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Approaches to and methods for evaluating new technologies in Technology Transfer Offices: How long is a piece of string?

Suma Athreye, rapporteur

Edited by:
Annarita Ferreri
Sergio Grande

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On 22 November, the third edition of the annual best practices workshops of the European TTO Circle was held in Brussels. The focus of this workshop was the evaluation of intangibles and novel technologies. The author is very grateful to Giancarlo Caratti, Annarita Ferreri who organised the workshop, all the participants listed below whose presentations form the basis of this report, to Talita Soares, (EARTO) for her notes on the second session of the workshop and lastly to Sergio Grande and Pauline Nguru for the smooth running of the workshop.

List of speakers

Massimiliano Granieri (MITO)

Ian Brewer, Valuation Consulting

Ian Tracey, The Knowledge Transfer Network

Ludo Pyis, AREOPA

Zane Smilga, VERHAERT Innovations

Victor Paulissen, TNO

Tony Prézeau, CEA

Aude De Clercq, ESA

Eva Maria Vaquero, CIEMAT

Kathleen De Belder & Katrien Meuwis, IMEC

The workshop presentations can be directly accessed by clicking on the hyperlinks at the following website:

<https://ec.europa.eu/jrc/communities/community/tto-circle-community/event/evaluation-intangibles-and-novel-technologies-art-or-science>

Executive summary

The lack of a practical method to value Intellectual Property Rights (IPRs) is the main challenge faced by Technology Transfer Offices (TTOs) in the commercialization of inventions generated by university scientists. This report reports the discussions of a day long workshop organised by the JRC on two issues of interest to TTOs, viz. methods for valuation that can close the gap in investor and inventor perceptions and how best to value early stage technologies.

Trying to value a novel technology is akin to asking how long is a piece of string? There can be no definitive valuation of a novel technology; its value to users will vary depending on the use to which the technology will be put and the size of that product market, whether buyer or seller is conducting the valuation, and whether the valuation is subjective or objective. However, TTOs that grapple with this problem need to select the technologies that need valuation as well as identify those that need nurturing before they can be transferred to a private firm for further development. The report presents the different options for both that were shared at the workshop held on 22 November 2016.

The first part of the report contains the approaches to valuation used by private sector technology brokers who typically manage a portfolio of technologies in different technology domains. These approaches and methods may prove useful for TTOs that are organised centrally at the university level. The main problem highlighted is deciding which technologies to pursue and what assets the university should count as capable of generating intellectual property income streams.

The second part of the report focuses on the approaches used to value of RTOs early stage technologies by TTO circle members - most of the presentations were by TTOs organised around specific technology area. The depth of knowledge about the area meant that these organisations typically had the resources to evaluate the potential of technologies and markets much better and implemented a form of real options valuations in preferring to develop and spin out the technology before selling it. Patents were used a means to pin the technology to the company.

The valuation needs of the two types of TTO organisations are different but they share some common obstacles. The uncertainties faced by the TTO in valuation could be partially mitigated by maintaining a register of technology valuations by technology class which other TTO members could use in their negotiations with private firms. These data may also allow more sophisticated real options analysis about the sorts of investment and time horizons that may be required to make incubation pay-off for the TTO. A second concern shared by all TTOs is the tension between exploitation of technology by society and the often implicit requirement of generating a profit for the university. Clarity about the objective of technology transfer activities should be part of the mandate of TTOs.

Quick guide

Sections 2 and 3 summarize the discussions on valuing novel technologies that took place during the workshop. Section 2 outlines the approaches presented by private sector technology brokers to address the gap between the expectations of the inventor and investor while Section 3 discusses European TTO practices related to dealing with early stage technologies. Section 4 concludes with some implications for policy and practice. In addition, the report also contains two brief reviews of the academic literature on patent and technology valuation in the annexes for the benefit of TTO managers. Annex 1 reviews the academic literature on the value of patents held by firms which uses three methodologies: market value approaches; patent renewal methodologies; and survey based inventor valuations. Annex 2 reviews three standard approaches to valuation used by TTOs viz. Cost-based methods, market based and income based approaches (including real option approaches).

1 Introduction

Trying to value a novel technology is akin to asking how long is a piece of string? There can be no definitive valuation of a novel technology; its value to users will vary depending on the use to which the technology will be put and the size of that product market, whether buyer or seller is conducting the valuation, and whether the valuation is subjective or objective.

However, the lack of a practical method to value Intellectual Property is a main challenge faced by Technology Transfer Offices (TTOs) in the commercialization of inventions generated by university scientists. A survey conducted jointly by the Joint Research Council/World Intellectual Property Organization (JRC/WIPO) in 2011, found that valuation was a problem encountered mostly in the commercialization phase. Disagreements about valuations often result in investors being reluctant to commit funds for further exploitation. In contrast to firms performing research and development (R&D) which conduct valuations as part of the process of protecting their Intellectual Property (IP) and applying for patents, the JRC/WIPO survey found that only around a third of TTOs carry out valuation exercises in relation to IP protection. When valuing early stage technology, TTOs use a combination of qualitative and quantitative approaches and more than half rely on internal expertise. The survey found that 53% of TTOs use only internal expertise, 33% combine internal with external experts and 13% outsource this task to external bodies. TTOs use several commercial search tools/databases (e.g., EPO-PATSTAT, QPAT-Orbit, Thomson Delphion, used to assess freedom of operation)¹. To estimate potential market values, websites such as marketsearch.com and reportlinker.com and databases such as Thomson Innovation, Dianeconsulting, Avention/onesource and business-insight.com can be used. When technology licensing is the preferred option for commercialization sources such as the International Public Relations Association (IPRA), Edgar (upwork.com), royaltysource.com, etc., can be used to define royalty rates.²

It is unquestionable that the practice of valuation is likely to be more difficult for TTOs compared to firms for at least two reasons that are at the heart of what is involved in technology exchanges. First, TTOs must manage the different expectations of the inventor and investor (which arise from asymmetric knowledge and information about the technology), mediating which can be difficult. The TTO must keep the industrial partner on board for further development and commercialisation of technology but as a member of the university body they are also somehow speaking on behalf of the inventor. Second, the focal invention may be at an early stage and commercialization possibilities and the value of the technology in particular uses will likely not become clear until there has been more investment and development. Early stage novel technologies are likely to need more nurturing and more investment before transfer or commercialization is possible and funds for these are usually available in very limited quantities to the TTO.

