The Benefits of Information Sharing
In Petroleum Exploration
An R&D Approach to the Study of the
United Kingdom Continental Shelf

Fernando Barrera-Rey

Oxford Institute for Energy Studies

EE22
1997
THE BENEFITS OF INFORMATION SHARING IN PETROLEUM EXPLORATION
An R&D Approach to the Study of the United Kingdom Continental Shelf

CONTENTS

Introduction .......................................................... 1
I. Petroleum Exploration as an R&D Process .................. 4
II. An Information-Based Model of Petroleum Exploration .......... 9
III. The Case Study of the UKCS ..................................... 14
    Sample .......................................................... 19
IV. Estimates .......................................................... 22
V. Conclusions ......................................................... 32
References .......................................................... 33
The Benefits of Information Sharing in Petroleum Exploration

An R&D Approach to the Study of the United Kingdom Continental Shelf

Introduction

This paper is an attempt to introduce information as an input in the production function of an exploration firm and apply this model to the study of the United Kingdom Continental Shelf (UKCS). This, almost trivial, observation to anyone acquainted with the workings of the exploration activity has been absent from economic-based models of exploration and it is our purpose to redress this balance by framing the analysis within the traditional R&D framework.

There exist various methods to model petroleum exploration. Geologists use simulation processes to model the probability of existence of the resource and the migration flows. Economists do not have the ability to ascertain where petroleum might be found but are more interested in the incentives the market provides to search for the resource. In the 1960s economists were more concerned with historical relations between economic variables, say the price of oil, and exploration effort; concerns summarized by Fisher's (1964) pioneering study of the USA. Although later criticized because of the absence of a specification of optimal firm behaviour, the model was however seminal in its influence on the exploration models of the 1970s.¹ With the advent of theoretical models of exhaustible resources based on intertemporal optimization coupled with uncertainty, economists believed they were

---

¹ Examples of the approach are the studies of Erickson and Spann (1971) and MacAvoy and Pindyck (1973).
on the right track in dealing with the poor performance of forecasts (Walls (1992)).

In spite of all the advantages of exhaustibility models, mainly their sound economic basis, they have been criticized for being very rigid and limited in their application because of methodological simplifications. More importantly, due to their complexity they have to simplify some important aspects of firm behaviour and by their nature they are also more suited to aggregate data analysis where firm differences and strategic behaviour can be assumed away. Parallel to this aggregate approach to exploration a more micro approach to exploration incentives has been running using analogies from industrial organization processes. Adelman (1970) made the link between petroleum exploration and Research and Development processes to back his alternative model (i.e. alternative to Hotelling’s exhaustibility model). The idea is that exploration produces not only discoveries, but also an intermediate input: information. The fact that information is by nature a public good also leads to strategic behaviour on the part of firms. This possibility was explored by researchers like Stiglitz (1975) and Peterson (1975), and more recently Hendricks and Kovenock (1989), and has recently found favour among researchers applying game theoretic tools to empirical industrial organization.

The results of the empirical applications of these models prove the claims of non-cooperative game theory. They show that as in a game of chicken companies may decide not to drill although it may be in all’s interest to do it. Apart from addressing the existence of externalities and hence the existence of market failure in exploration, all these studies have in common the choice of the case study. They are all studies of

---


3 There is a similar literature dealing with how the companies use and learn from their information. These studies are few but nonetheless important. See Mason (1985) for the case of uranium, and for oil see Eckbo, Jacoby and Smith (1978) and Smith (1980).

Information Sharing in Petroleum Exploration

the USA, and in particular the US offshore industry. The reasons are simple, not only was the USA the largest world producer until very recently, but mainly data quality and availability, both features of the American case, are instrumental to pursue this micro-based approach.

Extrapolating results from the American experience can lead to problems. The American upstream industry has some idiosyncratic features that could result in differences in the size and the way to deal with spillovers compared to other countries. In particular, other countries have witnessed the experience the Americans have had with petroleum exploration and have presumably learned from the errors of their policies. The experience of other countries is in fact, one where state intervention has been greater and allegedly aimed at dealing with the failures of the market. The case analysed in this paper, that of the UKCS, certainly fits these assertions. The development of the UKCS started in the 1960s a long time after the worst excesses in oil exploration in the USA had occurred. State intervention, aimed deliberately at dealing with competitive drilling, has been widespread especially in the allocation of licences where there is a very large discretionary component.

In contrast to most studies that use the American case as its case study we are not primarily concerned with the existence of market failure. The study serves both a methodological and an empirical function. The methodological function is wider than natural resource economics whereas the empirical function has natural resource economics as its domain. We argue, like Adelman, that not only should the exploration for natural resources be studied as an R&D process where information is a key input, but the petroleum industry is an industry where the returns to R&D and its associated spillovers can be quantified. This contrasts with the study of other manufacturing industries where the estimation of these returns has always been a disappointing area of applied industrial organization (Griliches (1992)). Also, we show that the UK case has radically different effects on the allocation of resources than the American where most knowledge has been extrapolated from.
I. Petroleum Exploration as an R&D Process

The similarity between the process of research and development in manufacturing industries and the exploration of hydrocarbons was made by Morry Adelman as early as 1970:

But the search for new deposits is only a special case of the search for greater knowledge, including better productive methods. The French have a feeling for words, and when they use *recherche* to mean both research and exploration, they are conveying a truth we cannot afford to overlook. Greater knowledge of the earth's crust and greater knowledge of the science and technology of extraction are only two exercises of the human spirit, two alternatives for investment. (Adelman (1970) p. 68, italics in the original).

Adelman used the idea to develop his theory that the search is not made for disappearing minerals but for cheaper minerals.

The exploration of hydrocarbons takes two forms, one is the analysis of geological data gathered by either the companies themselves or, in many cases, by the government agency of the country involved. The second is the actual drilling of a well where physical evidence is gathered and analysed according to the technology available. Although there have been a very large number of technical improvements to the processing and interpretation of the first type of data, the only certain way to know the existence and the extent of the resource base is actually to drill.5

While the acquisition of knowledge is not a linear process most research and development programmes take similar routes towards innovation. This synergy is highly pronounced for exploration companies. As a result of similar technical capabilities, information is the most valuable input in the exploration function of a company. Moreover, in a given geographical area information for competing companies is highly correlated. Given the fact that the size of licence blocks available

---

5 Among the most important developments the introduction of 3D and 4D (3D seismic over time) seismic have decreased dramatically the probabilities of drilling dry holes. While the chance of success is very large its cost is still high (see *Oil and Gas Journal* "3D, CAEX help independent ..." 18 January 1993).
is usually smaller than the average field (and certainly smaller than a promising geological formation), the worth of information about a given prospect can be very similar for two neighbouring companies. The right conditions for the occurrence and existence of hydrocarbons extend over large areas that however constitute a small, and concentrated, fraction of the earth's crust. Without failing to give prominence to the extension of the three mile limit by the Geneva Convention on the Continental Shelf, the exploration of hydrocarbons in the North Sea only received a push after the discovery of the Groningen gas field (1959) in the Netherlands and the realization that the field and similar geological structures extended seawards. This was corroborated by the first gas discovery (West Sole in 1965) and the discovery of the first oilfield in the Northern North Sea (Ekofisk in 1969).

