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**Abstract**

Technology is crucial for strategic success, and the valuation of technology is necessary for a firm's financial and accounting practices, strategic decision-making, and risk management. Although there have been valuable studies examining the impact of individual factors on the value of a technology, we still lack a comprehensive and systematic understanding of the determinants of the economic value of patented technologies. This article proposes a utility theory of technology value, which argues that the economic value of patented technology is determined by the utility that technology provides and is shaped by four intrinsic attributes: the usefulness of a technology and related market size, the quality of the technology, the enabling environment to deliver the utility, and risk and risk management. This valuation framework provides a valuable theoretical foundation for researchers and practitioners to use in future technology valuation.

**Keywords:** Technology, Patents, Valuation, Utility Theory, Startups

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## 1. Introduction

Due to the tacit and complex nature of technology and uncertainties in the market, there are information asymmetries between inventors and investors. This knowledge asymmetry has become a bottleneck hindering technology from being developed, transferred and commercialized for large-scale use in the economy and society. The increasing importance of intellectual capital relative to that of physical assets has made the valuation of technology even more important (Hagelin, 2002; Haskel and Westlake, 2018). Accurate valuation of technology assets is critical for a firm's strategic decision making and financial reporting, which subsequently affect a firm's mergers and acquisitions (M&As) transactions, capital raising, and intellectual property management (Dahmash, Durand, and Watson, 2009; Smith and Cordina, 2014).

Although the impact of individual factors on the value technologies has been discussed in the literature (e.g., Harhoff, Narin, Scherer, and Vopel, 1999; Reitzig, 2003; Hall and MacGarvie, 2010; Moser, Ohmstedt, and Rhode, 2018) and there have been different valuation approaches developed in the finance literature and in practice (e.g., cost approach (Mard, 2000), income approach (Thorn, Hunt, Mitchell, Probert, and Phaal, 2011), real option analysis (e.g., Oriani and Sobrero, 2008), the specific value points approach (Vega-González, Qureshi, Kolokoltsev, Ortega-Martinez, and Saniger Blesa, 2010), and peer benchmarking (Baek, Sul, Hong, and Kim, 2007; Hsu, Hsu, Zhou, and Ziedonis, 2021)), there is an absence of a systematic theory underpinning the practices used and a lack of a comprehensive valuation framework.

The existing theories of value, for example, the labour theory of value (Marx, 1867; Schroeder, 2008), the cost theory of value (Sraffa, 1951; Kurz, 2000), and the utility theory of value (Menger, 1976) have provided a valuable theoretical foundation for effectively defining and explaining the value of tangible goods, especially those labour-intensive products. However, there are significant limitations in applying these theories to explain the value of technology. Different from tangible products, technologies are characterized by a high level of human creativity, technical complexity, intangibility, and high risks and uncertainties in fulfilling their potential.

McMillan, Siegel, and Narasimha (1985) attempted to use an integrated framework to examine the criteria used by venture capitalists (VCs) to evaluate new venture proposals. The results showed that the quality of the entrepreneur was the most crucial factor in funding decisions. Following this study, other attributes of entrepreneurs, such as entrepreneurial passion and openness to feedback, are found to be important when VCs make investment decisions (Warnick, Murnieks, McMullen, and Brooks, 2018). These studies have offered interesting insights, but they, too, did not provide systematic theorisation for the factors considered important in the evaluation process.

This paper aims to fill the gaps in the literature by establishing a systematic valuation framework of patented technology, based on prior research. Drawing on the utility theory of value and other related literature in innovation economics and finance, a utility theory of technology value is developed to define the economic value of a patented technology and also offer a theoretical explanation for the technology valuation methods utilized in the industry. We argue that the value of a patented technology is determined by the utility it provides to consumers, and the utility is shaped by four intrinsic attributes: the usefulness of a technology and related market size (utility), the quality of the technology, the enabling environment to deliver the utility, and risk and risk management. This framework is corroborated by the evidence from a sample of 1,426 startup firms (aged <=5 years) with patented technology in the Information and Communication Technology (ICT) sector from California, US, from 2001 to 2022 (observations=2,616).[1] The ICT sector is selected because of its high intensity in patented technologies and California is the world leader in the manufacture of computers, electronics and software. Startups typically possess limited tangible assets, and their patented technology encompasses the utility of technology users and the competitive advantages gained from innovation (Fischer and Leidinger, 2014). Therefore, we use the fundraising of startups as the closest proxy for the private market value of their patented technology, which is unobservable in existing data.

This study makes several important contributions to the field of technology valuation. Firstly, compared to some earlier literature that explains VCs' decision to invest or not (e.g., Macmillan, Siegel, and Narasimha., 1985), this study provides a theoretical explanation underlying the commonly observed practices within the industry, develops a framework for estimating the economic value of patented technology, and addresses the pivotal question of 'how much' to invest, guided by the utility theory of technology value. The existing literature often focuses on one or two individual factors that affect the value of a patent (e.g., Harhoff et al., 1999; Reitzig, 2003; Hall and MacGarvie, 2010; Moser et al. 2018). Although some studies have made valuable attempts to examine the impact of some factors that affect VCs' decisions about investment (e.g., Macmillan et al., 1985), there is, in general, a lack of a comprehensive framework to understand the sources of value in new ventures and explain the rationales underlying VCs' decision behaviour. The finance literature provides various methods for the valuation of technology, e.g., the net present value approach (Sahlman and Scherlis, 1987;

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[1] Firm-specific data are obtained from Crunchbase, which contains information on 600,000 executives, entrepreneurs and investors, and monthly updates on over 100,000 technological startups, people and investor profiles. This sample is then merged with the patent data of firms collected from PATSTAT from the European Patent Office.