The organisation of the TTO may also need to be considered in the extent to which these two issues apply. When TTOs are organised as a centralised department, commercialising technologies from several different technology departments it is likely that they will behave similarly to technology brokers who manage a portfolio of technologies with more general competences for managing technology. However, when TTOs are organised around one broad technology area, then more in-depth knowledge is available about both the technology and its possible uses. In this situation, a real options analysis where a TTO evaluates the cost of incubation, the time horizon of returns and returns from eventual sale against an outright sale of technology can be very useful.

Sections 2 and 3 of the report summarize the discussions on valuing novel technologies that took place during the workshop organised by the JRC. Section 2 summarizes the

¹ EPO-PATSTAT is the European Patent Office Patent Statistical Database; QPAT is a patent search system run by Questel-Orbit; Thomson Delphion provides access to full text patent specifications.

² WIPO/JRC presentation – Grenoble 19-20 October 2011.

(private sector) approaches presented to address the gap between the expectations of the inventor and investor and Section 3 discusses European TTO practices related to dealing with early stage technologies that were presented at the JRC workshop. Section 4 concludes with some implications for policy and practice.

The report also contains two brief reviews of the academic literature on patent value and technology valuation. Annex 1 outlines the three methodologies used to identify the value of patents to firms viz. market value approaches, patent renewal methodologies and survey based inventor valuations. Although they can provide useful benchmarks of value in particular technology classes, patent value approaches are *ex post* in nature, whereas TTOs generally have to manage a portfolio of technologies and need *ex ante* assessments of valuation, which are more difficult to establish. Annex 2 reviews the standard approaches to valuation used by TTOs viz, the cost, market and income based approaches. It is hoped that individual TTOs will find these annexes useful to identify the most appropriate approach for their purpose.

2 Working with the innovator and working with the investor: approach to valuation

How should TTOs and other innovation brokers select which, among the many inventions in their portfolios, they should evaluate? There are two aspects to this question. First, TTOs need more information from researchers about the technology business case rather than myriad details about its novelty and the prior art. Second, and relatedly, novel technologies are often early stage technologies so the real commercialization prospects may be unknown. Therefore, it is not surprising that, despite representing the inventors' interests, TTOs are often swayed by the buyer, who often makes the best case for actual use of the technology. This underlines that it is possible to rigorously value a technology only in the context of specific uses.

The problem of asymmetric information between buyer and seller on the true nature of the technology and, especially, its value seems to be among the most frequent problems encountered by TTOs, who are organised organized as technology brokers, and when the final use of the technology is still unknown. **Massimiliano Granieri**, (MITO, Italy) emphasized that assessment of a patent portfolio in terms of its exploitation is quite different from evaluating a patent to define its value or price in an imminent transaction. In particular, for TTOs with a large portfolio of inventions, *selection of inventions for rigorous valuation* is very important, a point confirmed by **Zane Smilga** (Verhaert, Netherlands). However, MITO and Verhaert outlined slightly different approaches to tackling this issue.

Verhaert recognized that there is an inherent conflict between what the technology's owners can demonstrate and prove versus what the technology buyers require for their business and are prepared to pay for. As technology brokers, they use a number of tools to envisage, validate and prove potential value/technology. In particular, they explore the value potential of the same technology in relation to different applications, solutions and business scenarios, using a proprietary Quick to Evaluate Business Opportunity software program. They undertake this value potential analysis at a "high level" for multiple applications of a technology and select the cases with the highest potential value for further exploration.

MITO uses a slightly different method based on a proprietary software algorithm.³ This algorithm proceeds in three steps. First, it calculates the available IP portfolio for valorization by deducting the IP already committed; IP that is co-owned, IP that is a national priority and IP that is near to expiry. Second, it identifies potential portfolio "slices" where value can be achieved based on multiple technology uses, geographical coverage and the patent's residual life. Third, it ranks the portfolio according to achievable revenue. In this purely empirical exercise, which does not establish a market value, as little as 15% of the portfolio can be judged to have value potential.

Ludo Pyis (AREOPA) presented a very sophisticated approach to valuing IP assets based on a detailed inventory of the firm's intellectual capital assets that could be protected and used to deliver value and an income stream. AREOPA's method regards both patents and human capital and other intangibles as capable of creating value and multiple revenue streams (e.g., based on income derived from patents and value derived from human capital based consultancy). These revenue streams are estimated using the latest accounting standards such as IAS38. AREOPA has developed and placed trade secrets on 77 econometric formulas that enable, based on the collection of evidence, identification of present and future value for TTOs.

Even in cases where the end use of the technology is clear, as in the case of merger and acquisition (M&A) transactions, **Ian Brewer** (Valuation Consulting), noted many caveats

³ Please see details of the algorithm in the presentation downloadable from:
https://ec.europa.eu/jrc/communities/sites/jrccties/files/2._granieri_brussels_2016.pdf

to valuation using the income method (see Annexe 2 for a description of the method). First, he pointed out that 80% of the corporate worth is invisible in the actual valuation because its inclusion is not permitted in many countries. Table 1, which is based on his presentation, shows some of the categories of corporate intangible assets that do not translate easily into IP valuations. Second, he highlighted several caveats related to valuations. For example, many revenue forecasts are based on projections from tax records, which may not always be accurate since firms may understate this revenue. Another issue is the definition of the useful lifetime of a technology is problematic - does it refer to its physical life, functional life, technological life, economic life or legal life? Lastly, there are many sector specific issues, such as less than 20% of seed inventions not reaching the market, related to identifying appropriate discount rates in Pharma. Pre-clinical discount rates range between 55% and 80% depending upon the phase of the clinical trial and making such sector-specific adjustments requires very fine judgement.

Table 1: 80% of corporate worth is in intangible assets

Category	Examples
Market-related	Trademarks, trade names, service marks, trade dress, newspaper mastheads, internet domain names.
Customer-related	Customer lists, customer contracts, customer relationships, customer agreements.
Artistic-related	Ballets, books, plays, articles, other literary works, musical words, opera, pictures, photographs, video and audio-visual material.
Contract-based	Licensing agreements, advertising or service contracts, lease agreements, construction permits, operating and broadcast rights, employment contracts.
Technology-based	Patented technology, computer software, unpatented technology, databases, trade secrets, secret formulae.

