Scientia Iranica E (2020) 27(6), 3322–3337

SCIENTIA IRANICA

Sharif University of Technology
Scientia Iranica
Transactions E: Industrial Engineering
http://scientiairanica.sharif.edu

Technology valuation of NTBFs in the field of cleaner production in terms of investors' flexibility and uncertainty in public policy

K. Fattahi, A. Bonyadi Naeini*, and S.J. Sadjadi

Department of Progress Engineering at Iran University of Science and Technology (IUST), Narmak, Tehran, Iran.

Received 22 October 2018; received in revised form 28 February 2019; accepted 6 April 2019

KEYWORDS
Technology valuation;
New technology-based firms (NTBFs);
Real Options Analysis (ROA);
Option to choose;
Decision Tree Analysis (DTA);
Cleaner production.

Abstract. Technology valuation, especially in the early growth stages of New Technology-Based Firms (NTBFs), is one of the most critical challenges that most often hinders investors and entrepreneurs' deals in the Venture Capital (VC) financing process. It is clear that uncertainties arising from the likelihood of implementing public policies could significantly affect the volatility of NTBFs' cash flows in the field of cleaner production. Commonly, these types of technologies require public supportive policies for achieving success. Consequently, technology valuation is more challenging and traditional valuation methods are not suitable anymore because of the definitive assumption of cash flow and disregard for investors' flexibility and uncertainty. Therefore, this study proposes a method to perform the technology valuation of firms during all their growth stages by introducing a framework based on decision tree and real options analysis. Furthermore, unlike previous papers that have utilized the compound options, the option to choose approach was used to consider investors' flexibility. Then, the proposed framework was supported by a case study, which was conducted to verify and validate it. Finally, the conclusion section discusses the contributions and limitations of the study and provides directions for future research.

1. Introduction

Many scholars throughout the world have presented some pieces of evidence that small- and medium-sized technology-based enterprises lead to entrepreneurial moves and wealth creation [1–3]. It is clear that technology-based firms with high levels of Research and Development (R&D), production of new knowledge, and professional scientific and technical personnel [4] are deemed as a vital source of creating new jobs [5]. Meanwhile, today's world needs cleaner productions for reducing harmful materials; however, willingness to invest in these types of technologies is affected by their low return on investment, for which designing appropriate policies and incentives is required [6]. To this end, New Technology-Based Firms (NTBFs) can be useful and must be supported through implementation of new innovative public policies. For example, new environmental policies in Japan have induced technological innovation in this field [7]. According to Guerzoni and Raiteri [8], supply-side policies (R&D subsidies and tax credits) and demand-side ones (innovative public procurement) may reduce the uncertainty associated

*. *Corresponding author. Tel.: +98 21 73228056*
E-mail addresses: komeil_fattahi@yahoo.com (K. Fattahi); bonyadi@iust.ac.ir (A. Bonyadi Naeini); sjsadjadi@iust.ac.ir (S.J. Sadjadi)

doi: 10.24200/sci.2019.52078.2523

with the development and commercialization of new products of NTBFs, which will encourage investors to finance them.

To finance the NTBFs, as one of the most important challenges [9], the main problem of venture capitalists is the inability to ensure an accurate technology valuation of such firms, which is often a significant disruptive factor in the commercialization process and in the most important discussion between entrepreneurs and investors [10–15]. At the beginning of partnership, most of the investors incline to value the firm's technology lower than its real value and as a result, get a more significant share of the firm's ownership in return for the amount of their investment. Furthermore, entrepreneurs themselves are interested in high valuation and possession of a large share of the property due to their interest in the idea and also the overestimate of the market [16]. Moreover, the results of surveys show that investors are more interested in investing during the commercialization stage and are more reluctant to invest in the early stages of a firm's growth [17]. Therefore, focusing on the process of technology valuation of NTBFs, especially in their early growth stages, and considering the weaknesses of traditional methods, this research has proposed Real Options Analysis (ROA) by utilizing the option to choose as a suitable approach to technology valuation of these firms. By considering the ROA, two types of risks are identified: market risk and private risk. Market risk is related to variations in the expected future incomes driven by market conditions such as market demand and competition, etc. The private risk is associated with the efficiency and effectiveness of a firm during a project's implementation, which is related to not only organizational productivity in completing the project but also the effectiveness of a firm's technology [18]. According to Kodukula and Papudesu [19], the ROA is only suitable for market risk during the commercialization stage and also, real option solutions do not validate the private risk during the early growth stages of NTBFs. Indeed, to measure the technology valuation of NTBFs during the early growth stages, it is necessary to measure the success probabilities, which are related to private risk and applicable to Decision Tree Analysis (DTA).