Smith, Smith, Smith, and Bliss, 2011), but does not focus on the theoretical foundation underpinning the methods and the estimated value.

Instead of merely focusing on entrepreneurs' quality and/or patent characteristics, the utility of the technology provides a significant role in determining its value. Our utility theory of technology value explains that the utility of a technology is associated with four intrinsic attributes. Besides the usefulness and novelty of the technology, market size and team characteristics, the inclusion of complementary technology and technology life cycle position into the framework enriches the usual VC approach, which mostly focuses on people, the market and, in some cases, the product.

Secondly, it contributes to the literature by developing a utility theory of technology value that helps explain the observed decision behaviour of VCs. Different from the traditional utility theory which takes an individual perspective, we take an industry perspective and focus on the utility a technology may provide to human society and to meet market demand. We elaborate on how this utility is shaped by both external demand-side factors and the intrinsic characteristics of the technology. Different from the labour and cost theory of value, we extend the intrinsic characteristics of a technology beyond the number of labour hours and capital costs, by considering the characteristics of the idea creator and marketability developer, the creative aspect of the intellectual 'product' (i.e., the technology), and environmental enabling conditions needed for delivering the utility.

Thirdly, this paper provides a foundation for the future development of an empirical estimation method that could be used in practice by investors, innovators and intermediaries. We discuss factors and potential measurable indicators involved in each of the abovementioned four attributes. Using an example of ICT startups in California, we also provide initial empirical evidence to corroborate the framework's validity and illustrate the potential to develop an objective estimation methodology based on big data.

## 2. The Literature

### 2.1 Economic Literature on Value

There are three main streams of economic literature on value. The labour theory of value argues that the economic value of a good or service is determined by the total amount of necessary labour required to produce it (Marx, 1867; Rubin, 1978; Schroeder, 2008). The cost-of-production theory of value developed by Adam Smith and David Ricardo explains value as determined by the sum of the cost of the resources that went into making it, which can comprise any of the factors of production (including labour, capital, or land) and taxation (Araujo, 2019; Kurz, 2000; Sraffa, 1951). These theories are powerful in explaining the value of goods, especially those labour-intensive products that were the main products during the First Industrial Revolution. However, they are not effective in capturing the value of technologies that are products of human creativity. With the same number of hours of work and amount of capital inputs, people with different levels of creativity will create significantly different ideas and technologies.

The utility theory of value defines price and value based solely on how much "use" an individual receives from a commodity (Menger, 1976). It is based on an assumption that people have preferences for different outcomes. This theory is widely used in microeconomics to analyse an individual's behaviour and decision making. The unit price of a product is also argued to be determined by the marginal utility of the product. However, the utility value is also criticised as being subjective, as preference and the assigned value (utility) are subjective

(Gordon, 1964; Jevons, 1866). Although some literature also defines value as the worth of goods or services as determined by markets (Beckert and Aspers, 2011; Schroeder, 2008), the market often determines the price rather than the value of goods or services.

There have also been insightful empirical studies on the value indicators of patents, such as the number of forward citations, backward references, and claims (Trajtenberg, 1990; Harhoff et al., 1999; Reitzig, 2003; Hall and MacGarvie, 2010; van Zeebroeck and van Pottelsberghe de la Potterie, 2011; Moser et al., 2018). Patent statistics alone are only one factor determining the monetary value of technologies. The value of patents has also been estimated on the basis of patent renewal data (Schankerman and Pakes, 1986), opponents' benefits from successful opposition (Reitzig, 2004), and the incremental rents that a patent earns (Arora et al., 2008). These estimates, however, provide information on only part of the value of a technology (Bessen, 2008) or on only the value of patent protection but not the value of a technology itself. For example, Arora et al. (2008) find that the renewal value tends to underestimate the patent value since it ignores the strategic role of the exclusion rights in the context of cumulative or complementary inventions.

## 2.2 Innovation and Finance Literature on Technology Valuation

Prior innovation and finance research focuses on several methods used in practice for the valuation of technology, including quantitative methods such as cost approach (Mard, 2000), income approach (Thorn et al., 2011), real option analysis (e.g. Eichner, Germuenden, and Kautzsch, 2007; Oriani and Sobrero, 2008), and structural models (Park and Park, 2004); qualitative approaches such as fuzzy multiple criteria comparison (Cheng, 2013), the specific value points approach (Vega-González et al., 2010), peer benchmarking (Baek et al., 2007; Hsu et al., 2021); and hybrid approach (Doerr, Gates, and Mutty, 2006). However, these methods come with certain drawbacks and limitations. For instance, the cost model quantifies current costs to estimate the economic value of a technology, but costs do not necessarily equal future benefits, especially in relation to technologies which are human creativity intensive. The income-based method, the real option approach, and the hybrid approach rely on predictions of future income, which is inherently uncertain. The benchmarking approach assumes that potential buyers in the market would reasonably pay a similar price to acquire comparable technology (Reilly and Schweihs, 1999). Nevertheless, finding comparable technologies and their transaction prices is often challenging, as they are not always readily available and transparent (Baek et al., 2007).

Besides the above methods, McMillan et al. (1985) is a pioneering study that tried to use an integrated framework to examine the criteria used by venture capitalists (VCs) when evaluating new venture proposals. Using a survey of 100 VCs, they analysed the significance of factors such as the entrepreneur's personality, experience, product characteristics, market characteristics, and financial considerations. The results showed that the quality of the entrepreneur was the most crucial factor in funding decisions. Following this study, other attributes of entrepreneurs, such as entrepreneurial passion and openness to feedback, are found to be important when VCs make investment decisions (Warnick et al., 2018). Several teaching cases have also explored how VCs evaluate potential ventures, e.g., Roberts and Barley (2004).

