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THE VALUATION OF PATENTS:
A REVIEW OF PATENT VALUATION METHODS
WITH CONSIDERATION OF OPTION BASED METHODS AND
THE POTENTIAL FOR FURTHER RESEARCH

Background paper for discussion

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ABSTRACT

Intellectual Property Rights (IPRs) are viewed as being of increasing importance in many fields of business. However, one potential hindrance to their being considered of significant value, is the lack of appreciation of practical methods of valuing them particularly early in their life under conditions of uncertainty about their future prospects. Lack of practical valuation methods under such conditions can lead to sub-optimal decision-making in the course of managing an IP portfolio.

This paper considers the case of patents whose value constantly needs assessing during the application process, on renewal and for licensing, purchase and sale negotiations. Current practice in patent valuations are reviewed as is relevant literature gathered from a number of fields including accounting methods, discounted cashflow (DCF), related decision tree analysis (DTA) methods, and econometric methods based on renewal and stock market data.

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1 The OIPRC website is www.oiprc.ox.ac.uk

Particular attention is also paid to option pricing theory based valuation methods for real assets and frameworks are proposed for its application to the task of valuing patents. In particular it is suggested that one implication of studies of renewal data based models by Pakes et al showing that option values decline with patent life is that conservative filing decisions are usually justified.

Option based valuation approaches are thus proposed as a useful and potentially powerful framework in which to consider management of a company's patent portfolio and other IPR assets, and the difficulties of a rigorous application of the method form a fruitful field for future research.

1. INTRODUCTION

Intellectual Property Rights (IPRs) can be highly valuable rights playing a key role in many fields of business. However their value has been highlighted largely through their involvement in relatively rare but highly conspicuous transactions and litigation concerning successful businesses. In recent years concerns about IPR valuation have centred on Brand Valuation especially in the wake of takeover bids such as the Nestle bid for Rowntree in 1988 (Barwise, Higson et al. 1989). More recently this concern has broadened to include all Intangible Assets (Arthur Andersen & Co. 1992). However such concerns are primarily based on an accounting perspective. In contrast, attempts to assess IPR value and particularly the value of patents in order to make management decisions about them earlier in their life when their future value is highly uncertain has received far less attention.

The problem in the case of patents is particularly complex due to the, sometimes lengthy and certainly complex, application process involving initial uncertainties about both the technical and commercial success in competitive markets of the underlying technology as well as uncertainties about the legal challenges which can occur both during the application and subsequent enforcement.

Advances in the past two decades in the understanding of the valuation of options over financial assets under uncertainty and more recent applications of that work to what are known as "real options" over non-financial assets under uncertainty have shown that many accepted valuation methods neglect the value of managerial flexibility.

Most IPRs are subject to at least decisions regarding licensing and sale. However, Patents are subject to a particularly wide range of decisions both whilst they are being applied for and following grant. Patents thus involve both a high degree of flexibility in how they are managed and also a high degree of uncertainty as to their eventual value. They are thus likely to be a case where a consideration of real option valuation methods may give valuable insights into and potentially more accurate and useful estimates of their value than are available at present.

This paper aims to review firstly, exactly what patent valuation involves. Secondly, existing general methods of patent valuation and some of their advantages and shortcomings. Thirdly, the basic ideas behind option valuation methods and the literature relating to real options relevant to option based patent valuation methods. Finally, the issues involved in the

application of real option pricing principles to individual patents and patent applications will be reviewed. The conclusion comprises immediate practical implications and a description of the potential for further research in this area.

This paper is aimed at a mixed audience of economists, patent lawyers, business strategists and mathematicians interested in this field. It is therefore concerned more with concepts than mathematics. It draws on an earlier working paper (Pitkethly 1993) where I first explored the ideas but incorporates numerous revisions and additional sources, particularly in the area of understanding and applying real option valuation methods. It is hoped that whilst many readers may already be familiar with some aspects they will equally find other aspects that are unfamiliar. If this creates a bridge between different fields and viewpoints and provokes new ways of thinking about patent valuation in practice and new multi-disciplinary research into the area it will have achieved its objective.

One explanation which has been offered for the imagined ills of the patent system is in the words of The Economist in 1851 that "Patents are like lotteries in which there are a few prizes and a great many blanks" (Economist 1851). That might suggest that an accurate assessment of the expected value of individual patents might lead to the demise of the patent system. However, whilst similar valuations have not diminished the appeal of lottery tickets and even though the law of large prizes seems to apply as much to patents as lottery tickets; one can also say that patenting is not a zero sum game. My patent fees and costs do not fund your patented pharmaceutical's monopoly profits. A better appreciation of the value of patents and applications should therefore enable the system to work more, not less efficiently.

2. INVENTIONS, PATENTS AND PATENT APPLICATIONS

Before beginning any discussion of patent valuation it is necessary to make quite clear exactly what it is meant by the term. A patent can be described as an exclusive right of limited duration over a new, non-obvious invention capable of industrial application where the right - to sue others for infringement, is granted in return for publication of the invention. There is a distinction between the underlying invention which might be called the underlying intellectual asset and the intellectual property right (IPR) which confers exclusive rights over that invention as defined in the claims of the relevant patent.

This distinction is particularly important when it comes to thinking clearly about what is being valued. "Patent" is sometimes used in a very loose sense meaning either the underlying invention alone, the patent alone or both the invention and the patent and often the entire project of commercializing the invention. Furthermore in some cases "the invention" refers to a particular embodiment, in others anything within the scope of the patents claims.

However, the direct financial value of a patent or patent application per se, must be the value of the potential extra profits obtainable from fully exploiting the invention defined by the patent's claims in the patent's presence compared with those obtainable without patent protection. Projects comprising the commercialization of inventions and patents protecting such inventions are thus two different, even if closely linked, entities. In practice, dividing out the value of the patent per se from the value of a project comprising commercialization of an

invention may be difficult and may not even be necessary in some cases. Nonetheless it is worth distinguishing between them.

That the two are distinct is shown by what happens if one of the two proves worthless whilst the other remains still valuable. Firstly, the ability to commercialize an invention may be valuable even if any associated IPRs are unavailable, have lapsed, been found invalid or of limited use. IPRs are not essential to profitability and in any event many other non-IPR based means of appropriation may exist (e.g. Speed to Market, Control of complementary assets etc.). Secondly, if improvements to an invention or applications of it devised by others are commercially successful, the revenue from sale or licensing of the IPRs remains valuable even if the inventor no longer has any interest in direct commercialization. A patent is not just a right to protect one embodiment but includes the possibility of protecting anything falling within the scope of the claims.

A further complication in the case of patents is that patents do not come into existence as instantaneously as some other IPRs such as copyright. Some form of patent application process has to be gone through in which application is made to a patent office and following examination and perhaps negotiation as to the scope of the claims allowable, the patent is granted. Patent application procedures differ by country. Japan for example, allows examination to be deferred for up to seven years whilst most other countries do not. However, most patent systems have four major decision types confronting applicants and patentees. (I) Whether to file a patent application. (II). Whether to continue with it (at a number of decision points in the application procedure). (III) Whether to keep any patent granted in force or let it lapse. (IV). How to exploit the patent once granted (direct commercialization, licensing, a combination or outright sale).

To illustrate these decisions a simplified outline of the UK and European form of patent application procedure is shown in Fig.1. At each stage of the application procedure the potential future benefits of continuing the application have to be balanced against the cost of proceeding to the next stage. The relative scale of the increasing cumulative official costs is shown in Fig.2. However the costs can vary considerably in practice and the distribution of them over the various stages of the application procedure can vary too. Needless to say professional fees can considerably add to the initial official costs of applications and these also need to be taken into account. On the revenue side there are, as explained above, extra profits and/or licensing revenues due to holding a patent which are or might be available over the life of the patent.

A patent then is not a simple investment project involving initial costs and near certain future returns but a complex series of possibilities each involving costs and actual benefits or potential future benefits which unfolds over time under conditions often of considerable uncertainty as to the final outcome and with a considerable variety of courses of action open to patent applicants and patentees.

3. VALUING PATENTS AND PATENT APPLICATIONS

3.1. Why value patents?

For those managing both patent applications and granted patents it is essential to know the value of each sufficiently accurately if one is to make well-founded decisions about their

management. Since only a small proportion of patents turn out to be of extraordinary value in the long run and given that IP department budgets are limited any methods which lead to a better understanding of the value of given patent applications or patents should be welcomed.

On August 31, 1993 a US jury found that Honeywell had infringed a Litton Ring Laser Gyroscope patent and should pay $1.2billion in damages. This was somewhat less than the $1.96 billion. Litton claimed but nevertheless perhaps the largest ever award of damages for patent infringement. However, on July 3rd, 1996 the CAFC whilst upholding the jury's verdict on infringement awarded a new trial concerning damages saying that the study by Litton's damages expert Dr. Phillips was predicated on "speculation and unrealistic assertions" and supported the trial court's conclusion that Dr. Phillips' study was "pure fantasy".