Source: Presentation by Ian Brewer at JRC workshop, November 2016 downloadable from

https://ec.europa.eu/jrc/communities/sites/jrccties/files/3_european_commission_-_ian_brewer.pdf

While many of the approaches presented in this session are customized applications of income-based valuation methods, it was recognized that the future use of the technology and the resulting income stream may not always be known in such great detail. The data on which to base sophisticated revenue streams may not exist and may be known only in hindsight. Thus, often times, rule of thumb methods may need to be used; one such, proposed by **Ian Tracey** (Knowledge Transfer Network), is presented in Table 2.

In the ensuing discussion, many TTOs have recognized that there is always an implicit reservation acceptable minimum price and rate of return acceptable to the TTO, irrespective of the valuations. After that, much of the valuation results from bargaining with the potential investor and what is possible for a commercialization opportunity. However, most often the problem of valuation tends to be passed on to investors

because they have the best information on the particular use to which the technology will be put.

Table 2: A simple rules approach to stage valuation

Stage of Development	Estimated Company Value (£)
An exciting business idea or business plan	250,000 - 500,000
A strong management team to implement the plan	500,000 - 1 million
Can demonstrate final product or technology prototype, and the supply chain in place	1 million - 2 million
A range of strategic partners in place, or signs of a relevant customer base	2 million - 5 million
Making repeat sales, clear signs of revenue growth and obvious pathway to profitability	5 million and up

Source: Presentation by Ian Tracey at JRC workshop, November 2016

https://ec.europa.eu/jrc/communities/sites/jrccties/files/4_ttocircle_valuationsdraftttracey.pdf

Can TTOs use the returns from valuable patents to offset the costs of creating and maintaining the patent portfolio, in a manner similar to what drugs firms do? This question produced a lively debate. First, it was noted that since TTO research is funded by full cost research funding, there is no pressure to behave in this way, although new accounting standards based on accruals rather than costs (proposed for 2020) may change this situation. Second, despite corporatization, TTOs do not behave like firms because their mission is still seen in terms of public science objectives. This means that opportunities for co-creation of value will always be preferred to non-use of technology. However, the valuation of TTO patents, if part of a co-creation process involving the start-up's own patents, seems to be a grey area where many participants would welcome some clearer guidelines.

3 From research to market: Experience of an IP valuation among European TTOs

It is worth noting that even in market-based economies such as the UK, where technology transfer via university licensing is quite well developed, patentable technologies are a small part of the technology transfer activities of universities, and universities produce many technologies that are not amenable to patenting (Athreye and Rossi 2017). Siegel et al. (2007) argue that alternative non-patent modes of commercialization, such as establishing and incubating spin-offs, are becoming more attractive as modes for technology commercialization and technology transfer. Not all intellectual capital is patentable and sometimes spin-offs are the best way to commercialize a technology. In terms of the frameworks for valuation presented in Annex 2, the choice between incubating a technology rather than trying to license it immediately is an example of real options theory applied to the valuation of early stage technologies.

TTOs who are focussed on a particular technology area, often face the choice between sale of early stage technology now or incubate the technology now and for a better priced sale later. Five examples of best practice related to very early stage technologies were presented in the second session of the workshop. Each provided interesting insights into the types of dilemmas experienced by TTOs, and the prevailing managerial mind sets in TTOs that influenced them to adopt particular commercialization strategies. These examples were presented as case studies.

Victor Paulisen (TNO) discussed the case of a multiple use optomechanics technology with potential for application in various fields. This technology is now the subject of 11 patents and involves a great deal of knowhow. TNO needed to establish an infrastructure to develop this technology further, retaining the organization's independence to perform research and engage in innovation activities using the technology and investigating relevant markets. TNO looked at various different sectors where the technology might be used and identified five main markets and a number of subsectors before defining the fields of use. A separate company, Nearfield, was set up to commercialize the non-integrated circuit uses of the technology.

TNO entered into two agreements with Nearfield. At the research stage, it entered an IP non-assert and a license agreement, which gave market access to the technology without a royalty charge, and a cooperation agreement with Nearfield to develop the technology further. It was agreed that, in the production phase, a royalty payment and a license agreement would be applied with an exclusive license for patent and non-exclusive agreement for knowhow. Payment related to the cooperation agreement was in the form of shares in Nearfield. This reflected the TTO's perception that this agreement needed to favour the investor as, otherwise, the product development would not continue.

Tony Prezeau (CEA) referred to two ways that CEA commercialized its technology: Technology push and market pull. The technology push model implies the existence of promising technologies, a motivated entrepreneur, but no identification of potential industry partners. Thus, technology push is greater than market pull. In the market pull model, an experienced entrepreneur with good market vision sees a diversified and state-of-the-art technology portfolio to support his ideas. An industry partnership was established with CEA. Although CEA is involved in eight or nine start-ups a year, the industry partnership model is more popular due mainly to faster return on investment.

CEA engages in decision modelling to provide start-up support and predict whether a technology portfolio is better transferred through a partnership or the creation of a new business based on the techno/market fit. However, the presenter warned that simulations present only a partial picture; not everything can be rationalized and, especially, human factors. He presented two examples – one, Movea, a company set up in 2007 that owns over 500 patents involving motion capture sensors and intelligence. Movea went through a long incubation period because of the difficulty of identifying a good business model. Finally, Movea was sold to InvenSense in 2014 for \$50million.

Overall, the investment was profitable, but for several years CEA was unsure of the value of its patent portfolio related to motion capture sensors and intelligence despite market studies suggesting their potential as consumer goods. Another CEA start-up, Wavelens, was championed by an entrepreneur who believed strongly in the technology but found it difficult to obtain venture capital funding or other types of funding. CEA invested in the development of a proof of concept for the technology, which resulted in interest being shown by many firms, one of which eventually bought the company and the IP and launched a partnership project with Leti, (CEA Tech's parent company).

In CEA's experience, large US and EU companies are interested in packaged IP, an already existing business model and proof of concept rather than the actual technology. It is more difficult to attract investors based on only the technology. The existence of concrete IP is fundamental to a successful start-up. The financial aspects of technology transfer are complex because pay-offs require industry partnerships, which may not exist at the time that the public investment in the technology is being made and costs are being incurred. It is impossible to reduce everything to an equation without subjective elements, such as intuition, intruding into the decision regarding commercialization.