Recent studies have developed new methods to capture additional patent-related information about technologies. Kogan et al. (2017) base their valuations on the stock market reactions in the days following the news of patent grants. Bellstam, Bhagat, and Cookson (2020) and Arts, Hou, and Gomez (2021) argue that text analysis is more accurate than patent statistics in capturing technological novelty. Furthermore, studies such as Montani, Gervasio, and Pulcini (2020) and Blank (2020) have identified several crucial aspects which are, in general, missing from the above-discussed valuation approaches, including focusing on further forecasts and addressing the specific business model. However, these studies have offered interesting insights but did not provide systematic theorisation for the factors considered important in the evaluation process. There is still a lack of a comprehensive framework that incorporates the effects of all factors with a theoretical explanation. They do not produce an estimate of the value of a technology either.

## 3. A Utility Theory of Technology Value

Unlike traditional tangible assets, quantifying and capturing the value of intangible assets is a complex process. Although utility value and consumer needs are still relevant, traditional theories become inadequate when attempting to explain the value of assets without a physical presence in nature, such as technology. Technologies are characterized by a high level of human creativity and technical complexity, a zero marginal cost upon being reused independently or embedded in goods or services, and greater risks and uncertainties in fulfilling their potential.

Built upon the utility theory of value (Marx, 1867; Hicks and Allen, 1934), the current study extends the framework of technology valuation by considering: 1) Nature and Size of the 'Use' (Utility) which are mainly reflected in market condition; 2) Quality of The Technology, which is reflected in a vector of dimensions such as novelty of the technology, the position in the technology life cycle, team quality, etc.; 3) Enabling Environment to Deliver the Utility, such as the presence of complementary technology and institution conditions; and 4) risk and risk management, which is reflected in team characteristics and position in the technology life cycle. Essentially, incorporating market size into the framework is expected to capture the market potential and reflect future benefits and forecasts, while technology life cycle and team characteristics serve to address the heterogeneity of the business models.

### 3.1 Nature and Size of the 'Use' (Utility)

The economic utility of a technology is the total benefits derived from using it, which directly influences the demand and, hence, the value of the technology. Therefore demand, conceived of as market size, is a crucial factor determining the value of a patented technology (Kalcheva, McLemore, and Pant, 2018). A larger market size offers better opportunities for future profits and the potential to commercialize and fulfil a wider range of needs (Dubois, De Mouzon, Scott-Morton, and Seabright, 2015). A large market size provides great potential to commercialize, which in turn increases the potential profits generated from the technology. Preliminary information on market needs is therefore considered a good starting point for the valuation of a technology (Vega-González et al., 2010) because only technologies that the market needs and that consumers are willing to pay for can be valuable. For example, if we use the funding raised by the ICT startups in California as a proxy for the market value of their technology, we find that the higher the estimated revenue of the startups, the larger the amount of total funding raised by the firm (Figure 1a).

Of course, market conditions could change considerably between a new technology's development and its actual delivery and thereby affect its ultimate value (Park, Jun, and Kim, 2012). Knowing the likely demand for a technology can help a firm decide whether it is worthwhile to continue the innovation process. The market size shapes the initial road-mapping and planning processes for the technology (Mccarthy, 2003) and positively affects its value, as a larger market size results in a higher share of total realizable value materializing (Acemoglu and Linn, 2004).

## 3.2 Quality of the Technology

Novelty and reliability are vital attributes of a technology and determine the usefulness of a technology to fulfil the users' desires and needs. The novelty of technology refers to the immanent characteristics of the invention that contribute to its monetary value (Nordhaus, 1967). It is associated with the quality and creativity of the R&D teams and entrepreneur characteristics. Reliability requires the technology to perform consistently according to its specifications and is the key consideration when producing, marketing, buying and using the good or service from the technology. The novelty and reliability of the technology are closely related to its position in the technology life cycle.

Novelty of the Technology

Novelty is a crucial factor in fulfilling or improving people's needs, as well as creating new ones. Novelty describes the technological distance between the patented invention and the prior art (Reitzig, 2003). From a utility theory perspective, individuals or consumers derive a higher level of utility or satisfaction from such a difference.

Breakthrough patents have the potential to provide a unique competitive advantage and associated revenue to the inventing organization (Achilladelis, Schwarzkopf, and Cines, 1990). Patents are typically granted based on their novelty and newness, thus, "grant reflects value". A technology with high novelty has the ability to disrupt existing competencies, displace existing players from the market, and create considerable technological and monetary value (Ahuja and Lampert, 2001). The higher the quality of the patent, the more total utility and private monetary value the patented technology has, and the more inventions would be built upon it (Bessen, 2008; Fischer and Leidinger, 2014).

In the literature, a widely accepted indicator of patent novelty is the number of forward citations, which measures the patent's contribution to the prior art (Hall, Jaffe, and Trajtenberg, 2010; Harhoff et al., 1999). A patent also makes backward references to prior patents and non-patent scientific publications, reflecting the amount of extant technology in a technology field (Ziedonis, 2004) or the scope of the patent (Harhoff, Scherer, and Vopel, 2003). On the one hand, more backward citations require the applicant to circumvent more prior art to demonstrate novelty; on the other hand, more prior art indicates the knowledge base leading to a high quality of invention (Kapoor, Karvonen, Mohan, and Kassi, 2016). Therefore, the effects of backward citations on the value of technology might be ambiguous (Hall et al., 2001; Van Zeebroeck, 2011).