Valuation of a patent or patent application whether explicitly or implicitly involves making judgements about the future in much the same way that stock market prices have embedded in them judgements of investors about the future performance of a company. In that respect some degree of "speculation" is unavoidable. All methods of patent valuation involve some element of forecasting ranging from forecasting depreciation rates to forecasting future cashflows, market conditions, effects of competition and distributions and volatilities of returns to patents. The "speculation" necessary is all the more unavoidable since, decisions about continuing with patent applications and about paying renewal fees for granted patents have to be made. Even owners making quick unreasoned judgements on such matters are making implicit valuation decisions in addition to more explicit valuations necessary when considering licensing, litigation or sale. Owners cannot retreat into an assertion that valuation is optional and too difficult to produce any meaningful answers. Like the uncertainty it tries to account for it cannot be avoided. Therefore any insights which help put valuations and thus decisions about the management of patents on a more rational basis and help avoid accusations of "unrealistic assertions" and "fantasy" ought to be encouraged.

The first questions to be asked of any valuation are: who is doing the valuation?, for whom? and for what purpose? The one certainty about the Litton's RLG patent mentioned above is that Honeywell's experts did not value the cost of infringing it at the $1.96bn that Litton's expert did. 4 However, whilst it is possible to use valuation methods to justify a particular point of view or conform to certain rules, the aim of this article is to try to pursue objective valuation methods. This is a similar problem to that encountered in valuing businesses and parts of businesses for internal management use in what is effectively part of the companies overall capital allocation problem. Objective valuation methods are needed to make management decisions for example to decide how much to pay for or invest in a business as part of the firms overall financial planning. In the same way objective methods are needed to decide how much should be spent on or paid for a given patent or patent application when the returns are compared with those available from other similarly risky uses the money might be put to.

The aim of valuing both patent applications and granted patents then is to enable those managing them to know their value sufficiently accurately and objectively to make well-founded decisions concerning their management.

3.2. What circumstances are patents valued in?

Obviously, early in the life of an invention, information concerning the eventual value of any patent on it is likely to be scarce. The people most likely to have this scarce information are firstly the inventor, who will usually know how significant an advance it is compared to other technologies. Secondly, the Patent Agent, responsible for drafting and prosecuting the application, who will have a view of the scope and quality of patent protection that might be obtained. Thirdly, those with responsibility for marketing the underlying invention, who can assess its success in the market, the potential sales that might benefit from patent protection whether directly or indirectly through licensing and furthermore the effects of competition in the absence and presence of patent protection.

Ideally use of an objective valuation method in conjunction with the expertise of these people should enable well-founded decisions about applications and the resulting patents to be taken. However, two problems exist, firstly, lack of any commonly accepted objective valuation method with which to process this information and secondly, the fact that the decision processes involved in valuation are subject to a number of potential biases.

For example, the decision to file a patent application is usually taken jointly by the patent agent who will for good reasons usually be reluctant to advise an inventor not to file an application and the inventor who will gain in prestige from the filing of the application. Furthermore for many managers the potential opportunity costs to their company and perhaps to their careers of not applying for a patent or not continuing with an application are potentially so much greater than the immediate financial costs that the best advice always seems to be "When in doubt, file an application!" (Grubb 1982). This seems correct but can it be justified? How can the doubt which makes it seem the correct course of action be quantified or accounted for? Indeed, can it ever be accounted for and patent applications valued better so that they can be managed better?

No manager wants to be remembered as the person who didn't patent a successful invention. Furthermore if the application costs are also negligible compared to overall development costs, deciding to develop the invention further may effectively decide most of the issues relating to patents and other IPRs. This is especially so where IPRs must exist to enable successful commercial exploitation, as with pharmaceuticals.

Similar considerations apply to decisions about other stages of the application procedure and to decisions concerning renewal fees for granted patents. Obviously in some cases the decisions are simplified by the legal position dictating the course of action. However in virtually all cases where this is not the case, a decision must be made as to whether the potential future benefits are worth the costs of the next stage in the application procedure or the next renewal fee. In such cases there do not appear to be any commonly accepted methods of valuing applications or patents in order to make such decisions. Only in the case of products where the income stream is 5 well established and reasonably predictable is it relatively easy to use conventional project valuation methods.

There must therefore be the strong possibility of a bias towards conservative decisions to file, preserve or continue applications or patents wherever there is the slightest possibility of commercial success. In practice, in all but the most obviously worthless cases. Thus consideration is rarely given to objective valuation of patents or applications and patents are all too often renewed and applications pursued, not because they are valuable but because none can prove or wants to prove that they are not.

How can this state of affairs be improved on? Is it already the most efficient one? What implications might such considerations have in more commonly thought of valuation decisions in licensing, sale or litigation? First of all we should review existing valuation methods and the explore what additional methods might overcome any shortcomings they might have and how such methods might be explored further and perhaps used to influence current practice. Finally we should try and avoid patent valuation's Scylla and Charybdis of oversimplification and impracticality and at least aim for methods and insights which are both sufficiently sophisticated and practical.

4. POTENTIAL PATENT AND PATENT APPLICATION VALUATION METHODS

In valuing a patent - as distinct from any underlying invention, the fundamental issue as outlined above, is by how much the returns from all possible modes of exploitation of the patented invention are greater than those that would be obtained in the absence of the patent.

Making such a distinction is difficult even when the returns from the patented invention are well defined. However in the early life of the patent or application many other types of uncertainty are also involved. There will be uncertainties about both the technical and commercial success in competitive markets of the underlying invention as well as uncertainties about the legal challenges the application and subsequent patent may have to face during its life.
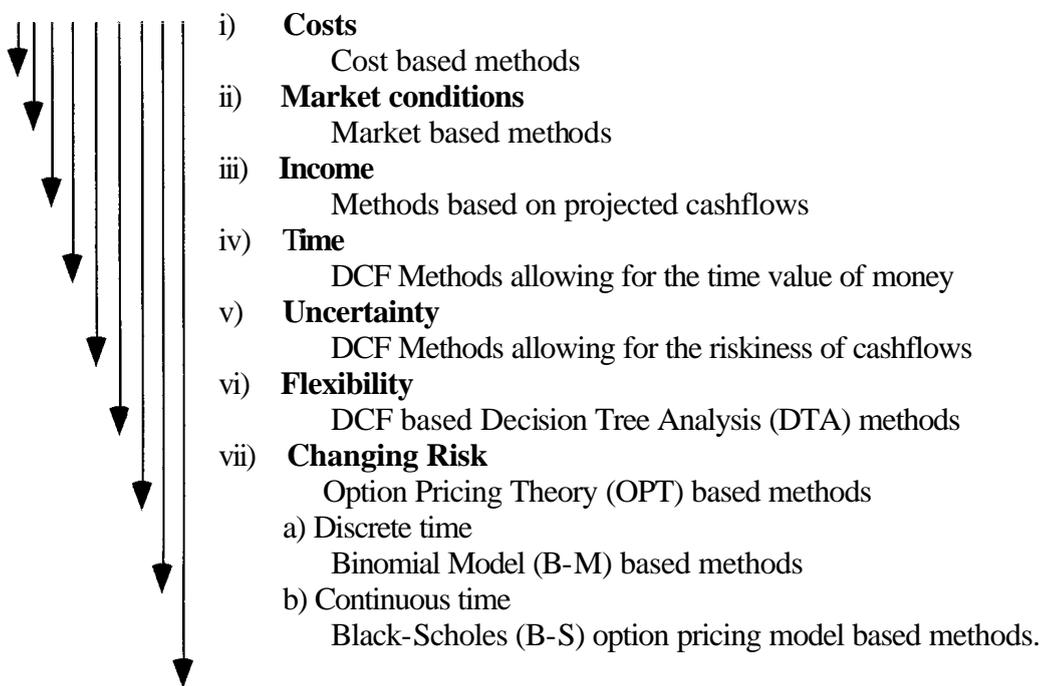
Describing the possible lives that a patent might live is thus a difficult task. A patent viewed as a financial project running from filing the application to expiry of the granted patent possibly twenty years later is thus a far from straight-forward one. All sorts of outcomes are possible and there are many stages in the application process when it may be abandoned or after grant, when annual renewal fees become payable, when the resulting patent may be allowed to lapse. Additionally, at the end of the first year from the initial application the applicant may decide to file corresponding applications abroad thus considerably expanding the "application" in the broader sense. Any decision tree describing it is thus going to be very complex and more of a decision forest.

Despite these problems a wide range of valuation methods which might be used have been described. Broadly speaking the writers fall into four main categories: accountants, patent agents, licensing executives[2] and economists. A distinction also needs to be drawn here

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2   *Patent Agent (or Patent Attorney)* : Someone with a scientific degree, trained and qualified in the law relating to patents and intellectual property who is employed in a company patent department or firm of Patent Attornies / Patent Agents. Main skills are in drafting and prosecuting patent applications and advising on Patent law. *Licensing Executive* : Someone employed, usually in a company patent / licensing department, to manage the process of licensing patents and other forms of intellectual property. Generally not legally qualified but with skills

between assessments of overall average patent values which are the aim of many economic studies (which will be mentioned briefly later) and the valuation of individual patents which this paper is largely concerned with.

