ELSEVIER

Energy Policy 27 (1999) 111–120

ENERGY POLICY

Risk:reward sharing contracts in the oil industry: the effects of bonus:penalty schemes

Alexander G. Kemp*, Linda Stephen

Department of Economics, University of Aberdeen, Edward Wright Building, Dunbar Street, Aberdeen AB24 3QY, UK

Abstract

Partnering and alliancing among oil companies and their contractors have become common in the oil industry in recent years. The risk: reward mechanisms established very often incorporate bonus/penalty schemes in relation to agreed base values. This paper examines the efficiency requirements of such schemes. The effects of project cost and completion risks on the risk: reward positions of field investors and contractors with and without bonus/penalty schemes are examined with the aid of Monte Carlo simulation analysis. The schemes increase the total risk for contractors and have consequence for their cost of capital and optimal risk-bearing arrangements within the industry. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Project cost and completion risks; Risk:reward sharing; Bonus/penalty schemes; Monte Carlo simulation and project risks

Introduction

In the North Sea in recent years there has been a rapid growth in the employment of partnering and alliances among oil companies and their contractors. This development has been widely seen as a key element in the endeavours to reduce investment and operating costs. The concepts have been hailed by some as devices which can reduce the adversarial element in the relationships between oil companies and their contractors. It is argued that the reduction of the adversarial element will encourage mutually beneficial co-operation which should stimulate speedier completion of work, innovations, and cost savings. Others fear that the employment of such contracts represents the transfer of more of the investment and operating risks to the contractors and a squeeze on their margins.

This paper analyses the risk-sharing attributes of some typical types of field development contracts. It highlights the effects of bonus/penalty schemes which are generally key elements of the contracts. An efficient scheme should produce required incentives without introducing other unwanted incentive effects such as exaggeration of cost savings and understatement of cost over-runs by contractors. Potentially severe penalties on contractors may also jeopardise their financial life. The study quantifies the effects of typical schemes on the relative risk: reward positions of contractors and oil field investors. The implications for the cost of capital of the respective parties and possible optimal risk bearing within the industry are drawn.

Contract definitions

In the petroleum industry a broad distinction can be made between cost-based and value-based contracts. This paper deals with cost-based contracts at the field development stage. These incorporate several variants. One is where the contractor is reimbursed at an agreed rate. Generally this involves the least risk for the contractor and a correspondingly greater risk for the client (field investor). The latter bears the burdens of cost over-runs and delays in work completion. Another variant is where the total value of the contract is fixed in advance. The contractor then bears the full risk of variations in his own costs. In this study the emphasis

* Tel: +(01224) −272168; Fax: +(01224) −272181; email: a.g.kemp@abdn.ac.uk.

0301-4215/99/$-See front matter
PII: S0301-4215(98)00069-X

is on reimbursable contracts with bonus/penalty schemes added.

At the field development phase an important consideration is the lead time between investment and first production. Under a cost-based contract the contractor may bear project completion risks if his payment is not received until after the work has been completed. The field investor still bears some of the project completion risks in the sense that the ensuing postponement of the production income will, other things being equal, reduce the discounted returns from the project.

Issues in design of efficient bonus/penalty schemes

Some propositions regarding an economically efficient bonus/penalty scheme are now developed. In general, under a reimbursable contract, if a bonus is given for reducing costs it will be based on a percentage of the difference in realised cost from a predetermined agreed base value. In these circumstances let x = agreed bonus rate, bc = base cost, rc = realised cost, m = contractor's percentage margin, p_0 = contractor's profit prior to the bonus/penalty and p_1 = contractor's profit after the bonus/penalty. The contractor's bonus is $x \times (bc - rc)$ and his profit position is as follows:

Where $x = m$ then $p_1 = p_0$

Where $x > m$ then $p_1 > p_0$

Where $x < m$ then $p_1 < p_0$

The effect of the bonus scheme on the field investor similarly depends on how it relates to the cost reduction. Let fc_0 = field investor's cost prior to bonus/penalty and fp_1 = field investor's cost after bonus/penalty. The field investor's costs are $rc \times m + (bc - rc)\, x$(or y). It is noted that $(bc - rc)$ will be negative when an overspend occurs. The field investor's position is then as follows:

where $x < m + 1$, then $fc_1 < fc_0$.

Thus, if the contractor's margin is 10%, the field investor's cashflow will improve if the bonus offered for reducing costs is less than 110% of the cost difference.