Since the work of Peterson (1975) it has become well known that there exist two externalities associated with petroleum exploration. The first externality is linked to the finiteness of the resource and the second to the public nature of geological information. The 'common-property-resource' external diseconomy comes from the fact that there are only a finite number of oil and gas fields. When one company makes a discovery it has removed one field from the stock of fields and as a result the work of other exploration companies has been made more difficult. The company takes into account only the cost of making its discovery and not the increase in cost this will represent for other companies searching in the area.

The second externality is of the public good type as the finder of a field, or a propitious geological formation, has seldom been allocated an area as large as the field, or more unlikely an area as large as the formation. Even in cases where the field

---

6 According to Brannon (1974) one third of oilfields in the USA cover 162 km² but typical licence blocks average about 37 km² (20-24 km² in federal lands). Although the UKCS licence blocks vary in size from 209-266 km² (see footnote 17), at least 50 per cent of all fields lie under more than one block.

7 As evidence of concentration of fields in the UKCS we have estimated that the 203 productive fields (405 discoveries as classified by the UK Department of Trade and Industry) are concentrated in 183 blocks (283 blocks) out of the 1,500 licenced blocks since 1964.
is smaller than the block there are many instances when a field straddles more than one block. Furthermore, information does not have to take the form of discoveries but even in cases where the well is unsuccessful (dry-hole) or the formation unlikely to contain hydrocarbons the neighbours benefit from this knowledge at no extra cost.

The public good character of drilling information was noted by the pioneers of petroleum exploration in the USA. The payment of scouts that would survey ongoing drilling work and exchange information informally with competitors is usually cited as a Coase type of arrangement to deal with small number externalities. More formal arrangements to cooperate are widespread and range from the payment of dry-hole money (where neighbouring firms share the expenses of the drilling company if the well turns out to be dry, see Isaac (1987)) to coordinated exploration activities.

The direct equivalent of a patent in the case of petroleum exploration is the unitization of the field. While unitization has been deemed to be a problem in American state lands in the past, unitization of fields in federal lands, as is also the case in the UKCS, has proved to be less difficult. To equate unitization with a patent is however, not wholly appropriate as not all the proceeds from the field go to the searching party. A fraction usually proportional to the size of the resource underlying the free rider’s block go to the passive party. While the institution of unitization has reduced the worst excesses of the oil industry in the USA by providing a patent-like cover, information in petroleum exploration does not only take the form of a petroleum discovery. Useful information takes the form of dry holes, petroleum shows, geological prospects, and so on. There is currently, no widespread arrangement geared at dealing with free-riding on the back of these sources of information. The

---

8 See the account of some of the antics pursued by oil scouts in Tait (1946) and the checker boarding approach devised by James O’ Neil to explore large unknown areas together with the location theories of a Mr Angell in Williamson and Daum (1959) as cited by Isaac (1987). Both theories rely on the creation of public information by private agents.

9 Unitization is an agreement by the owners of a single field which extends into more than one licence area to develop it as a unit.
failure of full-cover as provided by a patent, exacerbates the traditional disincentives created by the spillovers of R&D.

It is a source of frustration in empirical analysis that the attention given to R&D spillovers in manufacturing is only matched by the methodological problems in estimating them. There are however, some characteristics about petroleum exploration that contribute some new elements to this issue.

There exist four main difficulties in the empirical analysis of the returns to R&D in manufacturing and they all are mainly measurement problems. First, the measurement of the output of R&D is contentious unless the analysis is one of a particular innovation. Case studies of particular innovations are unusually expensive and may suffer from selectivity bias as they tend to be cases of successful innovations. Although patents are the obvious proxy for R&D output there is an enormous dispersion in their economic value and as a result aggregation problems become relevant. Another alternative, taken by economists, is to use an indirect approach and look at the ultimate impact of R&D, namely its impact on productivity growth (see Griliches (1995)). The empirical study of petroleum exploration as a case of R&D has the virtue that the final output of exploration (R&D) is incontrovertible. It is represented by either discovered fields or, more appropriately, a barrel of discovered reserves. The former is easily measured with hindsight while the latter can be altered over the course of field appraisal and production. The intermediate output of R&D investment (i.e. information) incorporated as additions to the stock of knowledge is even more difficult to quantify. In petroleum exploration however, there also exist obvious proxy measures of this effort and it could simply be represented by metres drilled or even number of wells; both measures suffering from aggregation problems but having the virtue of being easily defined.\footnote{One of the advantages of being able to measure the output of R&D is the fact that the quantification of the firm's borrowing (see below) can be made in terms of both input (expenditures) and output (result of the drilling effort).}
Information Sharing in Petroleum Exploration

The construction of the stock of knowledge is difficult as is in general the aggregation of intermediate R&D output to the stocks of knowledge. The first problem associated with the construction of this stock is the choice of its appropriate rate of depreciation/appreciation. While in manufacturing it is believed that all knowledge becomes obsolete within ten years, in petroleum exploration the stock of knowledge is as likely to depreciate as it is to appreciate. On the one hand, as the undiscovered field remains in the same place for the foreseeable future, old data may actually become more valuable with time as the processing ability may improve. On the other hand, data collected with old methods can prove to be erroneous or at least collected inappropriately and can thus be worthless.

The third set of problems in the analysis of the returns to R&D in manufacturing is the appropriate investment lag of R&D. In other words, how long does it take for R&D investment to affect output? In the case of petroleum, the investment lag is almost technically defined: currently, it takes an average of about three months to drill a well in the US offshore (similarly in the UKCS) and the development of a field worldwide takes an average of three to four years.

An area of special difficulty is the measurement of knowledge that can be borrowed. Borrowing is not only limited to R&D expenditures incurred by other firms, but in the case of manufacturing industries a given company can borrow from other industries. In applied research two simplifications concerning borrowing have been made. One is the assumption that all firms in a given industry (as defined say, by the ISIC) are equidistant in technological space. The second is that firms borrow from other industries according to their inter-industry purchases and this can be calculated by using for example, the input-output tables. While the second simplification would have to be made in the case of petroleum exploration (as knowledge is a wider concept than information generated by exploration); the assumption of firm equidistance in technological space is not necessary. Petroleum firms can be differentiated instead by the location of their respective drilling and the
borrowing could be weighed by the actual distance between competitors' location.

As Adelman, we are saying that the exploration effort of a company has to be understood as an input in the production function of the firm. This input has all the characteristics of a stock rather than a flow and its contribution is not circumscribed to the firm undertaking it, but on the contrary, it yields returns to neighbouring firms. This has consequences for the empirical study of petroleum exploration as it incorporates strategic behaviour, but also for the wider issue of quantifying the returns to R&D. While the analysis is still incomplete as it does not deal with R&D proper, the returns of a process analogous, and even alternative, to R&D can be estimated in an unequivocal manner.