The scope of a patent is also associated with the novelty of patented technology and its value (Tong and Frame, 1994). Broad patents covering several disciplines increase the attractiveness of the right of exclusion and the difficulties for competitors to invent (van Zeebroeck and van Pottelsberghe de la Potterie, 2011). The theoretical patent literature argues that the value of a patented invention may be affected by its technological fields, reflected in the number of (nonidentical) International Patent Classifications (IPC) classes (Vega-González et al., 2010). The more IPC classes identified by a patent, the more structurally distinctive it is from other technologies with respect to the technical principles. Similarly, the number of claims a patent makes in the application defines the specific aspects of the invention to be protected, suggesting the exclusivity strength of the technology.

Using the patent information of ICT startups in California, we find that patent forward and backward citations, the IPC scope and claims are strongly correlated with each other (Table 1). They are all positively associated with the funding raised by these startups at the 1% significance level. However, the correlation coefficients are around 0.2, indicating that although patent novelty is important for investors, it is not the only determinant when making investment decisions.

R&D Team and Entrepreneur Characteristics

The characteristics of a team can alter the values associated with technology. Team characteristics may affect the opportunities (e.g., information, resources, technology and productivity) and constraints (e.g., regulation, restrictions on capital or information) faced during the innovation and commercialization process (Damanpour and Schneider, 2006). As the “creator” of a technology, an effective R&D team should remain well-informed about pertinent industry trends and market dynamics. The quality of the R&D team influences the rate of innovation, the utility and the overall potential of a technology. A commercialization team can act as a “sponsor” of a technology, influencing the diffusion path and value creation of innovations. Similarly, a team with a learning-rich production system can also increase technological dynamism and provide the firm with more resources, greater access to technological information and complementary technologies, and improved knowledge hubs (Fennell, 1984). The entrepreneurship and leadership features of the organization also affect its capability to innovate and fulfil the potential of a technology (Boone, Lokshin, Guenter, and Belderbos, 2019). Therefore, the monetary value of a new technology cannot be fully understood without considering the characteristics of the leaders, R&D and commercialization team.

The extent to which a firm may be able to exploit its technological invention in the upgrading and commercialization of a new technology may depend on its age and size. Compared to young or small-sized firms, old and large firms are more capable of exploiting economies of scale technology accumulation (Dierickx and Cool, 1989) and allocating more financial resources to R&D (Moro, Maresch, Fink, Ferrando, and Piga, 2020), and are more experienced in commercializing their technology. This is supported by the evidence of ICT startups in California that old and large startups usually attracted more investment in their technology (Figures 1b and 1c).

Characteristics of R&D team and entrepreneurs can be measured in different ways - for example, the number of researchers and their degrees and awards, the number of founders and their genders and experience. A large, well-qualified R&D team is better equipped to generate innovative ideas and is more likely to lead to more valuable technological advancement. The characteristics of founders are important for management and development, particularly for startups. For example, compared with a single founder, having multiple founders adds value and credibility to the business and hence increases the private monetary value of the patent owned by the firm (Figure 1d). It is the same for more experienced founders or management team. However, too many founders increase the complexity of decision-making and might lower the firm's efficiency.

The Position in the Technology Life cycle

Novelty and reliability of a technology also depend decisively on its current stage in the life cycle. The perceived commercial gains of a technology are argued to follow a four-phase cycle of introduction, growth, maturity, and saturation (e.g. Achilladelis et al., 1990, with examples from the chemical industry, and Nieto, Lop, and Cruz, 1998, with examples from the ICT industry). This cycle reflects changes in the utility, sales volume and technology evolution.

The S-curved figure of technology life-cycle evolution is the most commonly recognized depiction of the creation and adoption of a technology over time (Tipping, Zeffren, and Fusfeld, 1995). As an example, Figure 2 demonstrates the life cycle curve of a type of information storage technology, aggregated to the IPC subclass of G11B, which is based on relative movement between record carrier and transducer, such as disc and tape and their parts (such as heads). Although patents under this class appeared in the late 19th century, they started to develop in the 1930s when magnetic tapes were invented. Patents in G11B grew quickly since the 1950s, following a sequence of inventions of hard drives, floppy disks, and compact discs (CDs). Floppy disks remained popular until the late 1990s because they were ideal for regularly writing new data. However, all changed in 2000 with the USB flash drive, so technology in G11B declined quickly after that.

During the basic research phase, the value of a technology is relatively low, and it increases slowly through radical innovations as only a small number of pioneer firms are willing to bear the risk of putting R&D ideas into practice (Swamidass, 2013). Some consumers highly value the novelty and are willing to be early adopters, while others may choose to wait until it becomes more mature and reliable. In the growth phase, higher consumer acceptance of the technology creates a broader range of available market alternatives and resolves fundamental technological and market problems and uncertainties, increasing the reliability and value of the technology, as well as its diffusion. At maturity, the technology may reach a point of diminishing marginal utility for some consumers. The incremental benefits of upgrades become smaller, and the sales volumes stabilize before decreasing in the decline phase due to high demand and a lack of new contributions to the technology. Thereafter, the potential for new product innovations on the basis of the technology decreases continuously, as it becomes outdated or replaced by new alternatives.

It is challenging to precisely measure the position of a patent in the technology life cycle. One solution is to seek opinions from professionals and industry experts to gain insights into the phase of each patented technology in its life cycle, for example, assessing based on Gartner hype cycles, which graphically represent the maturity and adoption of technologies and applications. However, such a measurement is costly and subjective. Constructing an objective measurement of the life cycle should rely on research and understanding the evolution of each type of patented technology to identify its position, which should rely on the analysis of big data involving the history and trend of development of each type of patent.

### 3.3 Enabling Environment to Deliver the Utility

Few technological products function in isolation. In most cases, complementary technologies enhance the feasibility and overall utility of the technology and enable the value that end users can derive (Nambisan, 2002). However, few studies on technological valuation adequately integrate the potential influence of complementary technologies into the framework of valuation (e.g. Chang, Hung, and Tsai, 2005). These complementary technologies may be in the form of component parts, production methods, or both. In these circumstances, a firm's technology may have commercial value only when it is supported by technologies from other firms in terms of applications. Thus, the presence of complementary technologies is, to some extent, essential for the commercialization of the technology being supported.