Aude de Clercq (ESA) noted that the aim of the ESA technology transfer programme for non-space application is to promote competitiveness in the space industry and to develop the technology. Its approach to commercialization is based on the dissemination of knowledge. It supports start-up companies and has a portfolio of 400 patents, in various fields. ESA faced some difficulties in 2014 when changes were introduced to portfolio management which was accompanied by budgetary issues. ESA used consultants to help manage these problems.

They proposed a methodology to create a score-card based on four criteria: Technology (maturity, technology royalty and licensing, industrial feasibility, complete or incomplete technology); IP (patent strength, competitive patents, relevance of protection); level of competitiveness (technology in the market, competition, control of different assets); market (sectors of application, market needs, value added, time to market). Based on these criteria the consultants suggested a dissemination strategy, but did not spend time on valuation for licensing since the main objective aim was to diffuse the technology and cover the costs of the research. ESA values the fact that its technology portfolio is being used. It tries to support start-up companies. Since 2014, ESA has been conducting a process of capitalizing its patents, but this effort is still in its early stages. They have encountered problems such as lack of recording of patent invoices before 2014, the need to separate out the costs of patents in development, the costs of patents granted, and the costs of patent applications.

Kathleen De Belder and Katrien Meuwis (IMEC) presented an example of a TTO in the electronics sector. IMEC has a variety of programmes. The electronics sector involves a significant level of in-licensing which, in turn, involves technology transfer and patent valuation as both the buyer and seller of technologies. As buyers of patents for in-licensing within spin-off companies, IMEC evaluates patents based on several criteria such as status, countries and scope. IMEC discovered that the price it was willing to pay was often lower than what firms were asking. However, its experience of being a buyer helped in the selling of patents. IMEC believes that selling patents without knowhow is difficult since it is important to look at all the risks involved (history, buyer's image, usage, age, value, etc.). Much effort is needed to conduct due diligence and detect infringements (call-back research and consultants are expensive). In the context of pricing, IMEC consults industry standards, foreign markets and citations. IMEC also related the case of a patent sale, something the other TTOs did not mention.

Eva Vaquero (CIEMAT) represented a different type of TTO. CIEMAT is the second largest research body in Spain and operates in 12 thematic areas and 47 different research lines. Currently, it manages 439 research projects. Its challenge is to organize knowhow encompassed by the organization in order to make it available to industry partners. Spanish law recognizes three types of intangible resources: IPR, industrial property (patents) and other property types (technical services, capabilities). It is not

possible to provide strong protection for all these intangibles so CIEMAT has developed a proprietary software system to manage these intangible resources, and a database containing information on them. The database is external-facing and allows firms to search for and generate technology transfer contracts. Development of similar systems might be useful for other large multi-technology TTOs.

An outstanding feature of the presentations was the universally shared belief that commercialization of university knowledge requires support from industrial partners. However, the mode of commercialization chosen would seem to depend on the time horizon within which returns are expected. Short times to commercialization could favour patents and licensing, but longer time horizons and the availability of capital (often involving TTO investments) may favour incubation of start-ups to realize the full potential of the technology. In general start-ups were considered a superior route to the commercialization of university technology.

It was apparent, also, that TTOs' core missions and objectives differ. Some TTOs, such as ESA, saw their core mission as being to diffuse the technology as widely as possible, consistent with a public science mission. Others were under pressure from universities and government to generate revenue to support their research activities. Almost all of the TTOs represented felt the need for greater clarity about the public science role of TTOs, which was frequently seen as inconsistent with the objective of generating revenue from research.

4 Summary and implications

Asking about the value of novel and early stage technology is akin to asking how long is a piece of string? The value of technology differs depending on how it is commercialized and for how long it can be developed. The benefits of technology to society and industry flow from the commercialization effort, to which valuation contributes. This report has reviewed several current practices in valuing patentable technologies. It has also highlighted the fact that the nature of problems faced are likely to be related to the overall organisation of university/RTO TTOs, with large centralised TTOs being more similar in their organisation and management to technology broker firms while decentralised technology area specific TTOs may not face the same kinds of issues. Indeed, the presentations suggested the problem confronting technology area focussed TTOs is on the best mode of commercialisation while the problem confronting technology brokers typically is the choice of which technology to select for commercialisation.

The methods used by private firms to value their technology are of limited use to TTOs because, in their role of broker between the inventor and the industry, they need to evaluate the technology before it can be offered for sale. However, the range of value methods presented could act as useful benchmarks for such TTOs. We also reviewed existing methods of valuation available to TTOs, but more detailed analysis which can highlight the match between technology and the method of valuation might be something that the JRC could consider commissioning in the future. More analysis would shed light on the appropriateness of certain methods of valuation for particular technology compared with others, and provide suitable benchmarks for early stage valuation of different technologies.

The uncertainty related to valuation for both types of TTOs could be mitigated by such methods as compiling a database of valuations by technology class, to which TTO members could refer in their negotiations with industry partners. These data might also allow more sophisticated real options analysis to identify the best means of commercialization through spin-off activity with incubation or patenting and outright sale of the technology. Currently, this choice depends crucially on whether or not a technology is patentable but a serious use of real options could demonstrate more viable options.

Lastly, policy bodies need to take account of the discomfort felt by TTOs at the compromising of their public science role, which has long term social benefits that far exceed the profits made by universities. There also needs to be more debate about the funding of public R&D and TTOs might find it useful to try to measure not only the private returns from technology but also the social returns on their technology investments. Private rates of return include the costs borne by the TTO (or university) and the benefits that flow to the TTO. Social rates of return would also include the costs and benefits to the rest of the economy (particularly taxpayers and industry partners that co-invest in the technology).

All these suggestions will strengthen the evidence base of policy and managerial action directed to the commercialisation of publicly funded research.