Russell & Parr divide all possible types of valuation of individual patents into Cost, Market and Income based methods, the latter of which includes simple DCF methods (Parr and Smith 1994). Arthur Andersen in a report on valuing intangible assets divide valuation methods into Cost, Market Value and Economic Value methods (Arthur Andersen & Co. 1992). However for the purpose of this discussion it is perhaps better to classify valuation methods for individual patents by the extra features they account for over and above less sophisticated methods. These can be summarized in increasing order of sophistication as:

i) **Costs**
    Cost based methods
ii) **Market conditions**
    Market based methods
iii) **Income**
    Methods based on projected cashflows
iv) **Time**
    DCF Methods allowing for the time value of money
v) **Uncertainty**
    DCF Methods allowing for the riskiness of cashflows
vi) **Flexibility**
    DCF based Decision Tree Analysis (DTA) methods
vii) **Changing Risk**
    Option Pricing Theory (OPT) based methods
    a) Discrete time
        Binomial Model (B-M) based methods
    b) Continuous time
        Black-Scholes (B-S) option pricing model based methods.

The above categorization is not of course comprehensive and since its development the Black and Scholes equation has been adjusted in numerous ways to take account of extra features such as dividends, changing underlying asset volatility and changing interest rates. However, even the most sophisticated adjustments cannot take account of all factors. Option pricing theory concerning share options for example assumes that competition will abolish arbitrage opportunities and yet whilst substantially correct, small differences in transaction costs, trading practices and information flows may nonetheless give rise to apparent arbitrage opportunities when prices are compared with their theoretical values (Cox and Rubinstein 1985). It needs to be remembered therefore that any valuation method is merely a starting point or a help towards better decision making.

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in marketing or locating licenseable technology and in arranging and negotiating licenses.

Before reviewing the various methods it should be said that we are concerned with the present value of individual patents. We are not concerned, at least here, with how they are to be paid for or whether they should be bought, sold or licensed. In theory at least an infinite variety of payment methods could be devised and each method could be reduced to a present value. It is this value, how much not how it might be paid that we are concerned with.

4.1. Cost based methods - Accounting for Historical Costs

Knowledge of at least the future costs of creating IPRs is needed as part of almost all valuation methods. However, valuation methods based on the historic costs of acquisition perhaps less any allowances for depreciation or obsolescence are worth only the very briefest of comment. Their most serious failing is that they make no allowance for the future benefits which might accrue from the patent. They are of no help other than in historical cost based accounting systems or where taxation methods dictate their use and useless for making rational decisions.

4.2. Market based methods - Accounting for Market Conditions

The aim of market-based methods is to value assets by studying the prices of comparable assets which have been traded between parties at arm's length in an active market. Perhaps the most obvious case where the method might be said to work and the only case where the cost of an IPR is a possibly useful guide to its value is when the cost concerned is the price paid for the same IPR in a very recent comparable commercial transaction (Arthur Andersen & Co. 1992).

In other cases, comparability with other patents whose value is known from market transactions is the main problem. There is a risk that the comparisons made may not be justified and be no more than convenient measures of value. An important point made by Parr and Smith (1994) is that the transaction used may relate to an IPR whose use may not represent the best use of the IPR to be valued (it could even be the same IPR that has not been used optimally of course). For an IPR to be exploited to the maximum extent possible requires 100% of the potential protected market for the underlying invention to be accessed. Some sale or licensing agreements may prevent this and values derived from them will be suboptimal.

Market based valuation methods may also be based on comparable royalty rates. When deciding royalty rates there are of course numerous surveys which look at industry averages (1992), (Ishii and Fujiono 1994), (Sullivan 1994a). Such averages are often used as a basis for setting royalty rates in licensing agreements or in establishing damages in litigation. However, these are likely to exclude rational consideration of virtually all factors other than the, albeit important, one of what people think is the "market rate". The risk is that for a particular IPR this may be a serious misvaluation and use of such average royalty rates may merely perpetuate sub-optimal decisions by a few leading companies throughout an industry.

Royalty rates selected on some other basis than an industry average rate can also have problems. Royalty rates set using returns to R&D costs or return on sales figures for the company or industry for example run the risk of valuing costs or other factors rather than value.

One possible market based alternative to such valuation methods is described by Parr (1988). This involves the valuation of the "Patented Product" of a one product firm by calculating the residual value after deducting all the value of all other known assets from the market value of the company. This is similar to the "Premium P/E" method which ascribes the additional price and thus P/E ratio paid for a business with significant IPRs to the value of those IPRs (Arthur Andersen & Co. 1992). Taking the residual value analysis one step further though, Parr determines the return to the "intellectual property" by calculating the proportion of the actual total return which can be accounted for by standard rates of return to tangible and other identified intangible assets thus leaving the return to the intellectual property as the residual. The percentage that this represents of the total revenue is then used as a base for a rate of return to the IP in licensing negotiations. In referring to the "Intellectual Property" and not the "Patented Product", the return is attributed solely to the presence of the patent enabling above average profits. In other words Parr's valuations give a value for the Invention plus the Patent and a measure of the return to the Patent but not a value for the Patent per se unless one takes the notional return and uses this to calculate a supposed NPV over the remaining life of the Patent.

However, whilst such a method may be a valid way of discovering the implicit market valuation of a "patented product", one cannot be sure that it provides an objective valuation. Furthermore it is arguable that use of a residual valuation method is impossible since one cannot be sure that the residual is really ascribable to the patent alone and not other intangible assets. Finally there are few companies with only a single product.

A more fundamental problem is that one is using a stock market valuation of the company as a basis for estimating the value of its IP and IPRs. One is thus making an assumption that the market is perfectly informed about the IPRs of the company and can calculate their value. If that is the case though, there is no reason why those who wish to calculate the value of the IPRs should not do the same calculations or have the same insights. If it is not the case, there is no reason why anyone should base their valuations on what is no more than a guess by others. This is especially so in the case of an internal valuation where the internal valuers should have more information than the external market.

In short, whilst cost and market based methods of valuation may be relatively easy to use they may not be providing answers which are as accurate as one might wish. As rigorous objective ways of calculating the value of a patent such methods still leave much to be desired.

4.3. Income based methods - Accounting for Future Value

Improvements on cost based methods of valuation include at least some forecast of future income from a patent and thus some appreciation of the value of the patent as opposed to just its estimated market price or its cost. This will inevitably also involve some element of forecasting the future cashflows. However it is only with the addition of trying to account for the elements of time and uncertainty in future cashflows as is the case with conventional discounted cashflow (DCF) methods that one begins to get valuation methods which have some sound theoretical foundations. There are no doubt some who propose methods using projections of future cashflows to value patents without taking account of time or risk but such methods can be ignored.

The key issue in these methods is how the forecast cashflow is arrived at. It may be possible to identify and or forecast particular cashflows which are associated with a particular IPR through licensing or through direct exploitation. Alternatively it may be possible to use ideas similar to those used in brand contribution methods (Arthur Andersen & Co. 1992) to calculate the contribution to a business of a given patent. This may involve study of the costs of unpatented goods, of the return on capital of unpatented goods, of the return on assets of unpatented goods or of the price commanded by unpatented goods with the actual financial data for the IPR related business. Such methods are in some senses market based methods since they rely on market-based averages. A further and very common method based on industry average royalty rates assumes that the income due to a patent per se is the royalty which would have to be paid by a licensee. Needless to say the same cautions apply as when setting royalty rates directly based on such average rates as described above.

4.4. DCF based methods - Accounting for Time & Uncertainty

Discounted Cashflow (DCF) methods of valuation are now used for all manner of applications. The two key factors they account for are the time value of money and to some extent the riskiness of the forecast cashflows. These two problems can be solved in two ways. Either by using a risk adjusted discount rate to discount the forecast cashflows, thus accounting for both factors at once. Or using certainty equivalent cashflows, in which forecast cashflows are adjusted to account for their riskiness and changing riskiness over time. These are then discounted at the risk free rate to account for the time value of money. The latter method separates the two issues of risk and time and can help avoid problems when the risk adjustment varies over time as it will with patents. However, it is not the aim of this paper to describe DCF methods in detail –explanations can be found in any textbook on corporate finance (Brealey and Myers 1984). What is worth discussing though are some of the peculiarities involved in valuing a patent using DCF techniques and some of the pitfalls of such DCF analyses are prone to.

One advantage of valuing patents with DCF methods is that since Patents have limited lifetimes one is not faced with the problem of estimating residual values for the cashflows beyond the edge of the forecasting horizon.

For a given project though the cashflow could be one of a wide range of possible cashflows. Assuming that the probabilities of the various outcomes are known the simplest (and most 9 incorrect) DCF mode of analysis would be to simply work out all the possible cashflow outcomes and their probabilities, obtain the total expected cashflow and discount this using whatever discount rate the company currently used. However, such an approach ignores several factors. Firstly the discount rate used should always be one which reflects the risk of the cashflow concerned. For example if the project is not an average project for the company this will not be the same as the company's cost of capital. In practice using the assumptions of the capital asset pricing model and by finding quoted companies with cashflows of equivalent riskiness suitable discount rates can be obtained. Secondly, with a multi-stage cashflow such as with a patent or patent application the risk associated with the cashflow will vary considerably over the lifetime concerned. That for a newly granted patent which is about to be litigated for the first time will be much riskier than for a 15 year old veteran which has survived many

attempts to invalidate it. Use of a single constant discount rate actually makes the opposite assumption that the risk adjustment increases as the patent ages.