Inventing new technological products entails significant risk, largely due to the absence of complementary technologies that support its application (Van De Ven, 1986). The impact of complementary technologies on the value of the focal technology is not limited to the avoidance of the costs for developing the complementary technology; it also encompasses the possible earlier introduction of the final product and realization of profits. Their presence can result in a faster expansion of the initial market and acceleration of product growth.

Measuring the readiness of complementary technology might involve assessing the degree to which other technologies necessary for effective integration with the new technology are prepared, available and accessible. It should also consider the regulatory or legal factors, cost and affordability, risks and challenges associated with the complementary technologies. In the ICT sector, countries like the US, the EU, Singapore and Korea are at the forefront in terms of the Network Readiness Index (NRI), a multi-dimensional indicator of a country's degree of readiness to exploit opportunities offered by ICT (Portulans Institute, 2022). In these countries, the utility and potential of new patented ICT technologies are more likely to be maximised.

### 3.4 Risk and Risk Management

There are high uncertainties and risks involved in the process of innovation and translating the outcomes into a commercially viable product or process that can be successfully scaled up (Gans, Hsu, and Stern, 2008). The level of risk associated with the new patented technology has a detrimental effect on the actualisation of the utility. Risks occur throughout different phases of the technology life cycle, including the risk of failure at the R&D stage, uncertainties of upgrades, the readiness of complementary technologies and changes of regulations at the growth phase, and threats of alternative technologies when achieving maturity. Therefore, incorporating risks into the valuation of technology is important for the accuracy of the valuation.

In addition, the capability of risk management of the firm can identify and analyse risks and implement strategies and measures to reduce those risks to acceptable levels. The presence of a capable team not only reinforces the patenting firm's corporate values, but also helps manage the uncertainties and risks involved in developing a technology into a commercially viable product or process by providing the necessary resources (Bitner, 1992). It is widely acknowledged that large and experienced firms are more capable of allocating more financial resources to IP protection and risk control of intangible asset investments (Ghosal and

Loungani, 2000). Similarly, multiple and experienced founders or management team add credibility to risk control.

In summary, Figure 3 summarises the framework of the utility theory of technology value.

It is possible to establish an objective predictive model of technology valuation using observable indicators of the above attributes. We carry out a linear prediction for the value of patented technologies owned by the ICT startups in California from 2001 to 2022. Figures 4a and 4b compare the predicted values against the actual values of the technology, measured by the money raised by startups with ICT related patents. All the predicted values are located within 15% of the actual values, indicating a strong predictive power using the proposed framework (0.866 and 0.832, respectively).

## 4. Conclusions and discussions

Ex ante technology valuation is important for a firm's financial and accounting practices and a critical step in the innovation investment and commercialization process. This study contributes to the important and under-researched field of technology valuation by proposing a framework for the valuation of technology that is derived from the utility theory of value in the context of knowledge production. Compared to the conventional valuation methods, our framework goes beyond patent characteristics and takes into account four attributes that determine the utility of technology, including the contribution of market size, the quality of the technology, the enabling environment, risk and risk management. Specifically, it is the first framework that considers the position of a patent in the whole technology life cycle, the readiness of complementary technologies and team characteristics that ensure the quality of the technology and risk control for technology valuation.

Our theoretical framework is supported by the evidence from a sample of ICT startups with patented technology in California, US. Results from the statistical analysis show that factors in these four attributes contribute to the value of patented technology. Using currently observable data from these startups, the linear regression shows a strong in-sample predictive power, showing the feasibility of applying this framework to the valuation of patented technology in practice. It is noted that this framework is not limited to the valuation of technology in the ICT industry but can be adapted to other industries by incorporating unique firm and industry characteristics.

The framework and evidence offer valuable insights for researchers, managers, and investors in their practices and decision-making process in relation to asset valuation, tax planning, IP management, technology transfer, commercialization and investment. For example, economic agents can use these insights to recognize the impact of a technology's position in the technology life cycle on its value and to decide the best knowledge management strategy, e.g., whether to transfer IP or wait (as an inventor) or to acquire IP or wait (as an investor). Moreover, technology managers can use this framework to distinguish the impacts of the different observed patent indicators, market demand, and firms' financing capabilities on the value of technology.

This framework also provides an opportunity for researchers and consultancy companies to develop an objective tool to evaluate the value of technology that can be employed in practice. This study has discussed available indicators for the four attributes in the framework and showed a relatively strong power in predicting the market value of patented technology using linear regression. Although some indicators are currently unobservable, such as the position of the technology in the life cycle, the readiness of complementary technologies, and some team/entrepreneur characteristics, they can be constructed or estimated with the help of big data. Additionally, considering the high correlation between some indicators (e.g. between patent variables as shown in Table 1) and the possible coexistence of linear and non-linear relationships between the dependent variables and technology value (e.g., life cycle indicators and number of founders as shown in Figures 1d and 2), future research could use machine learning to improve the prediction accuracy and overcome the limitations of linear regression such as the assumptions of functional form, interaction between variables and distribution of parameters.

More importantly, this framework and its future application in practice will help explore the potential of startups, which hold cutting-edge technologies but lack sufficient evidence of production and sales. For example, OpenAI, which has been a leader in AI technology, had no products, customers or profits at all at the beginning. Similarly, Google was initiated from a Ph.D. research project. They both obtained a large amount of initial funding for development. Such startups with groundbreaking technologies have values that cannot be measured directly using cost- or income-based approaches or peer benchmarking. The early-stage investors of Google and OpenAI considered the intrinsic quality and characteristics of the technology, potential market size, enabling environment, potential risks and the team characteristics as suggested by our valuation framework. Furthermore, using objective data from different resources also helps avoid over-estimation based on storytelling, particularly in fraud cases such as Theranos, which touted breakthrough health technology but then it was found that no research was published in any peer-reviewed biomedical literature (Ioannidis, 2015). Therefore, these stories demonstrate the usefulness of this valuation framework and its applications.