II. An Information-Based Model of Petroleum Exploration

The first aspect to be considered in order to accomplish our task of quantifying the returns to R&D (in our case exploration) is a measure of performance at the well level. As mentioned in the previous section the obvious measure is the addition of a barrel of oil, a cubic feet of gas, a barrel of condensate or an oil equivalent measure of reserves\(^\text{11}\). Ideally, the data should refer to hydrocarbons in place as the more common measure of proved reserves is directly influenced by the development of technology. Unfortunately, the data on total reserves is not available (the UK Department of Trade and Industry (DTI) publishes a total figure for the North Sea) at the well level. The only similar figure is data on proven reserves but it is only available for fields, or a combination of fields, that are already in operation.\(^\text{12}\) Under

---

\(^{11}\) With the data available we have no way of ascertaining whether the aim of the exploration company is the discovery of oil, gas or condensate, which is why the analysis undertaken here refers to petroleum in general.

\(^{12}\) According to the DTI there are 407 discoveries but the data on proven reserves refers to 209 fields or combination of fields. The impossibility of disaggregating the reserves discovered by a given well forced us to use a measure of commercial discovery as the measure of performance.
those circumstances, we have opted for the use of commercial discoveries as the measure of performance in a model explaining the probability of making a commercial discovery.

In order to give geology a prominent, and deserved, role in our model of exploration the level of aggregation is kept as low as possible, namely at the well level. While the model presented below contains variables affected by time and location it is mainly well-specific. The dependent variable takes the following values:

\[
F_w = \begin{cases} 
1 & \text{if the outcome of the well is a commercial discovery} \\
0 & \text{otherwise}, 
\end{cases}
\]

where \( F \) is the probability of making a commercial discovery and \( w \) refers to the well. The model aims to explain this probability as the outcome of three different sets of variables:

\[
F_w = f \left( G_w, E_t, Y_{wt} \right),
\]

where \( G_w \) represents geology (which is well-specific), \( E_t \) economic incentives (which is time-specific or equal for all wells at time \( t \)) and \( Y_{wi} \) is the information company \( i \) has for well \( w \) at the beginning of time \( t \) (which is well, company and time-specific), our variable of interest.

Geology as a variable is critical to the proper explanation of this probability and in our analysis it is proxied by location (according to geological zones explained below), drilling depth, water depth and drilling time. The three geological variables all have to be used as variables to control for different geological characteristics but there is no \textit{a priori} expectation as to the sign of their coefficients. While the three continuous variables are measures of cost and affect the decision to declare a find as commercially viable, they can also represent geological characteristics that make the discovery of hydrocarbons more likely. This is the case for water depth but it is not
fully appropriate for the case of either drilling depth or drilling time. These two variables are not fixed but depend on what the exploration company decides. Drilling depth for example, may refer to the depth where the resource is to be found but only in case of a discovery. In the case of a dry hole the company may decide to stop early since the likely size of the resource does not justify additional drilling. This argument can also apply to drilling time, a company may decide to spend more time drilling as the prospects are more encouraging. In these two cases, the causality seems to be running from left to right (i.e. the dependent variable affecting the "independent" variables) which is a problem of endogeneity. The violation of the assumption of exogeneity can be easily checked in this case by the sign of the parameter of time and drilling depth. Where negative we can expect them to be a measure of cost and where positive we can expect to have a problem of endogeneity. The solution to the problem of endogeneity can be addressed by using appropriate instruments but unfortunately in this setting very few appropriate ones come to mind.

The water depth (in metres), on the other hand, can be interpreted as a measure of cost. If the appropriate technology is available (semi-submersible drilling allowed the development of the Northern North Sea which has higher water depths than the first developed Southern North Sea), higher water depths could represent lower cost as there is no drilling to be undertaken before the sea-bed is reached. This is to be balanced against the effect of more expensive drilling equipment (in the early stages of the introduction of semi-submersible drilling) necessary to drill in those areas once regarded as impossible to explore.

Economic incentives in this analysis usually take the form of market incentives provided by the price of crude oil. As usual what is important is not the current price of oil but the expectations made by the agents concerning this price. Following Pesaran (1990), we use two alternative expectations assumptions: adaptive expectations and rational expectations. The adaptive expectations equation is constructed recursively in the usual form:
Information Sharing in Petroleum Exploration

\[ p_t^* = \theta p_{t-1}^* + (1-\theta)p_{t-1}, \]  

(2)

where \( p \) is the price of crude oil from \( t=\) January 1964 to December 1995, from the initial value of \( p_{\text{Jan64}} = p_{\text{Jan64}} \). This method ensures that the price expectation series is not sensitive to the choice of the initial value (Pesaran (1990)). The rational expectations price series is constructed as a linear function using lagged values of the dependent variable as explanatory variables:

\[ p_t = \lambda(L)p_{t-1} + e_t, \]  

(3)

where \( \lambda(L) \) is the appropriate polynomial of the lag operator and \( e \) the error term. The a priori sign of the expected price of crude oil parameter is negative as once the price is expected to be high it is worthwhile to undertake riskier exploratory searches where the probability of success is small (Fisher (1964)).

The final set of variables are the variables of interest for this study and can be grouped into two sets: incumbent’s (the firm being considered) and competitors’ information:

\[ Y_{jm}^f = Y_{jm}^f + \sum_{j=1}^{W} \omega_{ij} Y_{jm}^i, \]  

(4)

and information has to be understood as a stock at the beginning of month \( t \) (i.e. before the well is drilled). The stock of information is the simple sum of information in each period \( t \) according to a weighting function:

\[ Y_{jm}^f = \sum_{j=1}^{W} \omega_{ij} Y_{jm}^i \]  

(5)

where a company uses not only its own information but also information from its competitors’ \( j \) according to the “distance” between \( i \) and \( j \). As said in the previous section the distance in petroleum exploration can be defined in terms of actual spatial distance. The coefficient on the competing firms’ information parameter depends on
the relative importance of the two externalities and on the type of information that could be borrowed. In the case of the information being finds, we would expect the coefficient on incumbent’s information to be positive if learning is important and negative if the resource-finiteness diseconomy is binding. Similarly, in the case of competitors’ information the sign is positive if there is free riding and negative if common-resource diseconomy persists. The model does not enable us to separate the effect of both externalities but will show us which predominates. The final model is:

\[ F_w = \alpha + \beta_1 DD_w + \beta_2 DT_w + \beta_3 WD_w + \gamma'_p + \delta'_1 I'_w + \delta'_2 C'_1 + \epsilon_w \]  

(6)

where \( DD \) is depth drilled, \( DT \) is drilling time, \( WD \) is water depth, \( II \) is incumbent’s information, and \( CI \) is competitors’ information. The variables \( II \) and \( CI \) are represented by a set of results obtained from exploration (\( f \): discoveries, \( d \): dry holes, \( s \): petroleum shows and \( a \) the sum of exploratory and appraisal wells):

\[ \delta'(Z) I'_{w(z)} = \delta'_1 f_w + \delta'_2 d_w + \delta'_3 a_w + \delta'_4 s_w \quad Z = I, C, \quad z = i, j \]  

(7)

where we expect a differential impact from these results on the probability of success.