The general idea of a discount rate's risk premium component varying over time is dealt with, inter alia, by Hodder and Riggs who advocate the use of sequences of distinct risk phases in evaluating high risk projects whose risk varies from phase to phase (Hodder and Riggs 1985). This should be standard practice and is covered in most basic Corporate Finance books (Brealey and Myers 1984).

In practice this would mean splitting the valuation of the patent into several distinct phases, for example, from application to receipt of search results, from the decision to continue to commencement of substantive examination, from acceptance to the end of the first year after grant, from grant to the first year of commercialization and so on until the product becomes well established and the patent eventually expires.

Those articles which do deal with the valuation of patents or R&D from a DCF point of view do not usually take account of such considerations. Neil for example in writing on the valuation of "Intellectual Property" only uses a single discount rate and whilst not mentioning the variation of risk over a project's life takes the pragmatic view that small variations in the discount rate used will have a smaller effect than any possible errors in the forecast cashflow (1988). Parr (referred to earlier) also proposes the use of DCF method of valuation but also does not mention the possible variation in risk during the life of a particular piece of intellectual property (1988).

A further approach to uncertainty which uses DCF involves simulation methods. The simplest type involves sensitivity analysis where variables are each adjusted in turn to see the effect they have on final DCF values. Another example is that put forward by Stacey who advocates a probabilistic DCF approach (Stacey 1989). Since all the information involved in making a decision about Intellectual Property is highly uncertain the best that can be done is to consider the costs and revenues probabilistically, the end result being a frequency distribution of NPV values. In Stacey's example and other so called "Monte Carlo" simulations all the variables in a model are adjusted at once according to individual probability distributions to produce an overall distribution of possible valuations. However such methods, as Stacey says, involve time-consuming and costly calculations and are constrained by the difficulties in establishing the probability distributions needed. A further issue not raised by Stacey is as to what the NPV frequency distributions mean. If the probability distributions of NPVs are produced using a risk free discount rate not the opportunity cost of capital the NPV distributions cannot represent actual NPVs since only time has been accounted for. If they do use an opportunity cost of capital the risk is so to speak double counted first in the discount rate an secondly in the NPV frequency distribution (Brealey and Myers 1984). Problems with NPV distributions are also discussed by Trigeorgis (1996). The real role of such simulations is to understand the way in which the values vary with the parameters of the model constructed.

4.5. DTA based methods - Accounting for Flexibility

In addition to the problems of selecting discount rates appropriate to the risk associated with the various stages in a patent's life and those of calculating the possible cashflows which

might occur there is a third problem with simple DCF methods. This is that no account is taken of the various possibilities open to managers of a project or in the case of this discussion a patent. For example at various stages in the life of a patent or application it could be allowed to lapse or be abandoned. Following the initial application there is also the option to expand the patent family by making corresponding foreign applications.

To a certain extent simulations such as those described above can be used to try and account for the possible outcomes of management decisions though the same caveats outlined above apply. Where the number of such possibilities is limited though and the possibilities for management choice only occur at defined times they may be accounted for by the use of some form of Decision Tree Analysis. This ought to be based on an underlying DCF analysis of each branch, starting with the final ones and working backwards in time to give a present value.

The big advantage of the DTA method over simple DCF analysis is that it builds in the value of flexibility encountered in a project or patent. This allows at least some account to be taken of the ability to abandon the patent though it does not solve the discount rate problem. The rates used ought to be appropriate to the risk involved at each stage and following each type of decision, whilst in practice a constant rate is usually used.

4.6. Option Pricing Theory (OPT) methods - Accounting for Changing Risk

The theory behind option pricing was primarily developed for use in pricing financial options and financial options markets have perhaps funded the research into and certainly provided the testing grounds for some of the underlying theories. We need to understand at least the outline of these concepts to use them in the context of patent valuation.

An option can be defined generally as a right but not an obligation, at or before some specified time, to purchase or sell an underlying asset whose price is subject to some form of random variation. Most obviously though the underlying asset can be a share in a company whose price varies over time as a form of random walk (usually assumed to be Brownian motion type of Markov process) and which one has a *call* option right to buy or a *put* option right to sell at or before a specified *expiry date* in the future at a prespecified *exercise price*. *European* options can only be *exercised* at the expiry date but *American* options may be exercised before expiry.

Options have in common with situations subject to DTA analysis the possibility of different outcomes each with different cashflows each having different risk which in each case evolves over time. However, we have seen how each stage in the DTA method should use a discount rate appropriate to the risk involved in that stage and that the risk and thus discount rate may well vary over time due to the differing nature of the payoffs and thus decisions at each stage. Furthermore, in the case of most options the decisions normally associated with each stage in the DTA method do not have to be taken at any particular moment and the alternatives faced at each stage may not at first be precisely defined. In such a situation, however the problem is solved mathematically, some method which takes account of the continuous evolvement of the values of underlying assets and the nature of the decisions involved is needed. In other words some means of accounting for changing risk is required since in the limit that the continuous variations involved are made up of an infinite number of

discrete DTA stages each would need an appropriate discount rate to take account of the differing risks. In essence wherever there is the possibility of decisions being made there is a possible change of risk. Where the possible decisions keep changing the risk involved will also keep changing.

Another way of looking at the changing risk involved in an option is that as the time to expiry11 decreases, for an option presently "in the money", the risk of the exercise price exceeding (for calls) or being less than (for puts) the market price of the asset decreases and thus the risk of the option ending up "out of the money" and not being exercised decreases. The key point in accounting for this changing risk of future cashflows is to find some means of risk neutral valuation. The certainty equivalent approach mentioned earlier in the context of basic DCF analysis is one possible approach however another and more powerful method is to use contingent claims analysis the underlying idea of which is used in both discrete time period type analysis and continuous time option valuation models.

4.6.1. Discrete time - Binomial Model (B-M) based methods

Contingent Claim Analysis begins to solve the problem of changing discount rates which conventional DCF / DTA methods cannot solve easily. It uses the basic assumption that the returns to a call option on a share are equivalent to those of a portfolio or 'synthetic option' consisting of borrowing some money and buying some of the underlying shares. If one assumes that there are no arbitrage opportunities the price of the option on an underlying share will be given by the price of this synthetic option. This allows the construction of equivalent risk neutral decision tree probabilities so that the expected payouts can be discounted at the risk free rate. This avoids the need to set an appropriate risk adjusted discount rate for each branch in the tree.

Copeland and Weiner describe a number of situations in which non-financial "Real" options occur (1990) and in which a contingent claim analysis (CCA) valuation method can be used involving a portfolio of borrowing and shares being set up to replicate the returns of the project involving an option. One example used is a pharmaceutical R&D project (Copeland, Koller et al. 1990). Trigeorgis and Mason also discuss CCA analysis of options involved in a project (1987). CCA applied to a decision tree in the absence of any flexibility provides the same answers as a conventional DCF analysis since the use of a single discount rate does not then matter. For simple decision trees involving flexibility CCA is thus preferable to conventional DCF / DTA methods.

4.6.2. Continuous time - Black Scholes (B-S) Option Pricing Models

DTA methods can become inordinately complex resulting in what Trigeorgis calls "Decision Bush analysis" (1996). A further problem with DTA analysis methods is that whilst choices between courses of action with a few discrete outcomes may occur, in most cases a range of values is possible. In the case of share prices for example the range of values may be modeled as a log normally distributed process. A further problem is that decisions about the underlying asset or project may have to be taken continuously or the price of the underlying share may evolve continuously and not just at discrete stages. As mentioned above discrete stages involving different risk require different discount rates. Once one involves continuous

decisions one has a multiplicity of stages and thus the discount rate now changes continuously too, varying with the underlying asset value and time. Unlike DCF based DTA analysis using a single risk adjusted discount rate OPT methods accounting for continuous time such as the equation derived byBlack and Scholes provide a solution to these problems.

Before moving on to discuss the application of OPT to patent valuation though a brief overview of continuous time OPT valuation methods as developed for financial assets may be helpful.

4.6.2.1. Financial Options

There has been a long history associated with option valuation methods dating back to at least around 1900 (Bachelier 1900), leading eventually to work by Boness (1964), Samuelson (1965) and Merton (1973). However, the key paper which described the valuation of options on financial assets was published by Black and Scholes in 1973, appropriately coinciding with the opening of12 the Chicago Board Options Exchange and a great expansion in the trading of such options on common stocks. As with discrete time CCA described above, their equation was based on the assumption that the returns to a call option on a share are equivalent to those of a portfolio or 'synthetic option' consisting of borrowing some money and buying some of the underlying shares. The Black and Scholes equation can in fact be derived from a discrete time based CCA analysis by letting the length of period studied for each stage in the tree tend to zero (Cox, Ross et al. 1979).