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List of abbreviations

DCF	discounted cash flow
IP	Intellectual Property
IPRs	Intellectual Property Rights
IPRA	International Public Relations Association
JRC	Joint Research Council
M&A	Merger and Acquisition
TTO	Technology Transfer Office
R&D	Research and Development
rNPV	risk adjusted net present value
WIPO	World Intellectual Property Organization

Annexes

Annex 1. Review of the academic literature on the value of patents for firms

In a wide-ranging review of the literature on patent value, Arora, Athreye and Huang (2009) identify three main approaches used by firms to estimate the value of patents to firms: The market value approach; the patent renewal approach; and, the inventor survey approach.⁴ The market value approach uses stock market values and the investor's implied evaluation of the firm's tangible and intangible capital stock (which includes patent stock). The patent renewal approach analyses patent renewal records and the costs of patenting and renewing, in order to assess the distribution of patent revenue from the perspective of the patent holder. Although what is measured using this method is different from the market value approach, we expect the measures to be related. A valuable patent enhances a firm's profitability which, in turn, means that a stock market investor will value the patent-holding firm higher than some other firm. In a perfectly competitive market it should be possible to derive one measure of patent value from another.

Unlike, the market value and patent renewal approaches, which are objective evaluations in the sense that they use stock market and patent renewal data to infer the returns to the firm from patenting, the inventor survey approach is very different: It proposes a subjective evaluation (by the inventor) of the value of his/her invention. The subjective approach is prone to biases and over-estimation; Arora, Athreye and Huang (2009) found that inventor survey approaches produced the highest patent value estimates. In what follows, we examine each of these three approaches in turn.

The market value approach

In the long run, in a competitive market, a firm's market value should be directly proportional to the costs of replacement of its assets. In practice, tangible assets are the easiest to measure. Patents add to the firm's intellectual capital and have the capacity to generate future income. Firms in position of such intellectual capital are able to earn higher rates of return for the same physical capital and, therefore, will be preferred by stock market investors. Such firms will exhibit stock market values that are systematically 'in excess' of the replacement/book value of their tangible assets. This is the reasoning that informs the market value approach. Estimates of patent values are obtained by regressing the firm's market value per unit of capital (as observed by stock market investors) on its patent stock and adding this to the stock of physical capital, to obtain the elasticity of market value with respect to patent stock.

Griliches (1981) first applied this approach to an analysis of the data related to 157 US listed companies during the period 1968–1974, arguing that a successful patent was worth around \$200,000 (\$382,960 in 2005 values). Pakes (1985), analysing data on 120 US public firms for the period 1968–1975, find that a 1% increase in the number of patents, on average, represents only a 0.044% increase in the firm's market value, while each additional patent is associated with an increase in the firm's market value of \$810,000 (equivalent to \$3,041,148 in 2017). Cockburn and Griliches (1988) analyse cross-sectional data for 772 US manufacturing firms and report the average value of a patent in 1980 at around \$400,000 (equivalent to \$837,703 in 2017) and that this was significantly higher for industries where the effectiveness of patents (a variable to measure appropriability conditions) was two standard deviations higher than the average.

Methodologically, most studies in this tradition follow Griliches (1981) and use Tobin's Q as the dependent variable. Tobin's Q is defined as the firm's current market value divided by the replacement cost of its physical (tangible) assets. The explanatory variables used usually include R&D investment stock divided by tangible assets, patent stock divided by tangible assets and R&D investment stock. Most findings are reported as the percentage increase in market value associated with one additional patent application or one

⁴ This section draws heavily on Arora, Athreye and Huang's (2009) unpublished review.

additional patent citation. A few studies provide estimates of monetary values based, in most cases, on average industry parameters.

Although market value studies controlled traditionally for R&D stock, an important improvement during the 1990s was the introduction of measures to control for innovation quality, which can be an important omitted variable giving rise to large estimates for patent value. Trajtenberg (1990) and Hall et al. (2005) pioneered the use of patent citations as an instrument to measure the quality of innovation. Trajtenberg (1990) collected data on the value of and total gains from innovation in the case of tomography scanners, and the associated patents and citations to these technology patents. He found that patent counts weighted by citation rather than simple patent counts were significantly correlated with the value of innovation in that case. Hall et al. (2005), based on 1976-1995 data for US public firms, argue that, on average, one additional citation to patent increased the firm's market value by 3%. However, the returns to additional citations are skewed. Hall et al.'s analysis shows that receiving twice the median number of citations can increase Tobin's Q by about 35%, while receiving three times the median number of citations can increase the market value premium to 50%.

Market value studies show that the value of patents varies by technology sector. Lanjouw and Schankerman (2004), in the context of the US, use claims, citations and family size as indicators to construct a patent quality index for 1975-1993 patents. They found that, for a US public firm, an increase in the patent quality index distribution from the 50th to 75th percentile was associated with increased market value of 9.4% for drugs, 7.7% for health products, 2.5% for electronics and 1.3% for mechanical. The study also found that the 16% increase in citations in Hall et al.'s (2005) study was due to changes in innovation quality and that the remaining 84% reflected an increase in the "propensity to cite", which might be caused by computerization in patent offices. Measurement errors such as this will typically impose a downward bias on the estimated returns from patenting.

In sum, not all studies that adopt market value approach report monetary values for patents, but based on the estimates in those that do, the maximal estimate of the value (in 2005) of an additional patent is \$13,244,914 (Connolly and Hirschey, 1988) and the minimal is \$382,960 (Griliches, 1981).

The patent renewal approach

Another approach to estimating the value of patents assumes that patent owners aim to maximize the private value of their patents, which accrues over a number of years. The patent owner's objective is to maximize the discounted value of the returns from a patent minus the cost of the patenting process. If the discounted value of the return is greater than the cost of the renewal fee, the patent owner will choose to renew the patent. Based on these micro foundations, several studies use the proportion of patents renewed every year and the cost of renewal, to estimate the distribution of the initial returns and the decay rate of the returns.

Patent renewal studies vary in what they include in their models as constraints to the patent renewal decision. Shankerman and Pakes (1986), Pakes (1986), Pakes and Simpson (1989), Lanjouw (1998), Baudry and Dumont (2006) and Bessen (2008) model only the renewal decision. Putnam (1996) and Deng (2007) include the patent application and the renewal decision together. However, their models do not differ fundamentally from the earlier model proposed by Shankerman and Pakes (1986). Putnam and Dent include the cost of application as a constant variable in their application-renewal model, while adopting the rule and mechanism of the renewal decision in Shankerman and Pakes (1986). The rule is that the patent will be renewed only if the discounted present value of the return from the renewed patent is greater than the renewal fee. The mechanism in Putnam (1996) and Deng (2007) is that the value of patent right is allowed to decay deterministically.