If a bonus scheme is to act both as an incentive to the contractor to reduce development costs *and* not have a detrimental effect on the return to the field investor, the conditions are that the bonus percentage should exceed the contractor's margin percentage, but be less than the contractor's margin plus 100% of the difference in development cost as follows:

$x > m$ and $x < m + 1$

This is consistent with the win-win concept frequently discussed in the industry

The position with a penalty for a cost over-run depends on how the penalty relates to the cost over-run. Let y = agreed penalty rate. The contractor's penalty $= y \times (bc - rc)$ and his profit is as follows:

where $y = m$ then $p_1 = p_0$

where $y > m$ then $p_1 < p_0$

where $y < m$ then $p_1 > p_0$

The corresponding position for the field investor is as follows:

where $y < m + 1$ then $fc_1 > fc_0$

where $y = m + 1$ then $fc_1 = fc_0$

where $y > m + 1$ then $fc_1 < fc_0$

If the penalty < 100% of the cost difference plus the contractor's percentage margin, a cost over-run has a detrimental effect on the field investor. For a penalty scheme to act as an incentive to the contractor to avoid any cost over-run, but also to avoid any adverse incentive effect on the field investor, the condition is that the penalty percentage imposed exceeds the contractor's margin percentage, but is less than the contractor's margin plus 100% of the cost difference as follows:

$y > m$ and $y < m + 1$

The nearer the bonus/penalty percentage is to 100% of the cost difference, the less effect will any cost changes have on the total outcome for the field investor, and the larger will be the effect of any cost changes on the contractor.

If the penalty imposed is very harsh, and/or the cost over-run is large, the contractor may even suffer losses from the contract as follows:

If $y > m - (m/((bc - rc)/bc))$ then p_1 becomes negative.

In actual contracts variations in cost from an agreed base value are shared between the field investor and contractor according to a formula. Typically, they may agree to share equally in a reduction or increase in the cost.[1] In monetary terms this means the following:

x (or y) $= m + 0.5$

The field investor and the contractor gain equally from any cost reduction, and lose equally when there is a cost

[1] For a useful survey of bonus: penalty arrangements in practice see Farrell (1995). This indicates that 50:50 sharing of achieved cost savings is very typical.

over-run. The contractor will gain from a cost over-run if the penalty imposed is less than the margin on the cost increase.

Another possibility would be to maintain the contractor's total cashflow when cost reduction occurs. This requires that the bonus percentage offered equals the contractor's margin percentage. Let m_l = actual margin from cost reduction. To maintain the contractor's cashflow the *actual margin* earned has to increase such that:

$$m_l = ((m \times bc)/rc) - ((m \times bc)/bc)$$

If we assume that a cost saving of 20% is to be shared equally, then, although the saving in monetary terms has been equally shared, in percentage terms the contractor's gain is likely to be larger than the gain to the field investor. For example, at a base price of £100 the contractor's net cashflow may be £10, but with the cost saving and bonus it increases to £20, that is a 100% increase from the base position. The percentage benefit for the field investor, however, is only 9.09%. For the field investor and the contractor to share the gain equally from a cost reduction (or loss from a cost over-run) in percentage terms, the requirement is as follows:

$$x \text{ (or } y) = (m + m^2)/(m + 0.5)$$

This condition implies that, to share any cost saving or over-run equally in percentage terms, the bonus offered must be substantially less than 100% of the cost difference.

If the actual cost is less than the base value, the contractor would typically receive a bonus on completion of the contract based on the achieved cost saving. If the actual cost exceeded the base value he would pay a penalty, with the final payment to him being reduced by some amount based on the overspend. The bonus/penalty scheme chosen may be on a flat scale, or on a progressive scale where the (percentage) bonus or penalty varies with the size of the cost saving or over-run. In -practice in the oil industry progressive schemes are generally employed,[2] and so these are analysed here.

Progressive schemes may be on a slab or incremental basis. With a slab-based scheme when a higher rate of bonus or penalty is triggered the higher rate applies to *all* the cost saving or over-run. Where an incremental scheme is employed the higher rates apply only to the incremental range of cost savings or over-runs. Typically the penalty is capped to limit the contractor's downside risk exposure.

[2] See Farrell (1995).

An example of a typical bonus/penalty scheme on a slab basis is as follows:

Actual contract cost	*Bonus/penalty*
0 to 10% less than base value	25% of total cost saving
10 to 40% less than base value	50% of total cost saving
>40% less than base value	50% of first 40% of cost saving
0 to 10% more than base value	25% of total cost overspend
10 to 40% more than base value	50% of total cost overspend
>40% more than base value	50% of first 40% of cost overspend

This example scheme fulfils the conditions required for an efficient scheme provided that the contractor's margin is less than 25% of cost. If the contractor's margin is between 25% and 50% then there is no incentive for him to reduce or contain costs unless he is confident that he can reduce the cost by 10% or more. If the contractor's margin exceeds 50% he will gain from any cost over-run.

In the above example the bonus or penalty is limited to 25% of the cost difference when the actual cost is within 10% of the base value. If the actual cost differs by more than 10% of the base value, but by less than 40% of that value, a bonus or penalty at 50% of the cost difference would be applied to the difference in cost. The scheme also limits the bonus paid or penalty imposed to 50% of the first 40% of the cost difference.

There are significant differences in the comparative effects produced by slab and incremental schemes. The former can introduce distortions such as incentives to contractors to overstate cost savings or understate cost over-runs. In particular, a slab-based scheme can give the contractor an incentive to overstate the cost saving or understate the cost over-run. Let a = actual cost, am = actual cost × contractor's margin rate, $aslr$ = actual saving × lower bonus rate, oc = overstated cost, om = overstated cost × contractor's margin rate, os = overstated saving and hr = higer bonus rate. With a slab-based scheme the contractor will gain when the cost saving is overstated to the point at which the higher rate of bonus is earned in the following circumstances:

$$hr > (a + am + aslr - oc - om)/os.$$

With the example bonus scheme outlined above the contractor can gain when the cost saving is overstated to 10% of the base cost (so that he earns a higher bonus rate).