For the case of continuous time though, if one assumes that there are no arbitrage opportunities the price C of a European Call Option on an underlying share is (Black and Scholes 1973):

$$C = SN\left(\frac{(\ln(S/E) + (r + \frac{1}{2}\sigma^2)t)}{\sigma\sqrt{t}}\right) - Ee^{-rt}N\left(\frac{(\ln(S/E) + (r + \frac{1}{2}\sigma^2)t)}{\sigma\sqrt{t}} - \sigma\sqrt{t}\right)$$

The equation that Black and Scholes provided was based on several key assumptions: (i) interest rates are constant over time; (ii) share prices follow a random walk where the distribution of prices at the end of a given time period is log normal with the variance assumed constant overtime; (iii) only European options are considered; (iv) markets are friction free with no transaction costs, no margin requirements or other penalties for short sales and borrowing or buying any fraction of a share is possible; (v) dividend payments on the underlying share are excluded.

Thus options on an underlying asset can be valued given just the following information:

i)   S   the current price of the underlying asset
ii)   E   the exercise price of the option

iii)   t   the time to expiry
iv)   *   the standard deviation of the underlying asset returns
v)   r   the risk free interest rate.
vi)   N   the distribution function for the asset price.

Tables can be made to calculate the value of puts or calls given S / (Ee^{-rt}) and * t so valuing a simple call option need not be a particularly complicated operation. Furthermore the value of an option can be seen to increase:

i)   the higher the underlying asset value
ii)   the longer the time to expiry
iii)   the lower the exercise price
iv)   the higher the variance of the underlying asset returns
v)   the higher the risk free interest rate.

It can be seen that the varying risk involved in an option over time is accounted for by the inclusion of the time remaining to expiry and the variance of the asset returns. The longer the time to expiry and the greater variance in the underlying asset value the greater the chance that the option will expire "in the money". This varying risk problem is overcome by using risk-neutral CCA valuation which depends on using knowledge about the value of the underlying asset.

These points are important when it comes to considering the application of OPT to patent valuation. However, the most important statement in Black and Scholes original paper was that 13 option pricing methods could be applied to other financial assets. This resulted in a flood ofwork dealing with a wide variety of financial assets and a realization that almost any financial asset could be valued using some form of OPT based method. Cox and Rubinstein for example describe a wide range of financial OPT applications (1985).

4.6.2.2. Real Options

The basic definition of an option (a right but not an obligation, at or before some specified time, to purchase or sell an underlying asset whose price is subject to some form of random variation) can be applied to a number of other situations other than directly financial assets. Such non-financial options have become known as "Real Options" and a substantial literature has built up aroundthe application of OPT methods to their valuation. An example of one, the treatment of a pharmaceutical R&D project as a series of options, was mentioned above whilst discussing discrete time CCA methods (Copeland, Koller et al. 1990). Mitchell and Hamilton also likene he cost of an R&D project to the price of a call option. They identified the cost of an R&D project with the price of a call option on the future commercialization of the project and the future investment needed to capitalize on the R&D programme with the exercise price of the option. The present value of the returns the company will receive from the investment was likened to the value of the share subject to the call option (Mitchell and Hamilton 1988). However they did not discuss in practice how one might go about calculating the value of the options concerned.

For an overview of the subject of real options the most recent and comprehensive works are the books by Trigeorgis (1996) and Dixit and Pindyck (1994). A much less advanced outline of the subject and OPT in general can be found in standard corporate finance textbooks such as that by Brealey & Myers (1984).

The field of real options developed principally from the realization that as outlined above conventional valuation methods do not or cannot cope very well with managerial flexibility. Kester for example highlighted the existence of growth options in many capital budgeting decisions (1984). How valuable growth options are according to Kester depends on i) the time projects can be deferred, ii) the project risk iii) the level of interest rates, iv) the exclusivity of the project. On the last point Kester identified both shared and proprietary growth options. Proprietary ones resulting from "patents or the company's unique knowledge of a market or a technology that competitors cannot duplicate". Needless to say proprietary options are more valuable than shared options such as the chance to enter a new market or build a new plant which is shared with all other industry members (Kester 1984). There are many later examples of such critiques of conventional DCF techniques. Kulatilaka for example discusses an investment choice between gas and oil fired boilers and identifies not just conventional NPV value but value due to Investment timing options, Abandonment options, Shutdown options, Growth options, Input and Output Flexibility and Expansion options being involved in the decision (Kulatilaka and Marcus 1992). Dixit and Pindyck also discuss the failings of conventional DCF analysis and the presence of options of various kinds in most investment decisions. (1995) (1994).

There is thus an equivalence between the inputs required to value financial options and those involved in valuing real options:

	Financial Option on Share	Real Option
S	Current price of the underlying share	= Present Value of Project Cashflows
E	Exercise price of the option	= Investment Cost of Project
t	Time to expiry	= Time left to invest in
*?	Standard deviation of underlying share returns value	= Standard deviation of the Project
r	Risk free interest rate	= Risk free interest rate

Furthermore as shown by Kulatilaka's example above there are a wide variety of types of real 14 options. Trigeorgis has categorised these based on some of the distinctions noted by Kester (Trigeorgis 1996)(Kester 1984) into options which are either proprietary or shared (as noted above), simple or compound (the latter involving a number of successive options) and expiring or deferrable (the latter being such as to allow an investment or decision to be deferred). On this basis one can identify most patent related options as likely to be proprietary, compound, deferrable real options since they are by definition exclusive to the patentee (or exclusive licensee)23, involve a number of successive stages and involve decisions which can often be postponed, at least until the next deadline in the application process, renewal fee deadline or sale or licensing decision is due.

4.7. Real Options - Patents, Problems and Solutions

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3 This of course ignores the possible competitive that effect of non-infringing substitute goods.

Whilst Black and Scholes pointed out that many other financial assets could be valued using option based methods and other authors have identified a wide range of Real Options the applicability of financial option valuation methods to non-financial assets has raised a number of questions which are relevant to any consideration of applying option valuation methods to patents.

An early example of such a debate occurs between Emery and Parr et al. and Rao and Martin. Emery and Parr et al. pointed out differences between traditional capital budgeting methods and option pricing methods in the way the latter treats the probability distribution of returns, the relationship to interest rates and time to exercise date of the option and concluded that using OPT for real investment decisions risked illogical decisions (Emery, Parr et al. 1978). These criticisms were in turn criticised by Rao et al. who argued in favour of the use of the Black and Scholes model for "Real World" capital budgeting decisions (Rao and Martin 1981). However whilst refuting Emery and Parr's concerns their argument in favour of using the Black and Scholes approach to value real options still involved concern about the requirement for continuous trading in the underlying asset and the option and for the fact that the underlying asset must not produce interim cashflows.

Trigeorgis (1996) and Kester (1993)) identify three main points at which real options may differ from conventional financial call options on shares.

Firstly with shared real options, unlike proprietary call options on shares, the option holder also has to account for the effects of competition. Patents however are by definition proprietary so this should be of minor concern save for the possible effects of competition due to non-infringing substitute products.

Secondly there is the potential problem that the underlying real asset may not be one which is traded or traded easily. It is now clear though that the fact that an asset is not traded is not a bar to using option pricing methods. However, the Black and Scholes equation depends for its derivation on a no arbitrage equilibrium with a synthetic option comprising a traded security and some debt. CCA in general requires a "spanning" traded asset or portfolio of assets whose stochastic change in value matches exactly that of the underlying asset on which an option is to be valued and from which a volatility can be obtained. For most commodities and manufactured goods this should be possible. Dixit and Pindyck however have pointed out that:

"However, there may be cases in which this assumption will not hold; an example might be a project to develop a new product that is unrelated to any existing ones, or an R&D venture, the results of which may be hard to predict." (Dixit and Pindyck 1994).

Whilst Dixit and Pindyck go on to assume that spanning is possible in an example comprising 15 investment in a project of uncertain outcome the issue perhaps remains one for further discussion. Trigeorgis lists a large number of papers which deal with R&D related options (1996).

A key question must be whether the assumptions of CCA based methods as used in OPT and the use of Brownian Motion type diffusion processes to model the price of the underlying asset are justified when considering Patents.

North has pointed to a distinction between risk and uncertainty, quoting Arrow (1951) and Lucas (Lucas 1981). The latter of these said "in cases of uncertainty, economic reasoning will be of little value". North points out that Frank Knight (1921) made a fundamental distinction between risk and uncertainty for the former of which it was, given sufficient information possible to derive probability distributions of outcomes and for the latter of which it was not. One might wonder therefore whether if the processes involved in the success of innovations and on which the value of IPRs depends are in fact purely uncertain not merely predictably risky then it may not be possible to derive any forecastable value for IPRs at all. However, this should not deter us since against this view one can say that IPRs all have a value expressed in monetary terms and we have data showing that returns to inventions do form characteristic distributions suggesting particular underlying stochastic processes which we can model. We may not be able to predict whether a particular invention will be a success or not but we should be able to show what the distribution of returns from inventions and IPRs in general are and from this deduce information about their current values.

What remains a subject of discussion is what models should be used. The work of Scherer showing that the returns to Patents are highly skew even in the case of just Patents renewed to their full term (1997) as well as common experience which shows that distribution of returns from Patented inventions must be highly skew at the end of their life with a few highly valuable patents and a lot of worthless and or lapsed ones means that in valuing patents one may need to consider carefully what type of diffusion process and distribution may best be used to model the returns to patents. Is a Brownian type process or some jump diffusion process involving a mixture of Brownian type process with Poisson jump processes more appropriate? Should the distribution of returns be modelled as a form of paretian or lognormal distribution? This area could do with further consideration. Dixit & Pindyck also say:

"*Likewise one might model the value of a patent as subject to unpredictable but sizeable drops in response to competitors' success in the market*" (Dixit and Pindyck 1994).