There is no presumption as to the depreciation pattern of the stock of knowledge; there are as many valid reasons to expect its depreciation as there are to expect its appreciation. We assume therefore that no rate of obsolescence applies to the stock of knowledge. Given that the aim of our model is to show how much own and foreign knowledge could explain success in exploration, we make no assumptions as to the time lag of investment either. We assume that information exists at the time drilling starts, but we do not infer how much is borrowed or how much is used. Nevertheless the sign of the coefficients can provide an indication of

---

13 Since the analysis is carried out ex-post we make no inferences about the amount of information actually borrowed.
Information Sharing in Petroleum Exploration

whether information has been borrowed or not.\textsuperscript{14}

This section started with an apology for the absence of data on hydrocarbons in place at the well level but now that the model has been presented we can explain why the unavailability of that variable is not all bad news. Even though the natural measure of performance in exploration is the discovery of a barrel of reserves there is a problem in using that variable with the methodology developed in this section. The exploration sequence in all provinces produces a pattern of discoveries that has been fairly well established. Initially a small number of very large fields is found, as it is obviously easier and more desirable to hit a large target, but with greater levels of exploration the average size of the discovery tends to fall. The use of discovered reserves as the dependent variable and previous discovered reserves as the information variable would have resulted in a negative coefficient especially if no cross-section and no firm-level information is available (i.e. the model is an aggregate of the whole province). This is not an information-related result but mainly the fact that even under random exploration larger fields are more likely to be found. The success ratio on the other hand, does not have an established behaviour over time in spite of the fact that the average size of field decreases. In that sense the probability of discovery is a more appropriate measure of performance using the methodology described above.\textsuperscript{15}

III. The Case Study of the UKCS

Only heavily explored areas are amenable to be analysed using the information-based

\textsuperscript{14} Denote the number of places where a well can be drilled by N and the probability of making a find $\pi = F/N$ where F is the total number of fields. A new find reduces the probability, without information, to $\pi = (F-1/N-1) < F/N$. As fields tend to concentrate, the probability of finding a new field is higher in some places than in others. A find increases the probability of success in areas adjacent to it and if observed would dictate drilling to take place in these areas where the probability is higher than before the find.

\textsuperscript{15} It is also worth noting that the model is defined at the well level where cross-sectional variation is also present and exploited in the estimations below.
Information Sharing in Petroleum Exploration

approach to exploration as it is essentially econometric. A large amount of data is needed to quantify the returns to petroleum exploration and its spillovers in an unbiased manner. This should avoid problems of selectivity bias by ensuring a large number of not only successful but also failed attempts to discover petroleum are included. Although the availability and sheer size of American data have enabled very important contributions to this debate, this case study has some peculiar features that make the extension of this experience to other countries a biased affair.

The uniqueness of the American upstream industry is evident in many areas. In state lands we find the only example in the world of private ownership of the subsoil being conferred by land ownership. Although in federal lands, like the offshore and Alaska, the resource is owned by the federal government, other idiosyncrasies exist. There is a very large number of drilling companies with proven track record taking part in the auctions. The auction process itself is also unique and although it has been tried out in other places, even in the UKCS in the 4th and 9th licencing rounds, no other country comes close to the USA when it comes to experience with auctions or a market-based allocation approach. Similarly, many provinces that have come to maturity after the USA have learned from the existence of market failure in the exploration process and have presumably adapted their policies to cope with it.  

The UK government started promoting exploration for hydrocarbons as early as 1917. The initial aim was to prevent wasteful competitive drilling for the substantial onshore resources it assumed existed. In 1934, after very disappointing results and now worried about any drilling at all, the government vested all onshore petroleum resources in its own hands. This enabled it to use the petroleum licence as a way to transfer the resource from the government to the licensee and not from the

---

16 The worst excesses had to do with the use of the rule of capture in the settlement of litigations between landowners with competing claims for the resource. The rule of capture was originally developed to settle disputes over the decoying of wild game whereby game could not be shot over one's fence but could nevertheless be lured and shot in one's property. Applied to oil (which migrates but also has an optimum reservoir pressure) this led to wasteful extraction of the resource as a producer would attempt to extract as much of the resource as possible. This is known as competitive drilling (see Griffin and Steele (1980)).
Information Sharing in Petroleum Exploration

surface proprietor to the licensee as in American private lands (see Daintith (1981)).
The Continental Shelf Act of 1964, endorsed by the Geneva convention on the
Continental Shelf, extended these rights to the continental shelf. The government
soon reached agreement with Norway, Denmark, West Germany and Holland on the
drawing up of median lines and the shelf now covers more than 900,000 km².
Progress has been rapid since 1964. Following the Groningen gas discovery in
Holland in 1959 gas was found in the West Sole and Leman fields in 1965. With the
discovery of Ekofisk in Norwegian waters in 1969 and two large oilfields (Forties in
1970 and Brent in 1971) the scene was set for intensive exploration in an area that
even in the late 1960s was not regarded as promising and where discoveries are still
being made (Tern in October 1995).

There have been sixteen normal licence rounds (and two auction rounds) since
1964 and a total of more than 2 thousand blocks, or 1.5 million km². Companies
have to relinquish a certain percentage, about 50 per cent, of the area awarded after
about six years and that is the reason the block-area awarded exceeds the shelf area.
The continental shelf is made up of quadrants of 1° of latitude by 1° of longitude and
the quadrant is in turn divided into 30 licence blocks in a 5x6 grid. The average size
of block has declined over time, from 230 km² in 1964 to 140 km² in 1995, as blocks
are partitioned as part of their relinquishment requirements (see Figure 1). The award
of a licence depends mainly on the track record of the company (usually companies
as very few apply on sole ventures), on the size and expertise of the applicant and, in
the 1970s, on its nationality sometimes at the expense of expertise.

Due to the curvature of the earth block sizes depend on the latitude of their location. The
dimensions and areas of the original blocks are: Northern North Sea & Atlantic Margin (11 km x 19
km=209 km²); Central North Sea (12 km x 19 km=228 km²); Southern Basin/Irish Sea (13 km x 19
km=247 km²); English Channel (14 km x 19 km=266 km²).

In the early rounds American companies complained that the best blocks were awarded to
local companies. The government has always made clear that it aims to favour British companies but
in the early rounds it had to persuade the American majors to take part in the process (Dam (1976)).
In the 1970s with high oil prices and a bias towards local capital it was not difficult to persuade non-oil
companies to contribute capital towards exploration.
Information Sharing in Petroleum Exploration

Map of Quadrant 21 and part of Quadrant 22 Northern North Sea

Prospective Field  Operating Field  R: Relinquished Block  Oil pipeline  Gas pipeline


Figure 1
These considerations are part of the guidelines but how the government decides on similar competing applications is part of a black-box process undertaken at the Department of Trade and Industry. The DTI also has to approve the appointment of the operator of the licence which is agreed in a private bargaining process among the members of the consortium.\textsuperscript{19}

While the Americans have adopted as a measure to extract the oil rent a system based on auctions, the UK authorities have relied on a combination of tax-based measures to accomplish it. However, the market-based allocation system is not absent from the licencing system but rather undertaken in a different way. Dam (1976) refers to it as competitive bidding in work programmes as one of the criteria for allocation has always been to encourage the most rapid and thorough exploration. The criterion has been instrumental in deciding between competing applications and no trading of licences can be carried out before the programme is completed.