If osh = overstated saving × higher bonus rate, bl = base cost × lower bonus rate, m = contractor's margin rate and lr = lower bonus rate the contractor gains in the following circumstances:

$$a < (oc + om + osh - bl)/(1 + m - lr)$$

eg if we assume a base cost of £100 and a margin rate of 10%, the contractor will gain by overstating the saving provided that the actual cost is less than £92.94.

Similarly, it may pay the contractor to understate the cost over-run to ensure that the penalty imposed is charged at the lower rate.

If u = understated cost, um = understated cost × contractor's margin rate, uol = understated cost over-run × lower bonus rate, a = actual cost, am = actual cost × contractor's margin rate, and ao = actual cost over-run the contractor will gain when the cost over-run is understated in the following circumstances:

$$hr > (u + um + uol - a - am)/ao$$

Under the example penalty scheme outlined above the contractor will also gain when the cost over-run is understated to just less than 10% of the base cost (so that he pays a lower penalty rate). The contractor then gains in the following circumstances:

Let uol = understated over-run × lower penalty rate bh = base cost × higher penalty rate, m = contractor's margin rate and h = higher penalty rate.

$$a < (u + um + uol - bh)/(1 + m - h)$$

For example, if we assume a base cost of £100 and a margin rate of 10%, the contractor will gain by understating the cost over-run provided that the actual cost is less than £114.16.

> Incremental schemes can avoid the problems of extremely high effective marginal rates which can readily be produced by slab-based schemes.

An example of such a scheme is as follows:

Actual contract cost	*Bonus/penalty*
0 to 10% less than base value	25% of cost saving
10 to 40% less than base value	50% of cost saving above 10% + 25% of first 10% of cost saving
> 40% less than base value	50% of cost saving between 10 and 40% +25% of first 10% of cost saving
0 to 10% more than base value	25% of cost overspend
10 to 40% more than base value	50% of cost overspend above 10% +25% of first 10% of cost overspend
> 40% more than base value	50% of overspend between 10 and 40% +25% of first 10% of cost overspend

An incremental scheme of the type shown above ensures that marginal rates of bonus or penalty facing a contractor will not exceed 100%. The incentive to manipulate the value of costs is much reduced but not entirely removed. The effective marginal rates under the slab-based system for the same nominal rates are much higher than under the incremental one. The detailed performance of the two systems is discussed below.

Risk analysis—Monte Carlo simulation

Cost risks

An appropriate method for measuring the risks and rewards of the two parties is Monte Carlo simulation analysis. A normal distribution of possible costs relating to a large field development project is postulated. The width of the distribution indicates the extent of the risks faced by the investor. When bonus/penalty payments are introduced these are assumed to be paid on completion of the contract. The contract examined is a reimbursable one between the oil field investor and contractor.

It is next assumed that the contract has a mean (and agreed) total base value of £100 million with the expenditure being incurred evenly through time. The standard deviation is assumed to be 15% of the mean. The contractor's net margin over all costs including overheads is assumed to be 10%. To facilitate ready comparison between schemes the results are generally shown in present value (PV) terms with payments to the contractor being made on project completion. The field investor's position is indicated by the present value of the contract payments at 10% cost of capital. Similarly the contractor's position is measured by the net present value (NPV) of his margin again at 10% cost of capital.

The Monte Carlo simulations involved 1000 iterations for each case examined. Various statistics relating to the output distributions were calculated. To facilitate meaningful comparisons between distributions of net present values with different means emphasis has been put on the coefficients of variation in the discussion of the results.

The position facing the oil field investor in the absence of any bonus/penalty scheme is shown in Figure 1.

There is a 68% probability that the PV of the contract will lie between £53 million and £71 million, and a 95% probability that it will lie between £44 million and £80 million. The coefficient of variation is 15%.

The impacts of the bonus/penalty schemes are now considered. The distribution of the PV of the contract with the slab-based scheme is shown in Figure 2. There is

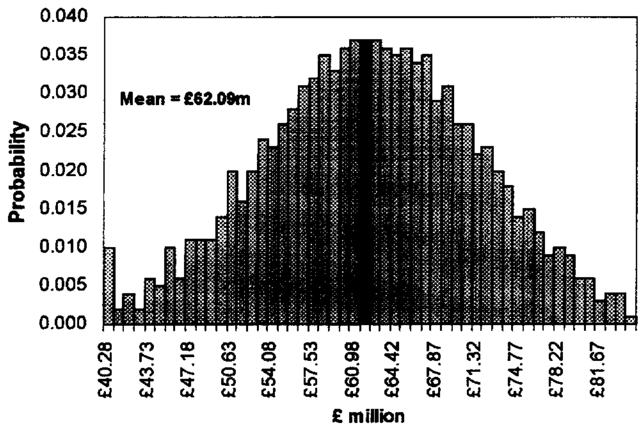

Fig. 1. Expected PV of contract @ 10% (£m) (payment on completion)