This paper proposes a ten-step framework according to ROA and DTA, which is suitable for technology valuation of NTBFs ranging from the idea to the commercialization stage. It initially identifies the critical success factors in assessing the private risk in the early stages of their growth. Then, it deals with volatilities that affect the cash flow and utilizes "the option to choose" to apply the investors' flexibility during the commercialization stage. The proposed framework offers an option value by applying DTA and ROA to the early and commercialization stages of NTBFs, respectively, which is in fact the strategic Net Present Value (NPV). This framework informs an investor by exercising the options and managerial flexibilities and also by considering the uncertainties arising from the likelihood of implementing the public policies, whether the investment is feasible and profitable or not. Finally, to evaluate the above-mentioned framework, the technology of a technology-based firm is valued.

2. Literature review

2.1. Technology valuation and approaches

Nowadays, knowledge with its intangible aspects has contributed to the growth of various firms [20]. In addition, technology-based assets such as patents and technological know-how can generate revenue and create value. In consequence, technological and innovative assets play a crucial role in determining the value of technology-based firms [21–23].

The intellectual property term includes patent, trademark, copyright, trade secret, and technological know-how [24] and their valuation is attractive for both universities and business sectors [25] because of its application for diverse purposes such as technology transfer negotiations, equity financing in Venture Capital (VC), and finally using them as collateral to receive bank loan [26].

According to previous studies, the main approaches to technology valuation have been distinguished into three main approaches: cost, market, and income approaches [24,27].

Regarding the cost of its production, in the opinion of some researchers like Battersby and Grimes [28], the cost approach focuses on technology valuation. In this approach, there are two methods in terms of reproduction and replacement costs. This approach is reasonable and simple due to the mere emphasis on cost monitoring. However, due to the complexity of technological projects, this approach is not suitable for technology-based firms. Moreover, ignoring the future economic incomes resulting from the commercialization stage should be considered as another limitation of this approach [29].

In the market approach, access to the latest similar technology deals is required to compare their value to achieve the value of new technology. In advanced technology and radical innovation cases, finding similar technologies is often difficult [30,31].

The income approach focuses on analysis of the potential of technology to generate net incomes over the technology life cycle (patent) along with the risks involved in investment. In this approach, different valuation methods were applied by companies and universities. According to the complexity of the matter, Discounted Cash Flow (DCF), risk-adjusted Net Present Value (rNPV), NPV with Monte Carlo simulation, and ROA were the most widely used methods [29].

2.2. Suitable approach and method for technology valuation of NTBFs

Given that NTBFs are characterized by being the owners of unique and unaccustomed technologies, technology leaders in each industry, creators of new industrial sectors, and sources of radical innovation as well as the high risk associated with these properties [32–34], it is clear that the income approach can be viably suitable for technology valuation of such firms. According to this approach, the following is a brief literature review on technology valuation methods of such firms.

In a survey conducted by Roman et al. [29], different technology valuation methods, applicable to university technology transfer, were considered. Their findings did not recommend any unique method appropriate for valuing all university technologies. They found that each technology had some characteristics and circumstances, in which a particular method or combination of several methods could be useful for determining valuation. Nevertheless, they identified the DCF as the most popular and easiest method to value the academic technologies that could be used in most technologies. In another study, DCF was used to value the technology-based firms because of its simplicity in their early growth stages [35].

Wang and Tang [36] employed ROA to value the agricultural technology-based firms in the process of VC as a consequence of the limitations of traditional methods such as investors' inflexibility and inattentiveness to uncertainties. In this research, the investor's options such as deferral and abandonment were considered essential for financing the growth stages of technology-based firms, and due to the overall valuation based on the constant information, DCF was weakly assessed at the time of decision-making. According to Razgaitis [37], use of Real Options Method was not just introduced as a valuation methodology, but was known as a useful means for constructing negotiations between investors and entrepreneurs and achieving final agreement on a VC. Hunt et al. [38] also emphasized the role of managerial flexibilities in R&D processes to reassess and modify decisions and engage the environmental changes in management decisions and recommended the ROA methodology for technology valuation of technology-based firms.

