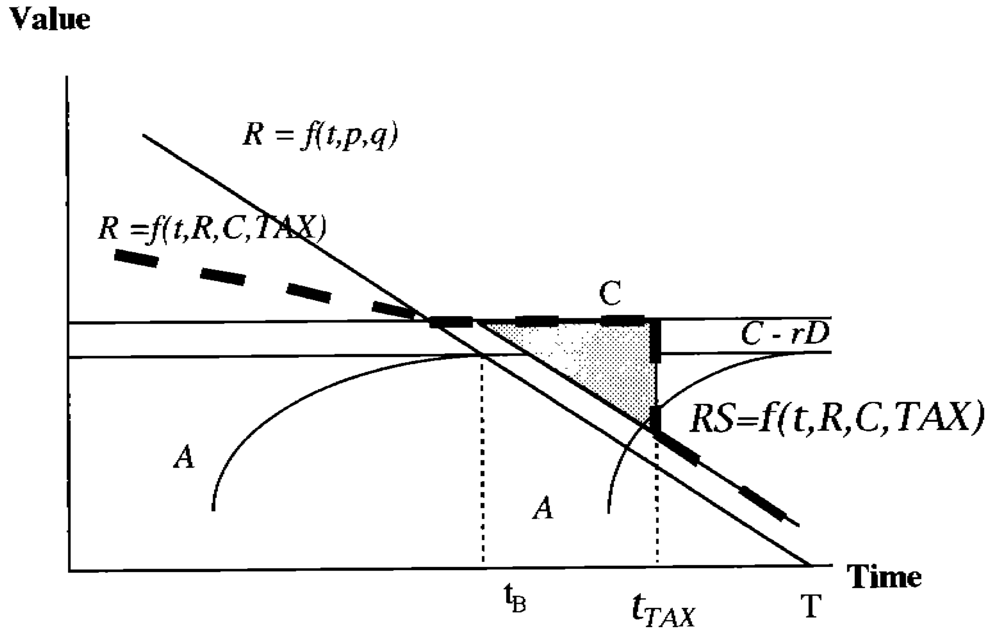
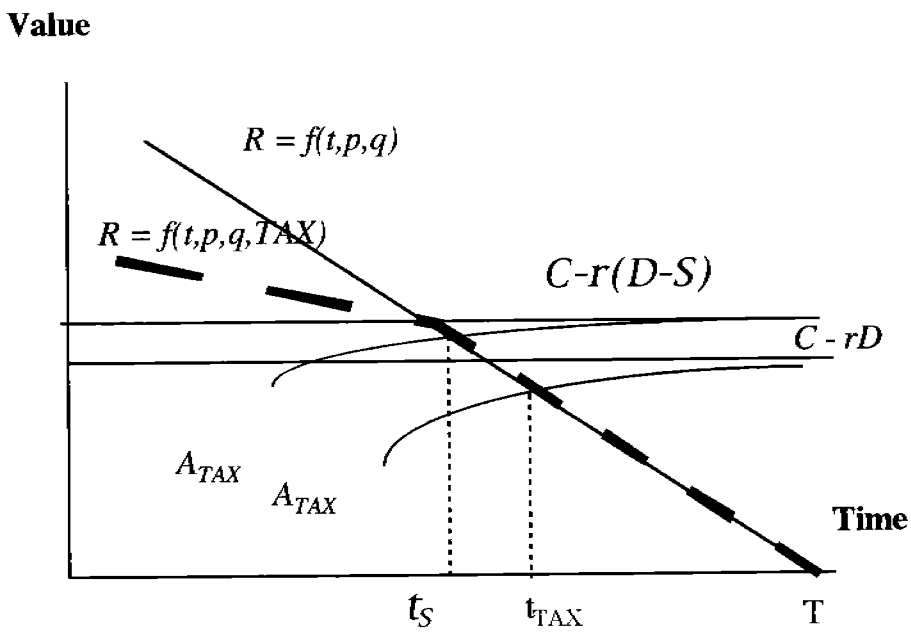


Figure 15



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