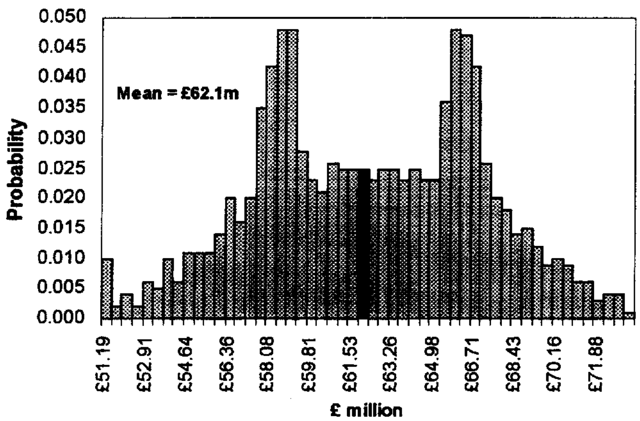

Fig. 2. Expected PV of total contract @ 10% with slab-based scheme (£m)

a 68% probability that the PV of the contract will lie between £57 million and £68 million, and a 95% probability that it will lie between £53 million and £71 million. The coefficient of variation is now 8%, considerably less than in the absence of the scheme. This results from the operation of the bonus/penalty scheme. Thus when there is a cost over-run the field investor receives some compensation from the contractor through the penalty. When there is a cost reduction the field investor pays a bonus to the contractor. The effects are to reduce the variability of the net contract value from the field investor's perspective compared to the pre-bonus/penalty situation.

The distribution is seen to have 2 distinct peaks. These are also a direct consequence of the bonus and penalty payments. They arise principally because of the large marginal increase in the rate of bonus offered when the cost saving or overspend moves from one band to the next, and to a less extent because the first band is limited to a 10% saving or overspend, whilst the cost distribution itself has a standard deviation of 15%. The overall risks as measured by the width of the range of outcomes

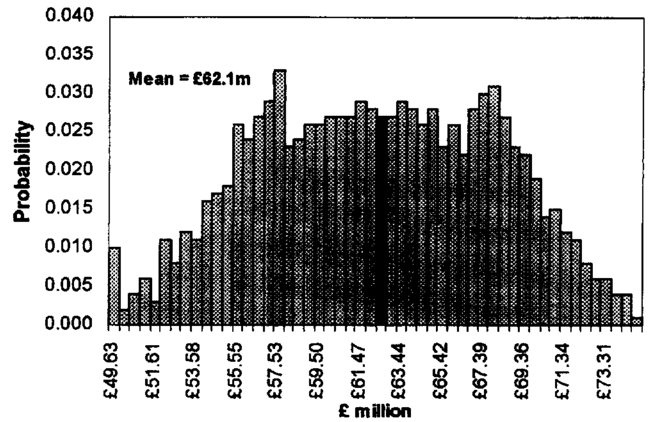

Fig. 3. Expected PV of total contract @ 10% with cost uncertainty and incremental scheme (£m)

are significantly reduced by the bonus/penalty scheme to £41 million from £66 million. In this sense the field investor's risks are reduced.

The expected PV of the contract under the incremental bonus/penalty scheme is shown in Figure 3. There is a 68% probability that the PV of the contract will lie between £56 million and £68 million, and a 95% probability that it will be between £52 million and £73 million. The coefficient of variation is 9%. For given cost bands and top marginal rates in nominal terms, the incremental bonus/penalty scheme gives a narrower range of bonus/penalty outcomes, and so results in a wider spread of final outcomes for the oil field investor than does the slab-based scheme. The peaks in the distribution which were so distinct with a slab-based bonus/penalty scheme are greatly reduced because the large marginal increase in the bonus/penalty rate has been removed. Some of the peak still remains because the first band is still limited to a change in cost of 10%. The risks are still considerably reduced from those without any bonus/penalty scheme.

The corresponding position of the contractor is now considered. The distribution of his expected NPV without the bonus/penalty scheme in this case reflects that of the field investor and is not shown. There is a 68% chance that the NPV will be in the range £5.3 – £7.1 million and a 95% chance that it will be in the range £4.4 – £8 million. The coefficient of variation is 15%, the same as that of the field investor.

In Figure 4 the expected NPV of the contractor is shown following the introduction of the slab-based bonus/penalty scheme.