Admittedly, this paper is only an attempt to explore the theoretical foundations for the valuation of intellectual properties. Although the general conceptual framework that we propose for the valuation of technology may apply to technology across industries, the value of technology is also affected by industry-specific features. Future research therefore can investigate how industry-specific characteristics affect the value of technology, and through which channels and to what extent market- and country-specific characteristics such as institutions and culture matter in technology valuation. It is also worth developing complex and comprehensive measurements of the technology life cycle and founders' skills by using big data and establishing more accurate predictive modelling using machine learning.

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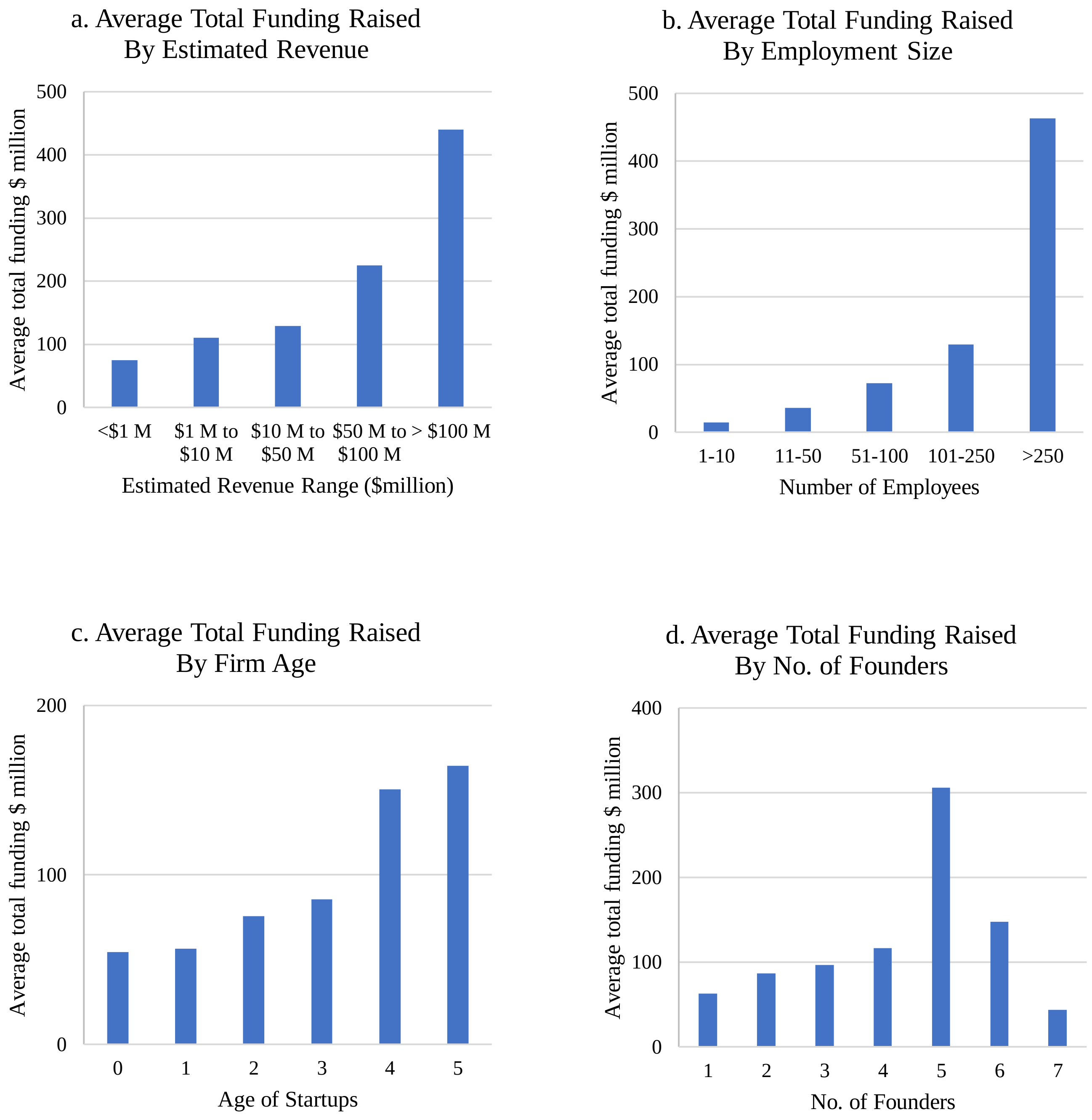
**Table 1 Correlation Coefficients between Patent Novelty Indicators and Fund Raising**

| | Funding | Forward citations | Backward patent Citations | Backward non-patent citations | IPC scope | Claims |
|---|---|---|---|---|---|---|
| Funding | 1 | | | | | |
| Forward citations | 0.207 | 1 | | | | |
| Backward patent Citations | 0.192 | 0.669 | 1 | | | |
| Backward non-patent citations | 0.255 | 0.615 | 0.616 | 1 | | |
| IPC scope | 0.201 | 0.690 | 0.881 | 0.660 | 1 | |
| Claims | 0.233 | 0.675 | 0.759 | 0.778 | 0.752 | 1 |