Competitive drilling is less of a problem in the UK; having benefited from the American experience the UK authorities (as the Norwegian) adopted legislation requiring field unitization \textit{ab initio}. The enforcement of the unitization rules are also guaranteed by the fact that the development plan of a field has to be approved by the DTI (known as the Annex B approval). As part of its commitment to maximize the recovery of oil, the DTI would presumably have to be satisfied that in the case a field extends to other licence blocks the developer has agreed terms with the other owners of those blocks. The threat of not granting Annex B approval is presumed to be enough of an incentive to the incumbents to start negotiations as early as possible but more importantly, to ensure no disagreement exists (English (1996)). The existence of this type of unitization agreements ensures that the discovery of a field that extends to other blocks is notified immediately to the neighbouring companies.

The use of unitization is not the only type of agreement to deal with market

\textsuperscript{19} The operator is the company whose job is to co-ordinate a programme of exploration and development on behalf of its co-licensees.
failure in exploration but there exist a multitude of agreements accepted by the government. These agreements in which a share in the block is exchanged by a service include exchange of seismic information, actual drilling, but the feature common to all of them is that they can only be undertaken once the work obligations accepted by the licensee are completed.

Sample
The data used in this study conform to the requirements on detail and precision demanded by the information-based approach and consist of three main databases. The first database comes from Wood Mackenzie (WM) (Wood Mackenzie North Sea Service) and consists of information on all the wells drilled in the UKCS. The information presented includes drilling results, name of the operator, depth drilled, water depth and location. The second database is the published result of the licence rounds (rounds 1(1964)-16(1995)) as published in the Edinburgh Gazette and with which a history of each specific block can be constructed. Finally, the third database is the DTI list of commercial discoveries published in DTI Energy Report (also known as the brown book).

The database used for the estimation of the model above does not fit into the usual time series, cross-section division. The information on exploratory drilling is reported as it happens and no grouping is attempted. WM reports on the results of exploratory drilling according to their industry sources, but will describe a well as a tight hole in case the outcome of the well is unknown. Those wells described by WM as tight holes are not included and as a result the database has very few wells for the year 1995. The result of specific drilling is not normally published although the companies have to report these results to the DTI which in turn makes it publicly available with a five-year lag.

\[20\] Called farmout agreements they are discussed by David (1996).
Information Sharing in Petroleum Exploration

The most controversial aspect of the construction of the sample used for estimations is the choice of economic unit. Ideally, this unit should be the one that generates and uses the information as an economic agent for its own sake. This agent should decide on its actions based on its own information, competitors’ information and its portfolio of licence blocks. One solution is to regard the consortia that bid for licences as the unit of analysis. The problem with this approach is that the ownership structure of the consortium changes very often and more importantly, a specific company can have very different shares in a large number of consortia. As a result of this objection we decided to regard the operator as the unit of analysis. The operator is supposed to maximize the profits of the consortium as a whole but its direct access to the drilling results, to the information of its co-licensees, and in general its hands-on involvement give it a privileged access to knowledge.21 While many objections can be raised to the use of the operator as the economic unit it can be said in its defence that it is the only practical way to deal with the analysis undertaken here given the preponderance of joint ventures.22

Discoveries as defined by the DTI are fields that can support development and production independently of others. Once a company has made a find later “discoveries” of the field in adjacent blocks are not regarded as successful exploratory wells. Thus, one of the most common occurrences of free-riding on the back of rivals’ information, striking a resource already found, is not present in our sample as the finds identified by the DTI can be regarded as true finds.23 The sample identifies 405 discoveries of which 198 have been producing at some point in the years 1964-95.

21 Anecdotal evidence suggests that there is a complex bargaining process in the appointment of the operator.

22 80 per cent of all the licence bids are in joint ventures and the trend since 1964 until 1995 has been upward (in 1964 36 per cent of the bids were in sole venture compared to 7 per cent in 1995).

23 The use of probability of discovery as a measure of performance does not incorporate all the spillovers from exploration in this context. A company having claim to a reservoir underlying its licence block can benefit from a competitor’s discovery, to a rate proportional to the size of the field in its block, thanks to unitization.
The sample consists of exploratory (wildcat) wells as defined by WM since the economic rationale of the model above does not apply to appraisal and development drilling. Although the model aims to explain exploratory drilling in the estimations below we also enable the drilling company to have appraisal drilling as part of its stock of knowledge (see above). There are a total of 1,950 exploratory wells in our database and a total of 86 operators.

The geological characteristics of the North Sea can be best described in terms of plays. The main plays are the Southern North Sea gas play (where the first large gas discoveries were made), the Jurassic Brent sand play (located in the Central North Sea where the first large oil discoveries were made), the Upper Jurassic sand play (Northern North Sea) and the Upper Cretaceous-Lower Tertiary chalk play (located in the UK and Norwegian southern border and in Danish waters). The plays broadly coincide with geographical zones and we have divided the North Sea in five broad regions. The Northern North Sea (NNS), the Southern North Sea (SNS), the Central North Sea (CNS), the Irish Sea and Bristol Channel (IS), and finally West of Shetlands and the Rockall trough (RKWS). These areas are represented by the inclusion of dummies in equation (7) above.

Knowledge stocks from R&D investment were constructed by the simple addition of the relevant type of results. The weighting functions could have been calculated as the actual distance in kilometres (WM reports the location of each well) but we settled for a less demanding approach. It is assumed that the only drilling relevant for operator \( i \) in block \( X \) is that carried out in its own block \( X \), in blocks adjacent to it \( (X-1) \) and in those adjacent to these \( (X-2) \). In Figure 1 above for example, take the case of quadrant 21 and block 19. We have assumed that only information from (where quadrant:block) 21:19 \( (X) \), 21:13-21:18 \( (X-1) \), and 21:7-10,

---

24 A play is defined as a group of fields or prospects in the same region that are controlled by the same set of geological circumstances (see Stoneley (1995) for a non-technical description of North Sea geology).
Information Sharing in Petroleum Exploration


IV. Estimates

The samples used for different model specifications vary in size according to the values that are missing. Table 1 presents the means of the variables used in the model according to the geological zones discussed above.

<table>
<thead>
<tr>
<th></th>
<th>CNS</th>
<th>NNS</th>
<th>RKWS</th>
<th>SNS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth Drilled (DD_J)</td>
<td>3653</td>
<td>3387</td>
<td>2215</td>
<td>2996</td>
</tr>
<tr>
<td>Drilling Time (DT_J)</td>
<td>85.9218</td>
<td>69.4358</td>
<td>62.1500</td>
<td>69.5646</td>
</tr>
<tr>
<td>Water Depth (WD_J)</td>
<td>90.1023</td>
<td>128.0192</td>
<td>136.5941</td>
<td>37.4477</td>
</tr>
<tr>
<td>Crude Price (p)</td>
<td>30.1209</td>
<td>30.0059</td>
<td>29.2619</td>
<td>21.7981</td>
</tr>
<tr>
<td>Incumbent’s Finds (f_J)</td>
<td>0.3178</td>
<td>0.3932</td>
<td>0.1016</td>
<td>0.3024</td>
</tr>
<tr>
<td>Competitors’ Finds (f_J)</td>
<td>1.0903</td>
<td>1.0048</td>
<td>0.1563</td>
<td>1.0094</td>
</tr>
<tr>
<td>Incumbent’s Shows (s_J)</td>
<td>0.2008</td>
<td>0.2567</td>
<td>0.0434</td>
<td>0.1252</td>
</tr>
<tr>
<td>Competitors’ Shows (s_J)</td>
<td>0.3216</td>
<td>0.8317</td>
<td>0.0559</td>
<td>0.3501</td>
</tr>
<tr>
<td>Incumbent’s Wells (a_J)</td>
<td>1.2960</td>
<td>1.9115</td>
<td>0.5310</td>
<td>0.9812</td>
</tr>
<tr>
<td>Competitors’ Wells (a_J)</td>
<td>9.4248</td>
<td>14.7598</td>
<td>2.7492</td>
<td>9.7338</td>
</tr>
<tr>
<td>Inc. Dry-Holes (d_J)</td>
<td>0.6128</td>
<td>0.8323</td>
<td>0.2238</td>
<td>0.3609</td>
</tr>
<tr>
<td>Comp. Dry-Holes (d_J)</td>
<td>5.3197</td>
<td>7.3508</td>
<td>1.6254</td>
<td>3.8354</td>
</tr>
</tbody>
</table>

F_2 = 0  
251 832 167 311

F_2 = 1  
84 165 20 115

Source: See text.