There is now a 68% probability that the NPV will be between £2.5 million and £9.9 million, and a 95% probability that it will be between minus £1 million and plus £13.4 million. The coefficient of variation is now 58%. There is thus a very substantial increase in the risk position facing the contractor. The contractor has to pay a penalty when there is a cost over-run while he receives

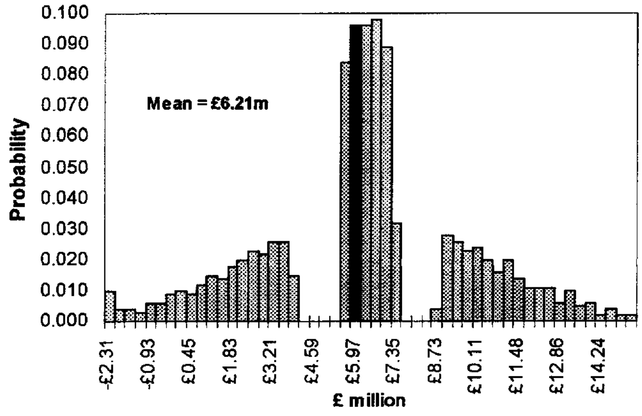

Fig. 4. Expected *NPV* of contractor @ 10% with cost uncertainties and slab-based scheme (£m)

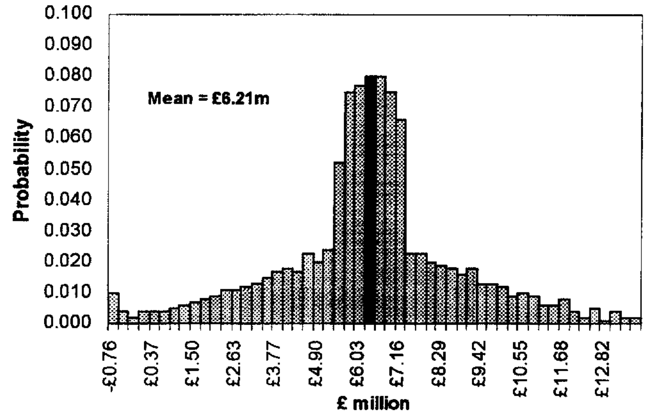

Fig. 5. Expected *NPV* of contractor @ 10% with cost uncertainty and incremental scheme (£m)

a bonus when there is a cost reduction. The net effect is to increase the variability of his returns compared to the situation in the absence of the bonus/penalty scheme. The discontinuities in the distribution are a direct result of the bonus/penalty payments. They occur because of the large marginal change in the rate of bonus/penalty when the cost change moves from one band to the next. This also causes the distribution to become more peaked.

It is noteworthy that the effect of the bonus/penalty scheme is to radically alter the conditions which produce the lowest and higher returns to the contractor. In the absence of the scheme, with the reimbursable contract, the contractor's highest *NPV* occurs when project costs are maximised. The bonus scheme transforms this situation. He now maximises his *NPV* when project costs are minimised. The scheme is thus operating efficiently. As costs increase the contractor's *NPV* is reduced, and as costs decline his *NPV* increases.

The returns to the contractor could equally have been presented in terms of the distribution of his (percentage) margin rather than *NPV*. In the case where the slab-based scheme operates there is a 68% chance that it falls between 3.5% and 18.8% and 95% chance that it falls between minus 1.2% and 30.2%.

The expected *NPV* of the contractor with the incremental bonus/penalty scheme is shown in Figure 5.

There is now a 68% probability that the *NPV* will lie between £4.1 million and £8.4 million, and a 95% probability that it will be between £0.6 million and £11.8 million. The coefficient of variation is 42%, indicating a less risky position than with the slab-based scheme, but still a much higher risk compared to the scheme without the bonus/penalty scheme. The results confirm that the bonus/penalty schemes significantly increase the overall risks faced by contractors, while reducing those faced by field investors to a relatively lesser extent. The highly peaked distribution arises because of the high probability (50%) that the change in the contract cost will be within the first bonus/penalty rate bands.

Project completion risk

Project completion risk constitutes one of the most important risks at the development phase of an oil field project. The effect of this is now examined with the Monte Carlo simulation modelling. The contract is again reimbursable. It is assumed that there is no overall cost over-run, and that payment is made when the contract is completed. The completion date is uncertain, and this is indicated by a standard deviation of 10% of the mean expected time. This is 60 months. There is then a 95% chance that the project will be completed within 48–72 months. The resulting distribution of the *PV* of the contract payment, indicating the position facing the field investor, without a bonus/penalty scheme is shown in Fig. 6.

There is a 68% probability that the *PV* of the contract cost will be between £59.2 million and £65.1 million, and a 95% probability that it will be between £56.4 million and £68.3 million. (The gaps in the distribution shown in Figure 6 reflect the discrete (one month) time periods for accelerated and delayed completion employed in the financial modelling). The coefficient of variation is 5%.

From information available in the public domain for the type and size of project being considered a bonus/penalty of £1 million per month was felt to be representative. Given the standard deviation the total variation in timing is very likely to be within a twelve month period which is again consistent with experience.