The studies by Pakes (1986), Pakes and Simpson (1989) Lanjouw (1998) and Baudry and Dumont (2006) relax the assumption that the returns to patent rights decay deterministically. They allow for a stochastic return, uncertainty and learning in the renewal decision; additionally, Lanjouw (1998) allows for litigation. The patent value is split between the value of the current year's return from patent protection and the value of the option to renew the following year should the patentee desire to do this. If the value of the current year's return is less than the renewal fee, but the value of the option to renew the next year is sufficient to allow the patentee to recover the loss, the patentee will renew the patent. In a patent renewal model with a deterministic decay rate, the patentee will choose not to renew.

Pakes (1986), Pakes and Simpson (1989) and Lanjouw (1998) also use dynamic programming to estimate the length of time required to learn about patent value, finding that the learning process is not overly lengthy. In a period of some 5–6 years, most patentees discover the value of the patent rights. The major contribution made by stochastic return models of decay is the finding that, because learning is concentrated in the early period of patent rights, the uncertainty surrounding patent value usually disappears after a period of 5–6 years. With the exception of Bessen (2008), none of the studies link patent data and firm-level data. Baudry and Dumont (2006) use a method similar to that proposed in Pakes (1986), but apply a more generalized stochastic process (binomial tree) that is standard in the finance literature, to evaluate the value of the option to renew the patent in the next year.

Table 3 summarizes the findings from a number of studies of patent value. The higher values of means relative to medians suggest a high level of positive skew in the data. In Table 3, the maximal estimate of the mean value of a patent is \$116,527 (Barney, 2002) and the minimal estimate is \$2,390 (Baudry and Dumont, 2006). There are differences, also, in the returns to patenting across broad technology sectors with pharmaceuticals earning the highest returns.

The means and medians of the estimates reported in Table 3 are thousands or tens of thousands of dollars, which is considerably lower than estimates using either the market value approach or the inventor survey approach (see Section 2.3). This is in line with our earlier discussion that the value of patent rights (which is what renewal studies measure) is likely to be lower than the value of patent protection.

Table 3 shows, also, that patent renewal studies (similar to the market value studies discussed earlier) demonstrate that patent returns vary by sector although this may be conditioned by national technological specializations. Thus, Lanjouw (1998), in a study of West German patents, finds that pharmaceutical patents earn the highest returns (median value \$19,632), while Schankerman (1998) in a study of French patents and in a similar time frame to the Lanjouw study, finds pharmaceutical patents to have the lowest value (median value \$3416).

Another significant contribution to this stream of literature is Bessen (2008) who, using patents matched to firm level variables, adds to the model controls for patent quality (e.g., forward citation and litigation), R&D expenditure and the assignee's number of employees. On this basis, Bessen (2008) is able to show that large firms have higher value patent than small firms, and that the number of lawsuits involving a patent is a better proxy for patent quality than forward citations to the patent.

The patent renewal approach is powerful because it uses observed behaviour. However, there are two principal methodological issues related to using this approach. First, in assessing the returns to patent protection, knowing the value of the median patent is insufficient or even misleading; the mean value is arguably more important.⁵ Estimating mean values requires assumption about the nature of the distribution and renewal studies typically assume log-normality. This assumption of log normality has not been

⁵ Ultimately, patent renewal studies focus on the most valuable patents since these are always likely to be renewed to their full term. Therefore, this approach can provide only a lower bound to the value of the firm's patent portfolio.

adequately tested in patent renewal studies. Silverberg and Verspagen (2007) apply extreme value statistics to citation and value measures of patent significance and find that while, overall, the distributions appeared to resemble a lognormal, they tend to have fat tails.

Second, and related to the first issue, the approach assumes that each renewal decision for each patent is taken independently of renewal decisions related to other patents. However, we know that a commercial product or process, typically, is covered by several patents and, at the time of filing, the firm does not know which will be more valuable. Over time, the more useful (valuable) patents become known to the firm and are renewed, while those that are less valuable are not renewed. In other words, a substantial fraction of patents are filed as options. As information is revealed, the worthless options are discarded and the worthwhile options are preserved. Moreover, it could be that, in the case of very valuable inventions, many patents are filed, most of which eventually are discarded. By not considering this interdependence explicitly, patent renewal studies may present misleadingly low values for patent protection.

Finally, this approach ignores other sources of returns from patent protection such as the ability to deter rivals.

The inventor survey approach

In contrast to the first two objective approaches, estimations of the market value of patents can be based on the subjective estimates of inventors at the date of invention. For example, in the PatVal-EU survey of EPO patent inventors in France, Germany, Italy, Netherlands, Spain and the UK (Giuri et al., 2007), inventors were asked to give their best estimates of the minimum price that the patent owner - whether a firm, some other organization or the inventor would have put on the patent rights on the day that the patent was granted. The estimated mean of the resulting patent value distribution is greater than €3 million (\$3,831,611) and the median is around 13% of the mean (\$510,882) (Gambardella et al., 2008).

Harhoff et al. (2003) analyse the 10,780 German patent applications filed in 1977, using a model similar to an ordered probit. The upper bound of the value of patent rights not renewed to full term is estimated at \$50,807. This value is higher than the sum of the patent renewal fees and the cost of patent attorneys, estimated by the authors to be about \$33,763.⁶ Reitzig (2004a) analyses the data from an EPO survey conducted in 1994, on 612 patents from five different industries. He finds that patent protected inventions, on average, are worth \$2.37 million to their owners.⁷ Giummo (2010) analyses the records of private corporations on the compensation paid to employees for their inventions, which is a requirement of the German Employee Invention Act. The mean cumulative value of the sample patents is approximately \$287,094.⁸

⁶ Original estimates were in DM and the value of the upper bound was estimated to be DM45,144 while the sum of patent renewal fees and cost of attorneys was estimated to be DM 30,000.

⁷ Original estimates were in Euros and patented protected inventions were estimated to be worth €2.04m.

⁸ The original estimates were reported as DM283,268 (1977 value).