Perhaps one needs to distinguish here between what happens after an invention is made and it gradually becomes apparent whether it will be a successful invention or not and what happens after an inventor is employed and it gradually becomes apparent whether they are going to invent anything. It is perhaps easier to study examples of and model the former. Furthermore the mention of jump processes shows that it is possible to modify the models of the stochastic processes involved to account for other factors.

One such factor concerns the volatility of returns to the underlying asset. There is the possibility that the standard deviation which Black and Scholes assumed to be constant may not be so and the variance of the return on the underlying asset may not be constant over time. In the case of a patent this is very likely the case. The example of a staged pharmaceutical R&D project provided by Copeland (Copeland, Koller et al. 1990) illustrates this. As such a project survives longer continuing with the project becomes less and less risky, the spread of potential outcomes narrower and more certain and the variance less. If one considers patents it is obvious

that the distribution of values whilst it might be assumed to be lognormal at the start of a patents life, towards the end it is definitely not, as worthless patents are abandoned and the distribution for a given cohort skews towards the upper end of the original distribution leaving a few highly valuable patents left in force for their maximum life. As Scherer says:

"That skew outcome distributions result with such striking regularity from innovation samples suggests that there must be some underlying stochastic process whose behavioural properties are well worth characterising" (Scherer 1997).

If the volatility of the underlying asset is a known function of time then adjusting the B-S formulae is not difficult with average values being taken over the options remaining life. However work has been done on pricing options on assets which even have stochastic volatilities (Hull and White 1987). As one might expect, one feature is that the longer the life of the option the more significant stochastic volatility becomes compared to the case where it is constant.

The third point at which real options may differ from conventional financial call options on shares according to Trigeorgis is that real options may consist of multiple or *compound* options in a chain with numerous interdependencies. Option values are not necessarily additive due to these interdependencies and so in general compound options will require more complex analysis.

The application of option pricing methods to real options involving innovation and by implication patents as well is thus by no means a straight forward task. There is also the task of convincing management that the consideration of OPT issues is worthwhile a subject dealt with by Kemna in connection with the consideration of real options in the Oil and Gas industry (Kemna 1993). However, whilst there is the question of keeping the complexity within manageable limits there seems a reasonable possibility that any fundamental reservations about the general applicability of OPT to real option valuation of patents can be overcome. That being the case, valuation is primarily a matter of identifying for a patent the variables described above which are needed for option valuation.

Despite these potential differences between financial and real options in the form of patents, there are several areas where there are definite similarities. Two areas in particular are the issue of limited liability and the establishment of optimal exercise strategies.

Limited liability or rather the ability to escape from financial commitments by going bankrupt and/or defaulting on interest payments is something which is a risk, or benefit, depending in one's view, of some financial arrangements. When evaluating a project using DCF techniques such financing considerations can be accounted for either by adjusting the NPV of the base case in the absence of financing considerations (i.e. all equity finance) or by adjusting the discount rate. However in the case of an options based approach the financing considerations can be considered as an option to default on debt payments which of course has a certain value over and above any option to just abandon a project. In fact as Trigeorgis (1996) points out the combined value of default and abandonment options can be considerably larger than the project abandonment option value alone. In the case of a patent there are obviously abandonment options to let the patent lapse and consequently various options associated with

financing the acquisition of the patent quite apart from other options involved in investment opportunities associated with the patent. Obviously abandonment of a patent is similar to abandonment of a project except that being a pure real option with no obligations attached to abandonment there is no downside toabandonment, save loss of the initial investment costs and a possible upside in the ability to exercise what amount to abandonment put options on the project. One might say that project abandonment options where abandonment involves no costs or penalties involve a form of limited liability.

Just as with analysis of a series of investment project related options there is usually an optimalexercise strategy for the options involved in a patent. For example when to let a patent lapse when to continue with an application, when to license or refuse licences and in many other situations. The more one concentrates on the investment opportunities associated with a patent as opposed to the options inherent in the patent per se the more the options concerned appear the same as any other investment option and the more ordinary investment option triggers become 17 important. However, similar triggers might also be devised for decisions about the options involved in a patent per se. "

I will now consider some of the issues which might be involved in attempting an option based method of patent valuation and review some of the other difficulties involved. Before doing so it is worth considering some of the concepts raised by econometric studies of option and renewal fee based patent valuation methods which also reveal the skew distributions referred to above.

5. ECONOMETRIC PATENT VALUATION METHODS

Outside the field of academic economics the work done on the valuation of Patents using econometric methods is probably little known. The work in general deals with aggregate value for particular types or cohorts of patents rather than the individual patents that we are interested with here. However it is nonetheless useful to review this field briefly here not just for the sake of completeness but for the interesting insights it gives into patent values as a whole.

5.1. Stock market based methods

Pakes has investigated the relationship between the stock market value of a firm and the level of inventive activity of the firm as measured by the number of successful US patent applications and R&D expenditures (1985). In this paper Pakes found, not surprisingly, that the stock market did take account of unpredictable changes in R&D levels and levels of patenting by firms. A result which Griliches has also referred to (1981). However, Pakes also commented that the results "may reflect an extremely dispersed distribution of the values of patented ideas". Whilst this may not be of immediate practical help in valuing patents it is relevant to the idea that patent's values are to a certain extent reflected in stock market valuations.

Kingston discussing Scherer's earlier work points out that one may not be able to assume that value distributions for patents and innovations are the same (1994). However, Scherer has recently compared the distribution of values of High Tech start-up companies over

time with the distribution of values of individual patented inventions and found that they have similar highly skewed distributions which may support such an assumption (1997).

There is therefore some factual support for the common sense view that Stock Market values are linked in some way to values of the IPRs held by the company. This however supports at least a possibility of finding shares which might reflect the volatility of patent values which may be helpful in option based valuation methods which require a knowledge of the volatility of the returns to a patent.

5.2. Renewal data based methods

The other main stream of econometric work looks at patent value from the patentees point of view using patent renewal data as a way of measuring the patentees assessment of a patents worth. The advantage of such an approach is that it is aimed at the value of the patent alone. It is thus probably a better valuation of the potential opportunities, for example licensing opportunities, than might be obtained from a stock market valuation, since the patentee usually has better information than the stock market does. The disadvantage is that it is only useful for valuing patents retrospectively and usually only in aggregation. It may also, due to some of the organizational bias related reasons mentioned above (which will encourage conservative renewal policies) be an overestimate of the true value. On the other hand because the value is merely viewed relative to official renewal fees and excludes other incidental expenses it may also be an underestimate. To what extent these biasses may compensate for each other is unclear.

Some of the first steps in this process though, are described in Pakes and Shankerman's paper on the rate of obsolescence of technical knowledge developed or invented by a firm. One of the ways of estimating this was to use patent renewal data to establish a rate of decay (Pakes and Schankerman 1984). This work led in turn to their work on the value of patents in Europe again derived from renewal data (Pakes 1986). Not surprisingly in the study patent quantity was founto be inversely related to patent quality, something those patent agents who have dealt with the output from companies who file everything they can, may agree with. Other critical resultsinclude the fact that there is a large number of patents of minimal value and a highly concentrated tail of valuable patents with those few patents kept in force for most of their potential life being highly valuable. A similar study of older patent data using similar methodology has also been carried out by Sullivan (1994b).

However, in Pakes' other paper the concept of viewing Patents as options was expressed more explicitly (1986). In this work the question facing a manager was not just whether the returns in the coming year exceeded the renewal fee as in the deterministic model. It was instead whether the returns for the coming year plus the value of the option of paying the renewal fee and maintaining the patent in the following periods together exceeded the renewal fee. The paper uses the renewal data from English, French and German patents to estimate parameters for the model which is then tested using the parameters against the actual data by calculating the expected drop out or lapsing ratios over time. In the process it calculates the distribution of values for patents and observes how this distribution of returns changes as time progresses. The model of the process for generating returns to the patents includes a Markov

process and assumes that initial returns at least are distributed lognormally both of which are also features of the Option pricing methods described earlier.

The work, whilst producing a model and parameters which fit the actual data very closely, does not of course enable us to calculate the value of any individual patent. The work is nonetheless highly valuable because of some of the concepts it introduces to the field of patent valuation, in particular the consideration of patents as a series of options.

5.3. Patents, Option Pricing and Econometrics

Pakes view of the options represented by holding a patent is that payment of a renewal fee for a granted patent not only buys the coming years monopoly profits but also buys (in all but the final year) an option on renewing the patent at the end of the year, the exercise price for which is the renewal fee then payable.

Pakes work elucidated a number of features of the options connected with the renewal fees. In common with normal financial options the value of the options represented by holding a patent or patent application are positive and increase with increasing value of the current returns. In a similar way to normal options their value decreases as the patent ages and the time to expiry of the patent decreases. This is not just because the time to expiry of the individual option considered is nearer its exercise date (for example the patent's renewal date) but because each option's value has built into it the value of future options and the fewer they are the less valuable the current option is.