The *PV* of the total contract is not shown, but there is a 68% probability that the *PV* of the contract will lie between £55.7 million and £69 million, and a 95% probability that it will be between £49.7 million and £76.5 million. The distribution of the *PV* of the contract including the bonus/penalty scheme is wider than it was without the scheme. The effect of earlier completion is compounded by the bonus, while the penalty further reduces the *PV* of the contract when completion is delayed. The coefficient of variation is 11% with the

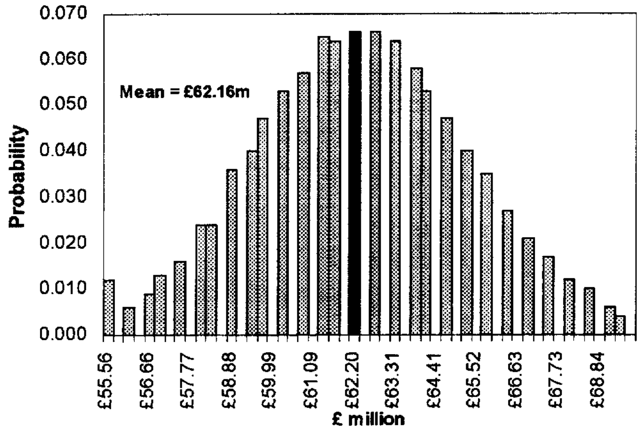

Fig. 6. Expected PV @ 10% of contract with uncertain completion date (£m)

bonus/penalty scheme. While the field investor's risk is increased by the bonus/penalty scheme it should be noted that earlier project completion can bring a major benefit through the acceleration in receipts of production income.

The contractor's position is now examined. He gains in PV terms through early completion even in the absence of a bonus and loses in PV terms with late completion even without the penalty. The distribution of his expected NPV in the absence of the bonus/penalty reflects that of the field investor and is not shown. There is a 68% chance that the NPV will lie between £5.9 and £6.5 million and a 95% chance that it will be between £5.6 and £6.8 million. The coefficient of variation is 5%.

The contractor's expected NPV with the bonus/penalty scheme is not shown. The mean expected NPV is slightly higher in this case because the acceleration of completion adds more to the NPV than late completion reduces it. There is a 68% probability that the NPV will be between £2.4 million and £10.4 million, and a 95% probability that it will be between minus £1.1 million and plus £15 million. The coefficient of variation when the completion date is the stochastic variable was found to be higher (63%) than when the development cost was stochastic (58 and 42% respectively depending on whether the scheme is slab or incremental). The bonus/penalty scheme has a major effect on the contractor's risk position. Late completion involves a penalty as well as a delay in receiving payment. It is again noteworthy that the risk position facing the contractor as measured by the coefficient of variation is relatively high compared to that of the field investor. The latter also has to bear the effects of the risks of completion delays/acceleration on the receipt of production income.

Cost and project completion risks

In practice both the overall cost and the project completion dates are uncertain. The contractor could have a contract which shared in both of these risks. This situation was modelled. The underlying assumptions for the mean values and standard deviations relating to the contract cost and completion date are the same as employed above. The contractor is again paid when the project is completed. In the first case it was assumed that the overall cost and completion risks were uncorrelated.

The expected PV of the contract in the case when there is no bonus/penalty scheme is shown in Figure A1 in the Appendix. There is a 68% probability that the NPV will be between £52.2 million and £71.8 million, and a 95% probability that it will be between £43.2 million and £81.1 million. The coefficient of variation is 16% which is closer to that found when development cost was the stochastic variable (15%) than when the completion date was stochastic (5%).

The effects of introducing the incremental bonus/penalty scheme on the expected PV of the total contract are shown in Figure A.2 in the Appendix. There is a 68% probability that the PV of the contract will be between £53.1 million and £70.8 million, and a 95% probability that it will be between £45.9 million and £79.8 million. The coefficient of variation is 14% compared to 9% when only costs were stochastic, and 11% when the completion date was stochastic.

The contractor's position is now examined. In the absence of the bonus/penalty scheme the distribution of his NPV mirrors that of the field investor and so is not shown here. There is a 68% chance that the NPV will lie between £5.2 million and £7.2 million and a 95% chance that it will lie between £4.3 and £8.1 million. The coefficient of variation is 16%.

When the incremental bonus/penalty scheme is introduced the resulting expected NPV of the contractor is shown in Figure 7.

There is a 68% probability that the NPV will be between £1.6 million and £11.1 million, and a 95% probability that it will be between minus £2.7 million and plus £16.6 million. The coefficient of variation is 76%. The corresponding values when cost and completion dates were stochastic were respectively 42% and 63%. The high coefficient of variation in the present case reflects the chances of double penalties or bonuses. For example, a cost over-run penalty could be payable in circumstances where the project was completed late entailing a further penalty. By comparing Figure 7 with Figure 5 it is seen that the high peak associated with cost uncertainty disappears when cost uncertainty and completion date uncertainty occur together. This occurs because in some instances a cost bonus may be associated with a completion date penalty and vice versa so that the bonus and penalty cancel each other out.