The probability of making a discovery tends to be higher in the CNS and SNS with the RKWS a distant fourth, which are also the places where most drilling has been carried out. The parameter \( \theta \) for the construction of the adaptive expectations
series (see equation (2) above) was estimated using a grid search and produced a value of 0.975. The optimum lag of the rational expectations model is only 1 and predicted values of this estimation were used to build the rational expectations price series.

Model (6) was estimated using maximum likelihood methods for samples of different sizes assuming the distribution of the error $\varepsilon_w$ is normal. The first set of models to be presented here will try to ascertain the role of the technical variables and price expectations to be able to concentrate on the role of information in the second set of models. Thus, information is aggregated into the weighted sum of both exploratory and appraisal wells (variables $a_i$ and $a_j$ in equation (6)). Four different models are estimated to sort out the role of the technical variables and these four models are estimated under the assumption of rational and adaptive expectations. Model (1) uses the largest amount of observations and proxies technical characteristics by the use of three sets of dummies for the regions NNS, SNS and CNS (the parameters measure deviations from the RKWS). Model (2) introduces the set of continuous geological variables instead of the zone dummies. Model (3) is model (1) using the sample of wells that report data on the continuous geological variables (to compare the role of geology using the same sample), while model (4) is model (3) including the continuous technical variables. Table 2 presents the estimates.

The performance of the adaptive expectations variable is consistent in the four models with Fisher's (1964) assertion. The probability of discovery should fall with higher crude oil prices as riskier projects become more rewarding. This is true of the rational expectations assumption but the parameter loses its significance in three of the four models. This leads us to the same conclusion as Pesaran's (1990) that as the models available to forecast oil prices have been so consistently wide off the mark agents can be expected to use a less demanding system of price expectations.
### Table 2: Estimates Using Alternative Price Expectations and Geology Proxies

<table>
<thead>
<tr>
<th>Variable</th>
<th>Adaptive Expect.</th>
<th>Rational Expect.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>(a)</td>
<td>-1.023*</td>
<td>-0.473*</td>
</tr>
<tr>
<td></td>
<td>(-6.673)</td>
<td>(-2.554)</td>
</tr>
<tr>
<td>(a_t)</td>
<td>0.066*</td>
<td>0.035*</td>
</tr>
<tr>
<td></td>
<td>(5.112)</td>
<td>(2.054)</td>
</tr>
<tr>
<td>(\text{DD}_w)</td>
<td>5.3E-5</td>
<td>4.9E-5</td>
</tr>
<tr>
<td>(\text{DT}_w)</td>
<td>0.006*</td>
<td>0.006*</td>
</tr>
<tr>
<td>(\text{WD}_w)</td>
<td>-0.003*</td>
<td>-0.002</td>
</tr>
<tr>
<td>Price Exp.</td>
<td>-0.010*</td>
<td>-0.013*</td>
</tr>
<tr>
<td></td>
<td>(-3.623)</td>
<td>(-3.321)</td>
</tr>
<tr>
<td>(\text{NNS}_w)</td>
<td>0.303*</td>
<td>0.081</td>
</tr>
<tr>
<td></td>
<td>(0.047)</td>
<td>(-0.164)</td>
</tr>
<tr>
<td>(\text{SNS}_w)</td>
<td>0.622*</td>
<td>0.360</td>
</tr>
<tr>
<td></td>
<td>0.140</td>
<td>(0.472)</td>
</tr>
<tr>
<td>(\text{CNS}_w)</td>
<td>0.660*</td>
<td>0.442</td>
</tr>
<tr>
<td></td>
<td>0.199</td>
<td>(0.680)</td>
</tr>
</tbody>
</table>

Notes: t-ratios in brackets. *: Different from zero at 5 per cent level of significance.

Source: Own estimates from the sources referred to in the text.

The information variables are significant in all models using either type of expectations formations. The positive sign in the incumbent's information parameters reveal learning by doing and the negative signs on the competitors' information parameters is sign of the finiteness of the number of fields. The region dummies in both models (1) show that drilling in the Northern North Sea, SNS and the CNS all have higher probabilities of success than wildcat drilling in the RKWS. The inclusion
of the regional dummies is significant: the likelihood ratio tests equal to $\chi^2(3)=34.5$ and $\chi^2(3)=30.8$ for the adaptive and rational expectations cases respectively both of which are different from zero at 5 per cent. Of the continuous geological variables only the total depth of drilling is not significant in any of the models and, unexpectedly, the water depth seems to contribute negatively to the probability of success. This can be explained by the fact that the probability of discovery is lower in the regions where the sea-bed is deepest (the NNS and RKWS); an assertion corroborated by the fact that the inclusion of the region dummies takes away the significance of water depth (model (4)). The parameter of the third continuous variable, drilling time, exhibits endogeneity problems. As said above, drilling time cannot be regarded as truly exogenous as once the prospects of finding oil are encouraging the exploration company would expect to spend more time trying to unearth it. In this case, drilling time is no longer a measure of cost but becomes endogenous as the causality runs from right to left. The contribution of the regional dummies to the sample containing the continuous technical variables is redundant: the likelihood ratio of this addition is equal to $\chi^2(3)=2.7$ in the adaptive expectations model and $\chi^2(3)=1.9$ in the rational expectations model, both of which are not different from zero at 5 per cent.

The conclusion from these estimates is that adaptive expectations should be used in the models to follow and that the continuous variables are to be preferred to the regional dummies. The exclusion of the dummies obeys some important considerations. First, continuous variables contain a richer amount of information that dummies cannot be expected to capture fully. Secondly, the only geological variable that retains its significance in all models is a continuous one ($DT$). Thirdly, use of the full sample creates the problem that the proportion of dry holes is unusually large (1,544 out of 1,950 instead of 573 out of 806 in the smaller sample) which is known to make the results sensitive to the choice of the error distribution.

Once the issue of price expectations and geology has been settled we proceed
to look at the role of information in more detail. Information has been partitioned into three types: finds, dry holes and petroleum shows. Four basic sets of models were estimated. Model (1) looks at the role of only finds, model (2) at only dry holes, model (3) at petroleum shows, and model (4) includes all these three stocks of information. Models (5) to (8) are equivalent to models (1)-(4) but include quadratic terms to the information variables to account for additional changes in the slope of the function. Table (3) presents these estimates.