Table 3 Estimated patent values from patent renewal studies

Authors, year	Coverage of data			Estimate of patent value			
	Country	Sector	Years	Original value*		Value in 2005 USD	
				Mean	Median	Mean	Median
Pakes, 1986	France	All	1950-1979	5,631	534	11,793	1,118
	Germany	All	1950-1979	16,169	6,253	33,862	13,095
	UK	All	1950-1979	37,826	1,517	79,217	3,177
Schankerman and Pakes, 1986	France	All	1950-1979	6,656	897	13,939	1,879
	Germany	All	1950-1979	19,124	5,710	40,451	11,958
	UK	All	1950-1979	6,962	1,861	14,580	3,897
Schankerman, 1998	France	Pharmaceuticals	1969-1982	4,313	1,631	9,033	3,416
	France	Chemicals	1969-1982	4,969	1,594	10,406	3,338
	France	Mechanical	1969-1982	15,120	2,930	31,665	6,136
	France	Electronics	1969-1982	68,502	7,933	143,461	16,614
Lanjouw, 1998	W.Ger-many	Computers	1955-1988	23,495 ¹	13,050 ¹	35,345	19,632

Authors, year	Coverage of data			Estimate of patent value			
	Country	Sector	Years	Original value*		Value in 2005 USD	
				Mean	Median	Mean	Median
Lanjouw, 1998	W.Germany	Textiles	1955-1988	17,486 ¹	8,514 ¹	26,305	12,808
	W.Germany	Engines	1955-1988	49,728 ¹	33,169 ¹	74,809	49,898
	W.Germany	Pharma-ceuticals	1955-1988	81,643 ¹	50,434 ¹	122,821	75,871
	W.Germany	All		30,000 ¹		45,133	
Barney, 2002	USA	All	1986	73,340 ²	6,930 ²	116,527	11,011
Baudry and Dumont, 2006	France	All	2002	2,081 ⁵		2,390	
Deng, 2007	Germany via EPO	All	1978-1996	69,400 ³	29,000 ³	78,288	32,714
Bessen, 2008	USA	All	1991	78,000 ⁴	7,000 ⁴	101,918	9,146
Gronqvist, 2009	Finland	All	1971-1990	7,550 ⁵		8,673	

* All original values are expressed in 1980 USD unless otherwise stated.

1 1975 DM; 2 1986 USD; 3 2000 USD; 4 1992 USD; 5 Euro

The maximal estimate of the mean value of a patent in the studies cited above is \$3,831,611 (Gambardella et al., 2008) and the minimal estimate is \$50,807 (Harhoff et al., 2003). An important contribution of the PatVal and other inventor surveys is that they focus on patents applied for rather than patents granted. Thus, the PatVal approach eliminates biases that can creep into patent value estimates obtained using older approaches, which examine patents already granted. Another important contribution (alluded to earlier) is that PatVal documents the extent to which patents are used for blocking (social welfare decreasing) and licensing (social welfare enhancing). However, this comes at a cost. In being subjective, PatVal leaves room for other kinds of biases in the valuation estimation, for example, inventors are likely to overestimate the importance of their work, and an inventor's valuation of his or her patent may diverge significantly from the firm's valuation.

Bessen (2009) offers some explanations for the discrepancies (in the range of hundreds of thousands of dollars) among estimates based on the market value approach and the higher estimates in the inventor survey approaches, particularly PatVal. He argues as follows. First, EPO patents are likely to be several times more valuable than the corresponding US patents because the EPO imposes stricter standards and inventors obtain fewer EPO patents per invention. Second, inventors' estimates relate to the value of the invention rather than the value of patent rents, which are estimated by the market value approach. The value of the invention, according to Bessen, includes the value of the patent rents plus the rents the firm earns from its lead time advantage, learning-by-doing, etc. Thus, the value that the firm puts on the invention is likely to be greater than the value of patent rents. Third, Bessen argues that the survey responses might be inflated in the case that there are multiple patents on a single invention. Selling just one of these patents to a competitor may prevent the original firm from using the invention and, thus, the reservation value might reflect the value of all the patents covering the invention.

Annex 2. Technology valuation methods commonly used in Technology Transfer Offices

The methods used to value the patents held by a firm are of limited use to TTOs. Although the values of patents for particular technologies can be useful benchmarks, the TTO office needs an *ex ante* valuation of the technology. Approaches to assessing the value of patents, such as those outlined in Section 2, consider patents and technologies in use in particular goods markets. However, a TTO may not always be able to assess in which market the technology will be used most profitably. Indeed, the purpose of technology transfer arrangements is often to allow firms to determine the best use of the technology. Patents, by conferring an ownership right to a piece of technology enable such transfer.

Once a technology is deemed patentable, the task facing a TTO is to determine a monetary valuation of the future licensing incomes that may be derived from the product. As Pitkethly (1997) points out, in effect, this is an estimate of future licensing incomes based on different economic scenarios. However, as Siegel et al. (2007) suggest, since TTOs are an intermediary safeguarding university IP, there is also a desire to maximize the returns from the IP portfolio for the university. Scientists' evaluations of their technology may not be accurate and may not match potential buyers' evaluations of that technology; TTOs can be caught in situations of asymmetric information, which complicate the process of assessing value.

There are several methods for valuing IP, but scholars of patent valuation emphasize three main technology valuation approaches, proposed by Parr and Smith (1994). These are the cost-based, market-based and income-based approaches. Below, we review each of these in turn.

Cost based approach to technology valuation

Cost based approaches seek to value the technology based on the costs incurred in production (Carte, 2005). Costs refer to all direct costs incurred in generating the technology, obtaining a patent and commercialization. The objective of this method is to fully recover the total investment from the sales value of the patent. Monitoring costs is straightforward and is a relatively simple method if the future uses of the technology are unknown or if the invented technology is a radical innovation, allowing no market comparisons.

Smith and Parr (1994, 2000) identify two variants of the cost method - reproduction cost and replacement cost. The reproduction cost method assesses the costs from the university's perspective and asks what the buyer should pay to exactly replicate the product. The replacement cost method assesses the cost from the point of view of the buyer (usually a firm) and asks what the firm would have to pay in order to produce a technology with comparable functionality. This is akin to an opportunity cost measure for the firm buying the technology.

The reproduction and replacement estimates may not coincide, which can be a problem for TTOs since cost based approaches may reflect the presence of asymmetric information between scientist and buyer, rather than being an objective method to settle any differences. Furthermore, the cost based approach takes no account of future income streams that might be attributed to the technology. This may be acceptable in the case of radical and early stage technologies, but not for mature technologies or technologies that have substitutes.