The next cases consider that, although both the cost and completion date are stochastic, they are likely to be correlated. The assumption is that when completion is late it is likely that the cost will increase, and when

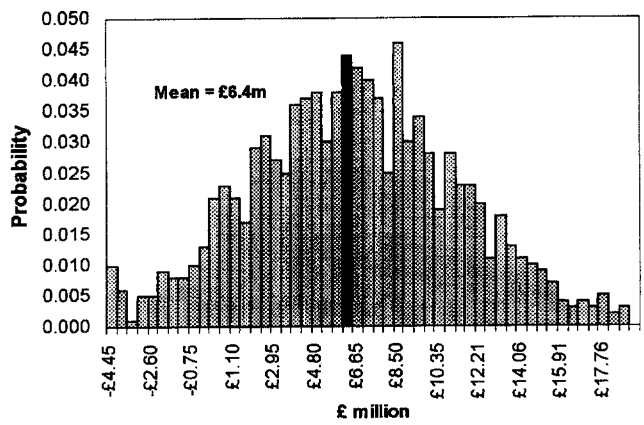

Fig. 7. Expected *NPV* of contractor @ 10% with uncertain costs and completion date and bonus/penalty scheme (£m)

completion is early it is likely that the cost will be reduced. Two cases are examined. In the first it is assumed that the relationship between the cost and completion date is weak (correlation 0.25), and in the second it is assumed that the relationship is strong (correlation 0.75).

The expected *PV* of the contract cost (excluding bonus/penalty payments) when the cost and completion date are weakly correlated is not shown but there is a 68% probability that the *NPV* will be between £53 million and £70.9 million and a 95% probability that it will be between £44.2 million and £80.2 million. The coefficient of variation is 15%.

The expected *PV* of the contract cost (excluding bonus/penalty payments) when the cost and completion date are strongly correlated is not shown but there is a 68% probability that the *PV* of the contract will be between £54.6 million and £69 million, and a 95% probability that it will be between £46.6 million and £75.9 million. The coefficient of variation is 12% which is lower than in the case when the correlation between cost and completion data was weaker. Late completion reduces the *PV* of the payment. Higher cost increases the *PV* of the payment. The results reflect the general proposition that the stronger the relationship between cost and completion date the higher the chance that the increase and decrease in *PV* terms would offset each other.

The *PV* of the total contract including the effect of the bonus/penalty scheme when the correlation between the completion date and cost is weak is not shown but there is a 68% probability that the *PV* of the contract will be between £54.7 million and £70.1 million and a 95% probability that it will be between £48.5 million and £78.1 million. The coefficient of variation is 12%.

The expected *PV* of the total contract (including bonus/penalty payments) when the correlation between completion date and cost is strong is not shown but there is now a 68% probability that the *NPV* will be between £57.7 million and £66.7 million and a 95% probability that it will be between £53.6 million and £71.3 million. The coefficient of variation is 7%, considerably less than in the weakly correlated case.

Although the mean bonus/penalty remains unchanged whatever the relationship between the cost and completion date, the standard deviations of the distributions are different. With no correlation it is £8.36 million, with a weak relationship £9.18 million, whilst with a strong relationship it is £10.87 million. With a strong correlation the chances of penalties for *both* late completion and higher cost are increased. With no correlation the chances are reduced, and there are also prospects of penalties for late completion being associated with bonuses for cost reduction.

The contractor's position is now examined. In the absence of a bonus/royalty scheme in the case when cost and completion date are weakly correlated there is a 68% chance that the *NPV* will be in the range £5.3 - £7.1 million, and a 95% chance that it will be in the range £4.4 – £8.0 million. The coefficient of variation is 15%.

When the incremental bonus/penalty scheme is introduced there is a 68% probability that the contractor's *NPV* will be between £1.5 million and £11.7 million, and a 95% probability that it will be between minus £3.5 million and plus £17.6 million. The coefficient of variation is 82% indicating a relatively very risky situation. It compares with 76% when the costs and completion dates are uncorrelated.

If the correlation between completion date and cost is strong there is a 68% chance that the *NPV* will be between £5.5 and £6.9 million and a 95% chance that it will be in the range £4.6 - £7.6 million. The coefficient of variation is 12%.

When the bonus/penalty scheme is introduced the resulting *NPV* is shown in Figure A3 in the Appendix. There is a 68% probability that the *NPV* will be between £0.5 million and £12.2 million, and a 95% probability that it will be between minus £5.3 million and plus £20.5 million. In terms of (percentage) margin rather than *NPV* there is a 68% probability that the margin will fall between 0.7 and 21.4%, and a 95% probability that it will fall between minus 6.9 and 41.8%. The coefficient of variation is 96%. The higher the correlation between cost and completion date the greater the chance that the contractor will experience a double bonus or penalty. He is now faced with both large upside potential and downside risk.

Conclusions

Partnerships and alliances among oil companies and their contractors were introduced in the UK in considerable part to encourage cost savings and speedier completion of work. Bonus/penalty schemes have formed an integral element of the agreements among the parties. In this study the requirements for an efficient bonus/penalty system have been determined.

The cost and completion risks of major oil field development projects were modelled and measured through the use of the Monte Carlo simulation technique. It was found that, with reimbursable contracts, typical bonus/penalty schemes, while introducing appropriate incentives, would substantially increase the overall risks borne by contractors. The cost risks of oil field investors were reduced by the bonus/penalty schemes. Project completion risks borne by contractors through the schemes could be particularly large, with large upside potential and downside risks. Cost and completion risks may be positively correlated and it was found that the risks on contractors increased directly with the degree of positive correlation.