First, we briefly look at the variables that are secondary to our analysis in order to concentrate our efforts on the information variables. As in the previous models the drilling depth is irrelevant and is excluded from models (5)-(8). The adaptive expectations price variable performs very well in all models with the exceptions of the models where all types of information are included.

Of the three information variables petroleum shows seems to be the least consistent. For example, the incumbent’s shows change sign between models (3) and (4) (and also the quadratic term between models (7) and (8)). The change of sign is also a feature of competitors' shows between models (3) and (4) as is the loss of significance of this parameter when other types of information are introduced to the model. The role of finds and dry holes seems on the contrary, to be much more consistent.

The role of the incumbent's finds seems to be detrimental to the probability of making a new find. It is unlikely that there will be more than one petroleum field within one licence block.25 Furthermore, although operators could secure access to adjacent licence blocks in the initial rounds (there were cases of companies like BP and Shell getting as many as six adjacent licence blocks) and access to adjacent blocks

25 Of the licence blocks that have discoveries 74 per cent have a single find. Only 4.6 per cent of the finds are located in blocks having more than two finds and the maximum number of finds in a block is five.
### Table 3 Estimates of the Effects of Different Information Types

<table>
<thead>
<tr>
<th>Model</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>-0.575*</td>
<td>-0.530*</td>
<td>-0.534*</td>
<td>-0.717*</td>
<td>-0.554*</td>
<td>-0.311*</td>
<td>-0.457*</td>
<td>-0.658*</td>
</tr>
<tr>
<td></td>
<td>(-2.898)</td>
<td>(-2.781)</td>
<td>(-2.871)</td>
<td>(-3.026)</td>
<td>(-3.198)</td>
<td>(-1.965)</td>
<td>(-2.987)</td>
<td>(-3.128)</td>
</tr>
<tr>
<td>$f_{wi}$</td>
<td>-0.753*</td>
<td>-1.554*</td>
<td>(-7.644)</td>
<td>(-9.593)</td>
<td>(-10.02)</td>
<td>-2.050*</td>
<td>-2.847*</td>
<td>(-8.660)</td>
</tr>
<tr>
<td></td>
<td>(-7.501)</td>
<td>(-13.134)</td>
<td>(-7.800)</td>
<td>(-10.500)</td>
<td>(-10.02)</td>
<td>(-2.050)</td>
<td>(-2.847)</td>
<td>(-8.660)</td>
</tr>
<tr>
<td>$f_{wj}$</td>
<td>0.411*</td>
<td>1.006*</td>
<td>(10.35)</td>
<td>(12.81)</td>
<td>0.988*</td>
<td>1.947*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$f_{wi}$</td>
<td>-0.101*</td>
<td>-0.139*</td>
<td>(-5.76)</td>
<td>(-5.229)</td>
<td>-0.009*</td>
<td>-0.020*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-2.145)</td>
<td>(-2.928)</td>
<td>(-5.229)</td>
<td>(-5.229)</td>
<td>(-1.214)</td>
<td>(-1.756)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$d_{wi}$</td>
<td>0.256*</td>
<td>0.936*</td>
<td>(5.339)</td>
<td>(8.965)</td>
<td>0.491*</td>
<td>0.653*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1.011)</td>
<td>(1.929)</td>
<td>(5.339)</td>
<td>(8.965)</td>
<td>(4.704)</td>
<td>(6.600)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$d_{wi}$</td>
<td>-0.0134*</td>
<td>-0.398*</td>
<td>(-8.573)</td>
<td>(-11.42)</td>
<td>-0.328*</td>
<td>-0.683*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-2.061)</td>
<td>(-4.809)</td>
<td>(-11.42)</td>
<td>(-11.42)</td>
<td>(-2.061)</td>
<td>(-4.809)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$s_{wi}$</td>
<td>0.139</td>
<td>-0.144</td>
<td>(1.011)</td>
<td>(-0.581)</td>
<td>0.173</td>
<td>1.288*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1.011)</td>
<td>(1.929)</td>
<td>(1.011)</td>
<td>(-0.581)</td>
<td>(0.612)</td>
<td>(2.439)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$s_{wi}$</td>
<td>2.68E-2</td>
<td>-0.653**</td>
<td>(0.151)</td>
<td>(-1.851)</td>
<td>-0.485*</td>
<td>-0.134</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2.68E-2)</td>
<td>(-1.851)</td>
<td>(0.151)</td>
<td>(-1.851)</td>
<td>(0.151)</td>
<td>(-1.851)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>price</td>
<td>-1.54E-2*</td>
<td>-6.8E-3**</td>
<td>-1.23E-2*</td>
<td>-3.98E-3</td>
<td>-1.68E-2*</td>
<td>-3.70E-3</td>
<td>-1.08E-2*</td>
<td>-1.04E-2*</td>
</tr>
<tr>
<td></td>
<td>(-3.876)</td>
<td>(-1.741)</td>
<td>(-3.249)</td>
<td>(-0.818)</td>
<td>(-3.936)</td>
<td>(-0.848)</td>
<td>(-2.853)</td>
<td>(-1.637)</td>
</tr>
<tr>
<td>WD</td>
<td>-2.82E-3*</td>
<td>-2.17E-3*</td>
<td>-2.32E-3*</td>
<td>-1.47E-3</td>
<td>-3.43E-3*</td>
<td>-2.29E-3*</td>
<td>-2.34E-3*</td>
<td>-1.47E-3</td>
</tr>
<tr>
<td></td>
<td>(-2.591)</td>
<td>(-2.119)</td>
<td>(-2.261)</td>
<td>(-1.167)</td>
<td>(-2.982)</td>
<td>(-2.205)</td>
<td>(-2.278)</td>
<td>(-1.065)</td>
</tr>
<tr>
<td>DT</td>
<td>6.18E-3*</td>
<td>4.98E-3*</td>
<td>5.68E-3*</td>
<td>4.64E-3*</td>
<td>5.85E-3*</td>
<td>6.23E-3*</td>
<td>6.47E-3*</td>
<td>5.39E-3*</td>
</tr>
<tr>
<td>DD</td>
<td>-1.24E-5</td>
<td>1.03E-4</td>
<td>4.66E-5</td>
<td>5.41E-5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-0.192)</td>
<td>(1.609)</td>
<td>(0.77)</td>
<td>(0.667)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Log Likel.** -387.88 -412.4 -448.97 -247.24 -350.68 -392.92 -446.66 -200.36

**Lik. Ratio** 193.6* 144.5* 71.4* 474.8* 267.9* 183.5* 76.01* 568.6*

**% Correct** 77.8 73.5 71.3 87.4 80.6 76.8 71.1 90.8

Source: Own estimates from the sources referred to in the text.

Notes: t-ratios in brackets. *: Different from zero at 5 per cent level of significance. **: at 10 per cent.
Information Sharing in Petroleum Exploration

for a single operator has been the feature of the frontier rounds (rounds of large unexplored areas) the partitioning of the North Sea has reduced the chances of having more than one field in a single block. This helps to explain why the existence of a previous find reduces the chances of further discoveries, or in other words, the resource-finiteness constraint starts to bind.