Market based approaches

Market based approaches, pioneered by Stewart (2001), adopt an intellectual capital model, which posits that the market value of a TTO reflects the total value of its tangible and intangible assets. Thus, using this methodology, the difference between the book value and market value represents the value of the patent. In this respect, the market based approach is quite similar to the market value approaches reviewed in Section 2.1. However, in the absence of projected/actual earnings, TTOs often assess the market value

of the technology based on comparative valuation of the focal technology and other similar technologies being used by buyers.

Wu and Tseng (2006) show that using a market based approach usually results in two values for the patent: A minimum value which is based on the cost of developing the patent, and a sale value which is based on demand (number of buyers). In terms of practicalities, Damodaran (2007) and Flignor and Orozco (2006) recommend that comparative valuation should be conducted in two steps. First, screening commercial transactions to identify similar businesses or assets being traded in the market; and, second, conducting an adjustment in which the valuation parameters are defined by estimates based on market data. In the screening stage, business analysts typically use companies in the same industry or transactions of similar (technology) patents. Copeland et al. (2005) suggest using an earnings-multiple approach to apportion the assets, while Damodaran (2007) suggests adjusting for such factors as market growth.

The market based approach is data intensive and suitable for use in contexts where huge amounts of data are available. It has been used to determine royalty rates based on industry standards reflected in databases such as the Licensing Economics Review. However, as Shane and Elgar (2004) note, in the case of research that generates radical innovations, it is often very difficult to find similar technologies and variables to use for comparison. Similarly, in the case of multipurpose technologies, the method can break down or become computationally expensive.

Income based approaches

Income based approaches are more complex computationally, but share the common premise that the value of the patented technologies should reflect their income earning potential. There are four main methods: The discounted cash flow (DCF), risk adjusted net present value (rNPV), NPV with Monte Carlo simulation, and real options.

Brearly and Myers (1998) note that DCF methods are used by managers to calculate internal rates of return and payback times or life of asset such as bonds, securities and buildings. The main difficulty related to DCF is finding an adequate rate of discount since future income streams depend on many factors such as the overall functioning of the economy. In practice, these problems can be overcome by the use of capital asset pricing models and the cash flows of other companies with equivalent risks. Once a discount rate is established, the investor compares the discounted rate of return with the internal rate of return and funds those projects with a higher internal rate of return or one equal to the discounted rate of return.

DCF methods underlie the calculation of NPV, which is defined by:

$$NPV = -I \pm \frac{\sum_{t=1}^n FC_t}{(1+k)^t}$$

where I refers to the value of investment, FC_t is present cash flow value, k is the discount rate and t is the payback life of the technology. A positive NPV indicates a technology that is economically viable, while a negative NPV indicates a technology that is not economically viable. If $NPV=0$, I indicates that the investment in the technology is recovered and the NPV method yields similar results to the cost method discussed earlier. The payback life of the project t is an interesting variable since it is generally based on the number of periods that a TTO manager considers reasonable to recover the investment in the technology. It is likely that firms may have a shorter implicit t than TTOs.

Technologies developed by universities are embryonic or in the early or intermediate stage of development. Razgaitis (2009) identifies four types of risk that need to be evaluated when valuing technologies. First, there are risks specific to the technology, such as the stage of development, and risks associated to R&D activities, product development and design for manufacture (prototyping) and the (rising) costs of raw materials. Second, there are risks associated to the market such as forecasting market demand, acceptance of the technology product, product lifecycle and purchasing power of

the target market. Third, there are IP related risks such as the scope of the protection and the protection of trade secrets. Fourth, government policy and societal values can make certain types of technologies infeasible. In recent years many applications of stem cell technologies, such as cloning, or use of genetically modified seed, have encountered ethical objections in Europe.

The rNPV takes a static view of these risks and assigns both a risk rate and a discount rate to NPV calculations. These two rates can vary according to the stage of development of the technology; the pharmaceutical industry tends to favour this valuation method since prior research shows that the probable success of a drug differs at different stages in the drug's technological development (e.g., discovery stages have the highest risk, while the risks can be considerably reduced at the clinical trials stage). In general, the rNPV method involves five stages of calculation. First, the cash flow in the technology development phase is calculated; second, the cash flow for the market phase is calculated; third, the discount rate is applied to the cash flow to obtain the DCF; fourth, there is an adjustment made for the risk (probability of success) involved in each stage; five, the risk adjusted DCF are summed. In terms of the NPV equation, the rNPV can be written as (note that $p(t)$ refers to the probability of success at any stage):

$$rNPV = -I \pm \frac{\sum_{t=1}^n p(t)FC(t)}{(1+k)^t}$$

rNPV methods can be made more sophisticated by the incorporation of probability distributions instead of point probabilities. Thus, one could use a binomial distribution of $p(t)$ modelling the probability of success or failure at every stage, or employ Monte Carlo methods which allow the inclusion of any probability distribution to model the risk profile.

Given the irreversibility of technological investments, uncertainties inherent in the development and commercialization of early stage and novel technologies, and the possibility of postponement of these investments, a more promising development is real options theory for evaluation. When DCFs are modest or minimal, TTOs often have to rely on some form of subjective judgement in order to decide whether or not to pursue commercialization. Van Putten and Macmillan (2004) explain that *options* provide the right, but not the obligation to invest in a project. Therefore, their value is driven by the possibility of achieving a large upside gain combined with the fact that TTOs can usually abandon a project before the investment becomes too high, which limits the downside. Therefore, the value of an option must increase as the uncertainty (and, thus, the potential upside) surrounding the underlying asset increases, whether the asset is financial or "real."

There are several examples of real options valuations from the pharmaceutical sector, where agents keen to acquire a technology have a number of options. They can decide on investment in an early stage technology in the expectation of a large gain in the future but, at a lower premium, they may choose to acquire a more developed version of the technology, at a higher price but with lower risk. Similarly, university TTOs can use real options to decide whether it is better to choose commercialization now or to postpone licensing in order to develop the technology further for particular applications. Section 5 shows that in several TTOs, this form of thinking implicitly underlies the choice between commercialization through patenting or incubation.

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