The results of the study have wider implications. The acceptance of higher risks by contractors will raise their cost of capital. The logical reaction to this is to build in a higher expected return when bidding for projects. The extent to which a contractor's cost of capital increases will substantially depend on how well he is able to diversify his risks. A large company with many contracts whose risks depend largely on circumstances which are specific to each should not experience a noticeable increase in its cost of capital from the acceptance of one contract involving rather more risk than it has on average accepted to date. The diversification of its portfolio of contracts keeps down its overall risk. A small company with contracts in only a few projects is by definition not so well diversified, and it may experience a more noticeable increase in its cost of capital from the acceptance of a project involving higher risk than it had accepted to date.

A further implication of the study concerns the design of the optimal arrangements for sharing the risks of petroleum exploitation among oil companies and contractors. As a generalisation it may be stated that particular risks should be borne by those participants in the whole activity who are best able to bear these risks. This could mean, for example, that some risks are better borne by an integrated oil company because, if they were borne by a contractor, the increase in the latter's cost of capital might result in the total cost being higher.

Alliancing contracts incorporating risk: reward features of the type discussed in this paper are enthusiastically being promoted by many of the major oil companies. They also form key elements in the CRINE initiative (Cost Reduction Initiative for the New Era). This has the full support of the UK Department of Trade and Industry, particularly the Infrastructure and Energy Projects Directorate (commonly referred to as the OSO). Scottish Enterprise through its Energy Group also plays a significant role in promoting contracting companies in the oil and gas sector.

All these organisations have a direct or indirect interest in facilitating cost reductions. In the current environment of low oil prices with associated marginal fields the contracting sector can enlarge its volume of business through cost-reducing initiatives. Efficient contracts can play a worthwhile role here. Both those who are direct signatories to contracts and those who are involved in an advisory role need to consider the full effects of contracts on the risk position of oil companies and their suppliers. This requires analysis of the risk-bearing capacities of the different parties to the contracts. In turn this is necessary to ensure that the overall costs of the oil development and production activities are optimised over the longer term.

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Appendix

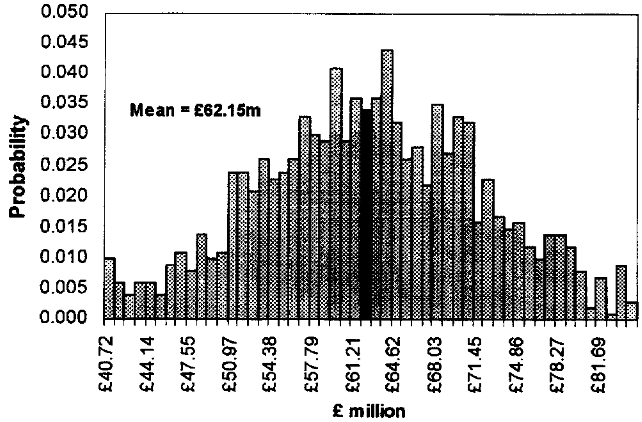

Fig. A1 Expected *PV* of contract @ 10% with uncertain costs and completion date (£m)

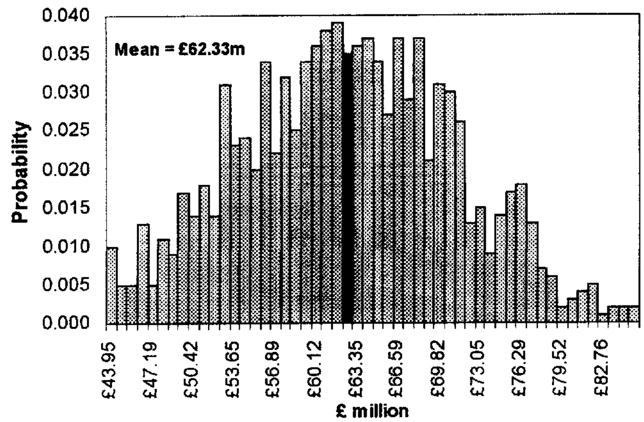

Fig. A2 Expected PV of total contract @ 10% with uncertain costs and completion date and bonus/penalty scheme (£m)

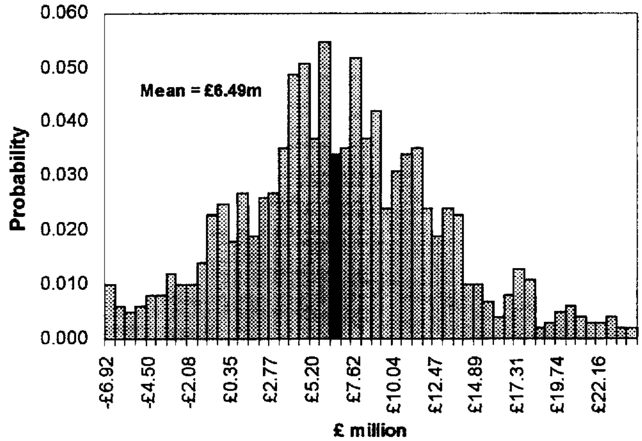

Fig. A3 Expected NPV of contractor @ 10% correlation 0.75 (£m)