The coefficient of previous finds made by the incumbent is negative in all the models where this variable is included and to appreciate its contribution we have plotted its relationship with the probability of success in Figure 2a. The horizontal axis represents the observed values for the stock of i’s success and the lines represent the predicted values for the four models where fi is included. The values are calculated at the sample mean of all variables in the model with the exception of the competitors’ counterpart information which is assumed to be equal to zero. The purpose of this is to appreciate the sole contribution of finds (or dry holes) to the probability of success when no information is available (models (1) and (5)), and when other information is available (models (5) and (8)). That is the reason the probability of success differs at zero fi; in model (4) and model (8) there are other sources of information in the form of shows and dry holes which affect the probability of making a discovery.

In model (1) the probability of discovery when no finds have been made and no other information is available is equal to 0.2 and falls to zero when the value of incumbents’ information is equal to 2.52 (which corresponds to 4 discoveries in the X block or 8 in block X-1 or 16 in block X-2 or a combination thereof). The numbers are higher than those predicted by model (5) where the inclusion of the quadratic term in the variable incumbent’s finds pushes the function down to allow for high values of the variable. Predicted values of this variable in models (4) and (8) are progressively lower as we allow the incumbent to observe the information on dry

26 Similarly, in Figures 2c and 2d that assess the contribution of competitors’ information it is assumed the incumbent possesses no information.
Information Sharing in Petroleum Exploration

Figure 2: The Effects of Information on the Probability of Success.
Information Sharing in Petroleum Exploration

holes and petroleum shows.

The effect of competitors' finds is highly attractive to the incumbent, or in other words there is a very large spillover. As there are very few \( j \) finds in \( i \)'s block most of the contribution comes from the X-1 and X-2 blocks. The contribution of the first find in a X-1 block raises the probability of success by between 3 and 12 percentage points (in models (2) and (4) respectively). The probability of success converges to 1 in all models but model (6), mainly because the quadratic term attaches too great a value to high values of \( j \)'s stock. The speed of convergence differs for each model with (8) converging to 1 after 7 finds in block X-1.

The empirical results confirm the observation made in the first section, namely negative information also commands an economic value. Without any information whatsoever, it takes a very large amount of drilling to strike petroleum (model (2) in Figure 2b). With the availability of other information the chances of hitting petroleum are greater and this shows the positive information a dry hole contributes. Once again the existence of a positive relationship between incumbent's dry holes and the probability of success indicates the existence of resource finiteness. The drilling of dry holes by competitors also has sizeable effects on the probability of success of the incumbent. Here, as in the case of finds, the spillover signals that the inability to find is a reflection of the fact that petroleum is unlikely to be found in the area. In fact, the drilling of the first dry hole reduces the probability of success by between 0.1 and 1.8 percentage points in models (2) and (8) respectively.

The disaggregation of the information by type explains why the learning effect seems to be predominant in the results of Table 2 and resource-finiteness the effect of the competitors' knowledge stock. When the results of drilling are pooled it is true that other companies' drilling reduces the probability of success as they are exhausting the resource. However, when this information is discriminated by type the results are clear, finds in adjacent blocks increase the probability of a find and the opposite for dry holes. The larger size of the dry-holes effect outweighs the effect of
the discoveries unless these two types of information are given a separate treatment.

In order to provide a final account of the size of the returns to exploration and the size of spillovers Table 4 presents the maximum change in the probability of success with information as a proportion of the predicted probability without this information for the estimates of the models above.

**Table 4 Quantification of the Returns to Exploration (per cent)**

<table>
<thead>
<tr>
<th>Block</th>
<th>Maximum Returns to Exploration</th>
<th>Dry Holes</th>
<th>Maximum Spillovers from Exploration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Finds</td>
<td>Dry Holes</td>
<td>Finds</td>
</tr>
<tr>
<td>X</td>
<td>48.8 84.4 85.8 96.4</td>
<td>14.1 27.1 19.8 17.6</td>
<td>45.7 106.7 97.5 25.4</td>
</tr>
<tr>
<td>X-1</td>
<td>27.1 57.0 59.6 79.3</td>
<td>7.0 14.7 10.4 9.4</td>
<td>22.8 62.0 49.6 19.2</td>
</tr>
<tr>
<td>X-2</td>
<td>12.9 24.0 24.0 26.6</td>
<td>3.5 7.1 5.1 4.5</td>
<td>11.5 28.7 24.4 7.0</td>
</tr>
</tbody>
</table>

Source: Own estimates from the sources referred to in the text.

The largest estimates come from the existence of previous finds and have very large values. Returns to exploration that double the probability of discovery are not unusual especially when other types of information have been accounted for (like those in the second and fourth columns of figures corresponding to models (4) and (8) respectively). The spillover from discoveries is very large indeed, reaching more than 100 per cent but values of 50 per cent are not uncommon. The contribution of dry holes is less pronounced than the contribution of discoveries but nevertheless very important.
**Information Sharing in Petroleum Exploration**

**V. Conclusions**

The relevance of information in explaining the outcome of exploration is almost a trivial observation for anyone vaguely acquainted with the principles of petroleum exploration. However, empirical economic models have been stubbornly reluctant to include this aspect to the analysis of exploration mainly as a result of the preponderance of exhaustibility considerations. We have made the case for including information and strategic behaviour in the analysis of petroleum exploration and have been rewarded with empirical results that are not only sensible but also very intuitive. This was done by using the analogy of petroleum exploration as a traditional R&D process. While this idea is not novel it is surprising that it has not been applied empirically since it provides a very clear framework for the analysis of exploration. This has enabled us to reach important results for the quantification of returns to exploration and add a new dimension to the discussion of spillovers in petroleum exploration by using a case study that is perhaps more relevant to other countries.

The size of spillovers and the dramatic effect they can have on the probability of success of exploration companies is evidenced by the estimates of spillovers we have produced. It is also very clear that spillovers differ according to other information available but also by the type of results available. In particular the stock of competitors' finds can have a dramatic effect on the probability of success of the company in question. The contribution of previous finds made by competitors can almost double the probability of finding petroleum. On the other hand dry holes drilled by competitors reduce the probability of discovery but this is also beneficial to the company as it may decide not to drill after all. The returns to exploration are very high and by showing the large spillovers we can make the case for information-sharing agreements not only from a theoretical perspective but also from an empirical angle.

Taking the debate away from the USA also adds new dimensions to the
Information Sharing in Petroleum Exploration

analysis of spillovers. The American experience is one where non-cooperative outcomes are the norm (see the estimates of Hendricks and Porter (1988, 1996) and Farrow and Marshall (1992)) and have been the motivation for correcting some of the drawbacks associated with their market-based allocation policies. The measures have varied from compulsory unitization to enlargement of the licence blocks. The American industry has also exhibited some very innovative Coase type agreements to deal with market failures but government sponsored measures have been generally acknowledged to be slow to react.

The UK experience analysed here shows that the outcome of exploration is not totally consistent with market failure. Anecdotal evidence of the absence of market failure is corroborated by the lack of litigation between the licencees compared to the American case (Cameron (1983)). We have been unable to show how much information is shared but have shown that the sharing agreements devised by the companies and the government produce results more in line with a cooperative game.

References


Information Sharing in Petroleum Exploration


Mason, C.F. (1985) “Learning from Exploration Information: The Case of Uranium”, Resources and