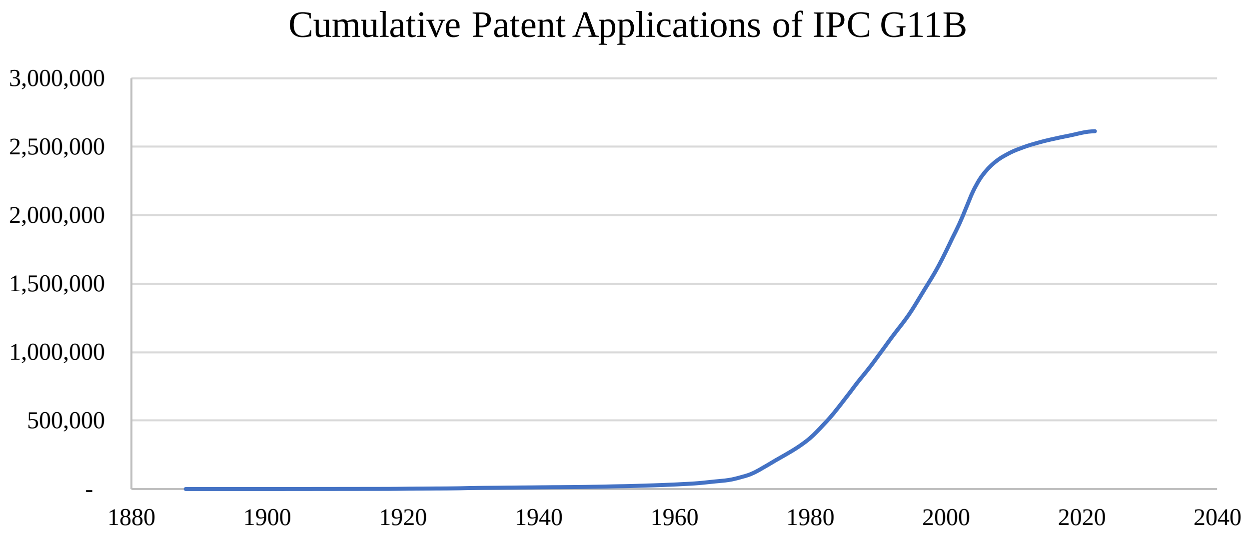
Note: All variables are logged to reduce the skewness of the distribution. Patent variables are collected from PATSTAT of the European Patent Office and then merged with the fundraising data from Crunchbase. All the correlation coefficients are significant at the 1% level.

**Figure 1 Funding Raised and Firm Characteristics of ICT Startups in California**




*Source: Constructed by the authors using data from Crunchbase.*

**Figure 2 Technology Life Cycle of IPC G11B**




Note: G11B is a subclass of IPC and refers to information storage based on relative movement between the record carrier and transducer. The subclass covers the recording or playback information by relative movement between a record track and a transducer; the apparatus and machines for recording or playback and parts (e.g., heads); record carriers (cylinder, disc, card, tape or wire); and associated working of other apparatus.