Some features however differ from more normal financial options. One oddity is that for each option the exercise price increases year on year as the renewal fees which are the price to gain the benefit of next year's returns increase with the age of the patent. A further feature shown by Pakes work is that as the patent ages the distribution of the potential returns skews towards there being a few highly valuable patents and many relatively worthless ones. Options increase in value with increased variance of the potential returns, so this decrease in variability leads to a decrease in the value of the options which occur later in the life of a patent. Pakes paper also included description of both deterministic (where no option values are included) and stochastic models (where they are). Interestingly they differ most at the beginning of the patents life illustrating that the effect of also considering the option has a much larger effect early in the patent's life. Intuitively this is what one would expect. Also the actual data shows that the dropout rates slow towards the end of a patents life one potential explanation for which is that this will be the case if the option value of the patent drops to zero towards the end of the patent's life.

Previously I outlined how the valuation of a patent needs to be distinguished from the valuation of the underlying invention. The approach adopted by Pakes avoided this problem by working backwards from patent renewal data which reflect patentees valuations of the patents alone. However, Pakes work only helps assess mean values for groups of patents in the past and not the value of individual patents. Furthermore, the method will not provide a basis for a new valuation process not only because using renewal fees makes it retrospective but because basing an improved objective estimate of patent value, on renewal data which results from the existing and often ad hoc valuation methods one is trying to replace will be unlikely to result in

improvement. Despite this it is valuable for the purpose of this review in that it highlights several concepts useful in consideration of individual patents as options.

6. OPTION PRICING AND PATENT VALUATIONS

It should be obvious by now that firstly valuation methods for assets which involve choices and varied potential outcomes may seriously understate the true value of assets if they do not take account of the value of the options involved and secondly that patents and patent applications are just such assets.

Fig.1 outlined the application process for a patent and the subsequent decisions involved in keeping it in force. Fig.2 shows a simplified version of this showing the costs involved inacquiring and maintaining the patent/application. We need now to identify what options may be involved in valuing a patent. For example Pakes treated the post-grant phase of a patent as a series of call options on the next years benefits. Hamilton and Newton each treated R&D projects as call options on the eventual project of commercialising the R&D project results, whilst Copeland et al. viewed an R&D project as a series of abandonment put options. Eldor has treated patent royalty cashflows as a perpetual American option (1982) as does Norris who also points out the option to sell the patent and the option not to license the patent as being two options in addition to the usual collection of real options comprising expansion, deferral, abandonment and switching options (1996).

Norris is mainly interested in the patents value as a means of deferring investment incommercializing the invention. Lambrecht also treats a patent as an element of a deferred investment problem (1997). Takalo and Kanniainen also investigate a series of research, patenting and development investment decisions concluding that the value of options to defer investment resulting from holding patents may result in delays in commercialization (Takalo 1997). Interestingly Norris also models a cross-licensing deal using Magrabe's exchange option model (1996). However, neither Norris nor Lambrecht distinguish clearly between the value of the commercialization project as a whole and the value of the patent per se. The distinction drawn is instead between the race to obtain the patent and the commercialization of the invention with the valuation concentrating on the value of the patentees option to invest in commercialization of the invention under the protection of the patent. By separating the research and patenting decisions as well as the commercialization/development decision Takalo and Kanniainen do distinguish between the value of the project in the presence and absence of a patent (Takalo 1997).

These examples of the use of option based thinking and valuation methods to situations involving patents however tend to concentrate on patents, on the one hand, as call options on the commercialisation of the underlying invention and on the other hand as options to abandon the Patent, R&D project or Invention in various ways. Firstly, there is a need to distinguish the patent from the underlying invention and secondly, there is a need to see the link between the different ways of looking at patents using options since call and put option valuations are linked. One of the basic equivalencies which lies at the heart of option valuation is that:

Call + (Present Value of the Exercise Price) = Put + Underlying Asset

It is this, which holds for European options at least, which enables R&D projects to be considered in terms of both puts and call options. Similarly, whilst Pakes referred to calls, one could also express patents in terms of puts.

A Patent application could thus be valued as the present value of the expected future monopol profits from the patent less the present value of the cost of the application plus the value of the put option to abandon the application (which has an exercise price of the as yet unspent future application costs). Similarly the granted patent could be valued as the present value of the expected future monopoly profits from the patent less the present value of the future renewal fees plus the value of the put option to let the patent lapse (which has an exercise price of the as yet unspent renewal fee costs).

Alternatively, the application could be considered to be worth the value of a call option on future continuance of the patent application whose exercise price is the cost of moving to the next stage in the application. To value such a call option one would need to know the value of the underlying asset which is the option to continue the application to the next stage, and so on, the final link in the chain being the asset of the present value of the expected future monopoly profits from the patent. This is illustrated in Fig.3. However, this final asset can itself be expressed (as per Pakes) in similar terms as a chain of call options on the next years benefits (including an option on the following year's benefits) exercisable by payment of the next renewal fee.

It is thus possible to divide up the various stages of a patent or patent applications life into a series of options which it should be possible to value using some of the concepts described earlier. Needless to say this may well be easier said than done and whilst a number of potential problems have already been disposed of in the preceding discussion there remain some which will need to be overcome.

7. PROBLEMS IN APPLYING OPTION PRICING BASED METHODS

7.1. Variance

One problem which has already been mentioned in passing is that at each stage in the application process and at each stage in the life of the patent the variance of future returns will be different as the fact that the patent has survived thus far makes it increasingly likely that it will be successful and profitable. As we have seen single options or DCF valuations which do not take account of this and use the same discount rate and variance at all stages in the life of the patent/application are flawed. Some provision or estimate of the cost in inaccuracy of ignoring this will have to be made.

Newton for example has outlined how one might begin to obtain volatilities for applying Option pricing theory to R&D even if not to patents. The overall approach adopted treats R&D as a call option on the development of the R&D results (1992). It is a straight application of Black and Scholes formula to R&D with the consequent need to derive measures of volatility for what takes the place of the underlying security - the R&D project. Newton discussed how these volatilities of R&D projects might be deduced. However the method proposed did not take account of the fact that as with patents the variability of returns to an

R&D project will probably vary throughout its life. Final clinical testing of a proven pharmaceutical is obviously going to be less variable in its possible outcomes than early exploratory research on an unproven discovery. Similar considerations must be dealt with when considering patents alone and perhaps further studies of such variances are needed.

7.2. Compoundedness

The Black and Scholes formula inherently cannot be used to value an option on an option (Black and Scholes 1973), since the variance of return on the option would keep changing and the formula assumes it to be constant. However, there have been a number of studies which address this problem. Trigeorgis discusses this area extensively (1996). Option values are not necessarily additive due to interactions between them but the interaction which can in some cases significantly affect values depends on a range of factors such as the type of options, the overlap of expiry dates, the value of the underlying asset relative to the exercise price (whether the options are in or out of the money). This is a complex area where if the interactions become too complex some solution using numerical analysis or Monte Carlo simulation methods may be needed.

7.3. Interim Payments

A further assumption of the Black and Scholes formula is that no interim dividends are payable. For a patent valuation, cashflows may well occur during the period the options concerned are held. However in general if the schemes of analysis outlined above are followed involving a series of discrete steps the cash inflows concerned will be for a different period than that covered by the option for a given step. For example the value of holding a patent could be stated as being the present value of the current year's cashflows plus an option on the present value of next year's cashflows and benefits. The current cashflows are thus not connected with the option concerned. There are in any event means of adjusting the Black and Scholes equation to account for at least constant dividends (Merton 1973).

7.4. Cashflows

However, despite it being possible to overcome many of the problems outlined above, in practical terms, valuing patents using options whilst attractive theoretically is still a complicated problem. In addition to the standard deviation of the Patents value, obtaining data on the present value of the projected cashflow of the patent is also likely to prove difficult.

One will need a complete predicted cashflow resulting from the patent from its filing date until its lapse together with a complete breakdown of all the costs involved in obtaining and maintaining it including any legal costs incurred after grant in oppositions or litigation. As pointed out the cashflow should be just the extra cashflow resulting from the patent per se. Obviously establishing this requires a highly detailed knowledge of the effect of the patent on demand and on the cashflow the underlying invention generates. The effects of potential competition from rival non-infringing inventions also need to be considered. Quite apart from problems with revenue cashflows one will also need to decide how to treat the costs of the initial application as opposed to the costs of prosecuting any subsequent individual national

applications. This will involve making decisions as to how to allocate the common application costs amongst the various national patents which might result.

8. PRACTICAL STEPS

Studies which produce theoretically attractive analyses are sometimes of little practical use. In view of the difficulties of obtaining the data required to carry out a thorough option based analysis of a patent's value it is therefore all the more important to ask what lessons can be learnt from the present analysis pending some conclusions from a more comprehensive study. It is reassuring though that option based patent valuation methods have already been used in practice as shown by Norris whose work was connected with a consultancy project (1996). The key perhaps is not being overwhelmed by the mathematics and trying to reduce the problem to its essentials. However effort is required on two fronts. Firstly and most simply to construct general guidelines which are based on the insights of option based patent valuation. Secondly more work on the detailed issues involved in the application of option based methods of patent valuation. In either case one is in effect applying option pricing theory to establish optimal exercise strategies or rules for the management of the options inherent in a patent or patent application. This again emphasises the similarities with financial and other options where establishing optimal exercise strategies is very often the major aim. Here we shall briefly consider the former issue of general guidelines.