**Figure 3 Valuation Framework of Technology Based on Utility Theory**

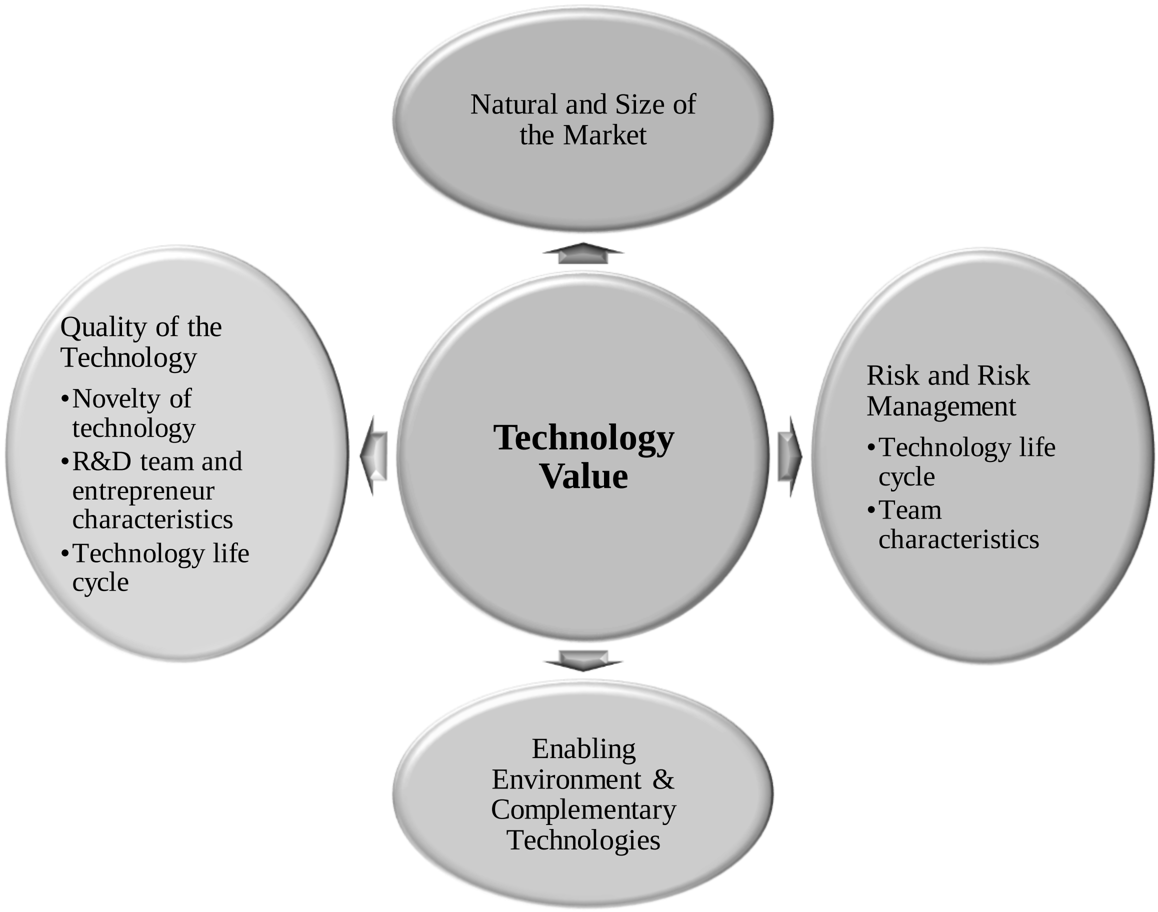
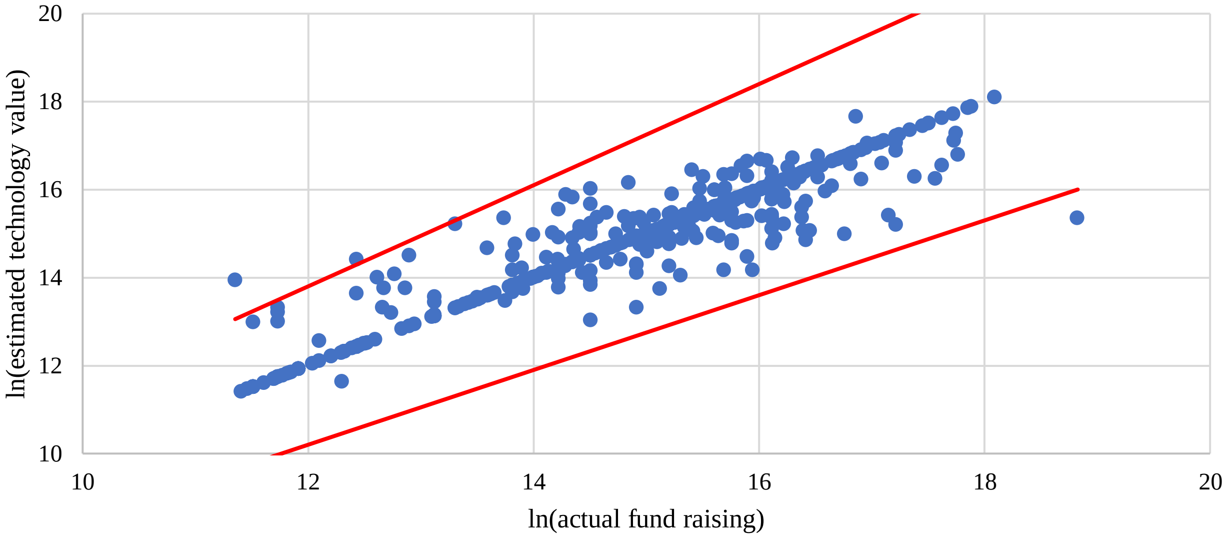
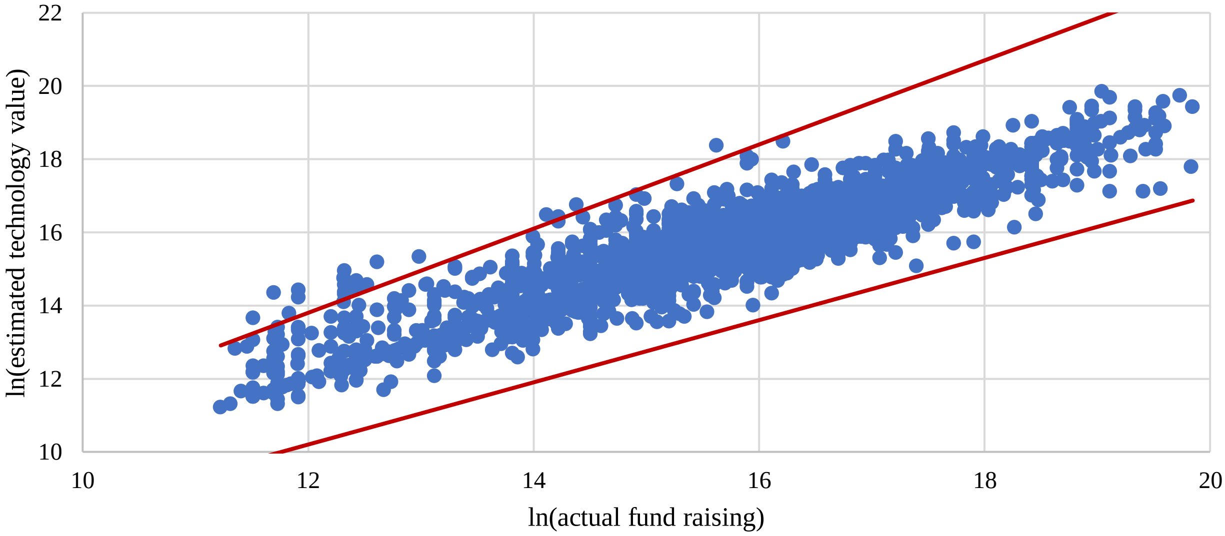


**Figure 4 Estimated Technology Value of ICT Startups in California, 2001-2022**

a. First Funding Round Only (515 startups, $R^2$=0.866)




b. Excluding Startups with only 1 Funding Round (1246 firms, $R^2$=0.832)




Note: Predicted using linear regression using a set of indicators of patent novelty, market size, readiness of complementary technology, team characteristics, location, industry, and time-specific effects. The scattered dots indicate the relationship between the actual fundraising, as a proxy of the monetary value of startups' technology, and the predicted value of technology. The two red lines are the upper and lower bounds within 15% of the actual values. Figure 4a includes the startups that only had 1 round of fundraising and the 1st round of fundraising for those with multiple rounds.