8.1. Options at different stages of a patent's life

Pakes work has shown that for renewals the later years of a patents life are dominated by the effects of technical obsolescence rather than the options on future monopoly profits (1986).

As a patent ages therefore the option based part of its value decreases in importance and purely non-option methods of valuation will become more justifiable. The point is that managers need not be so concerned about option values late in a patent's life.

Conversely, early in a patent or application's life the option component comprises the major part of the value and is non-negligible. Added to this, renewal fees early in a patent's life tend to be smaller than those later on and initial application fees are not very large. These facts would indicate that firstly, there is support for the view that one should always file an application on a prima facie patentable invention. This accords with most patent agents experience and reluctance to decide against filing. Secondly, early in the patent's life the major part of the patent's value will be contained in the options associated with it and these are likely to be considerably more valuable than any initial renewal fees.

An option based view of patent valuation therefore supports giving consideration to renewing patents very early in their lives even in the absence of substantial or even any returns which later in their life should be more likely to indicate that lapsing is required. The presence of valuable options early in a patent's life are what justify Grubb's exhortation "When in doubt, file an application!" (1982).

8.2. Hurdle years for renewal decisions

These considerations reflect part of Pakes method of analysis which involves the concept of a cutoff value for the present return. This is a hurdle rate for the current returns to the patent which it must exceed to be worthy of renewal. Theoretically the value of the option on the future returns may enable this value to be negative, as with an application. In practice any patent on a product already in production will probably be producing non-negligible returns in comparison to the renewal fee. However, if the returns or more precisely returns and sales are zero later in a patents life then there will come a point when with the option value also almost zero, it should be lapsed. The critical decision is as to when the cut-off or hurdle year for non-renewal beyond which lack of any returns is unacceptable will occur. This is something which might be determined but which will very probably depend on the industry and product concerned. A consideration of the decline in value of the options involved in a patent may thus justify setting some form of hurdle year for patents by which they should be generating revenues and repaying their costs.

8.3. Foreign filing decisions

Another critical decision comes about two thirds of the way through the first year of a patent application's life when a decision must be made about foreign filings. It is quite likely that no further information will be available on the commercial prospects other than general market sizes and the only extra information may be early search reports giving some idea of patentability. In general therefore the decision will be driven by the consideration that if the product is being developed further with the aim of putting it on the market foreign applications should be made anyway on the basis that the cost of the options they represent will probably be negligible in relation to the development costs. If the costs are not negligible vis a vis the development costs then more attention must be paid to the likely value of the options involved. At this early stage it is worth remembering that the applications option value is high and related to the potential future, not just current, market size that the patents will protect and future and not just current levels of protection that are available. This is especially important when considering developing markets.

8.4. Sale and licensing decisions

Option based valuation methods can provide justifications for many existing decisions made about patents which depend on what might happen in the future and how the patent or application might be managed. Use of option based valuation methods to calculate precise values as has been shown is rather more complex. However, whilst more work is needed to show how the methods can be generally and regularly applied in practice the above discussion shows that all valuations including those for the purposes of sale and licensing of patents should ideally be carried out using option pricing based methods outlined above.

9. POTENTIAL FOR FUTURE RESEARCH

The few practical conclusions described above are naturally temporary since they are only using a new theoretical framework to justify existing practice. Further work is needed to apply the methods discussed here to generalised patent valuation problems. The key areas for

further research concern assessment of the magnitude of the values of options involved in overall patent values, the establishment of means for estimating the variables used in the valuation methods described above and the assessment of the effects of any simplifying assumptions which will enable them to be used readily by patent managers. This will involve studying the effect of various assumptions about discount rates, volatilities, compoundedness and other factors on a rigorous approach. The aim being to determine when they should be used and to maximise their ease of use and utility when they are used.

Finally there is considerable scope for examining a number of specific current issues in the field of patent management using an option valuation perspective. One example is the case of the high number of Japanese Patent applications. No one reason provides a complete solution to this. However, one usually unconsidered factor is the value conferred by Japan's deferred examination system. Japanese Patent Law, unusually among the world's major patent systems, allows deferral of a patent application's examination for up to seven years (Art.48.III). However, being able to defer a decision confers a valuable option. The deferred examination system in Japan must therefore act at least as a potential incentive to file patents which in a less flexible system might not be filed because they would be less valuable. No Japanese Patent Manager at present would conduct a full option based valuation before filing a application. However, acting on a feeling that things could change in seven years, is in effect an implicit use of such a valuation. The idea that flexibility confers value is particularly applicable to the patent application process and this may well have more general policy implications.

Option based valuation approaches are undoubtedly a useful and potentially powerful framework in which to consider management of a companies patent portfolio and other IPR assets. Despite the possible difficulties of a rigorous application of the method and the fact that much work remains in developing its practical use the technique is already being used in some specialized situations and should be developed further. Patent valuation is an exercise which is not optional but inherently about options.

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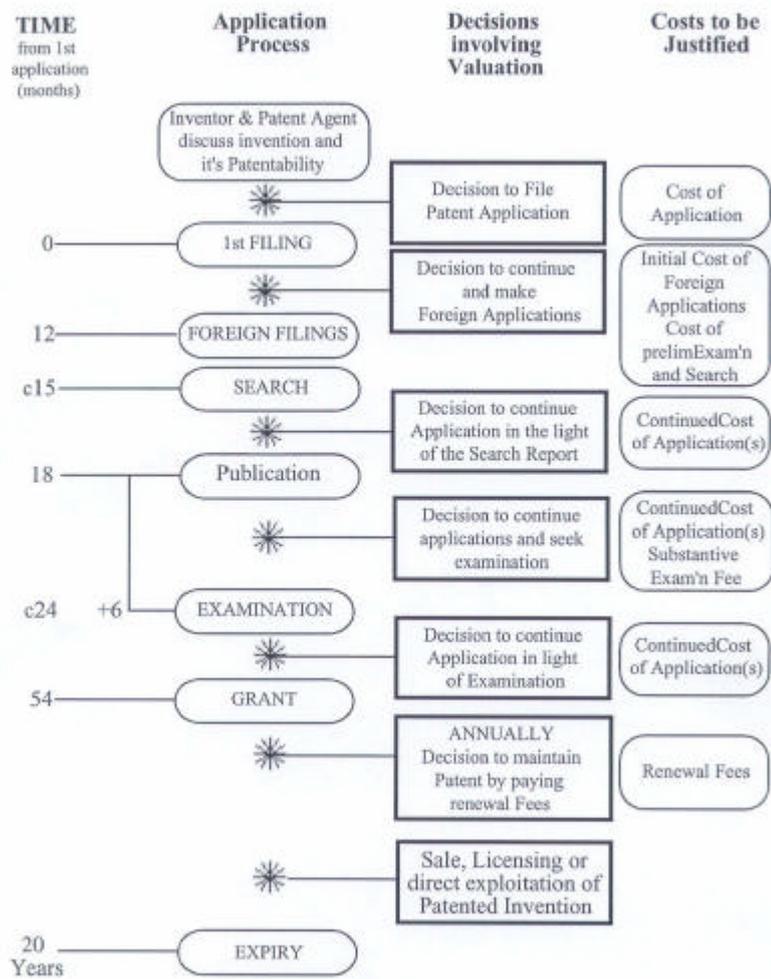
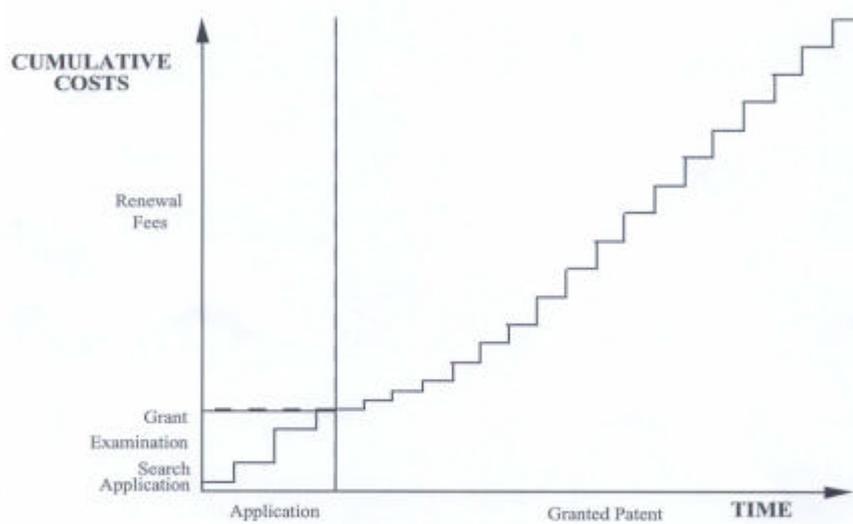Fig.1 Patent Valuation Decisions

Fig.2 Patent Application and Patent Renewal Costs

Fig.3 Patent Option Valuation Decisions