According to Kjærland [39], Lee and Shih [40], Batista et al. [41], Lee [42], Boomsma et al. [43], Detert and Kotani [44], Martinez-Cesena et al. [45] Abadie and Chamorro [46], Kim et al. [47], Kroniger and Madlener [48], Jeon et al. [49], Weibel and Madlener [50], Zhang et al. [51], and Martín-Barrera et al. [52], the traditional methods such as DCF were not useful and adequate for valuing the renewable energy projects; consequently, the ROA was proposed and applied. They expressed several reasons such as underestimating the value of technologies, inflexibility of conventional methods in management decisions, and lack of attention to market uncertainties for not using the traditional valuation methods.

Of note, in all previous researches, ROA was conducted and the investment could be devoted in several stages by utilizing the compound option and granting options to the investor to stop or continue the investment in each stage. Now, for a technological project, there is no research on the application of investors' flexibilities in order to abandon, expand, or contract the investment in the commercialization stage. Therefore, in this paper, a framework for technology valuation of a technology-based firm was proposed and utilized by applying the mentioned flexibilities via option to choose in ROA.

Kodukula and Papudesu [19] believed that DCF was based on a set of fixed assumptions related to the deterministic income, where the income is uncertain and probabilistic in the real world. An investor may initiate the next steps of investment if it is desirable, i.e., defer and abandon. The values of these contingent decisions are not included in the DCF analysis because the project is assumed to be in a predetermined and fixed path.

Other traditional valuation methods are the expanded forms of DCF, but they are not substitutes. DCF takes a set of input parameters and calculates an NPV for technology life cycle. Monte Carlo simulation performs the same calculations thousands of times for each scenario by only changing the input parameters. The results of simulation, on average, show the distribution of project income based on the DCF. In a condition where the simple DCF method is deterministic, Monte Carlo simulation provides the probability distribution of the possible technology NPVs. Monte Carlo simulation has the same drawbacks similar to the DCF and does not deal with contingent decisions and their impact on the technology valuation [29]. DTA is an old method and a more sophisticated tool than DCF, where the value of a multi-stage technological project with contingent decisions is measured. It calculates the risk by using the probability of outcomes instead of the risk-adjusted discount rate. One of the limitations of this method is subjective estimation of the probabilities used in decision-making nodes and critics argue that analysts and managers can distort these numbers in their favor [19].

Despite the ROA potential for a broad use, the application of this method remained limited due to its newness, complexity, and the need for a higher understanding compared with conventional methods such as DCF. Furthermore, analysts and advisors' attentiveness to this method, which better informs decision-making managers, limits its functionality and applicability. Finally, use of the Black-Scholes method rather than the binomial method made it an ambiguous black box and these complexities have limited the usage of ROA [19].

Regarding the utilization of ROA, both Black Scholes and binomial methods are utilized for this approach. Although the Black-Scholes method can be applied in order to value different problems with proper setting, using this method for a complex problem does not make it easier. This method has become popular because (a) The binomial method is more flexible and easier to use than Black-Scholes, (b) The input parameters such as strike price and volatility can easily be changed over the option life time, and (c) Convenience of explaining the results to top-level managers to help managers make informed decisions. Although the Black Scholes provides a more accurate valuation outcome, the binomial lattice gives almost close results to it [19]; therefore, in the current research, the binomial method is applied to ROA.

Although several studies have employed newer models of ROA, none of them has focused on how to value the NTBFs for all stages of their growth. In 2014, Chen et al. [53] demonstrated that application of ROA in stage financing could lead to a more reasonable valuation of the IT programs; moreover, extra earning was obtained. In this paper, the Black-Scholes pricing model was used along with the geometric Brownian movement to calculate the option value. In 2016, Chu et al. [54] integrated ROA with robust least squares to improve least squares Monte Carlo approach and then, applied it to evaluate the Carbon Capture and Storage (CCS) investment. In a case study accomplished in China, robust ROA and ROA were compared and the proposed robust ROA was more realistic and suitable for CCS valuation than common ROA; however, robust ROA program consumed much more time than ROA program in numerical computations. Wang et al. [55] used ROA in the R&D planning. They developed the methodologies to help R&D managers to evaluate and select the optimal investment decisions, which maximize the market payoff for the better R&D planning. Finally, it should be noted that none of them considered the research gap.

After reviewing the literature on technology valuation approaches and methods and considering the features of NTBFs, it could be concluded that DTA along with the binomial lattice of ROA and the option to choose might be selected as the primary tools for proposing a specialized framework to value the NTBFs for all their growth stages from the idea to commercialization.

2.3. Critical success factors and assessment of the private risk of NTBFs

According to Kodukula and Papudesu [19], the uncertainty about the effectiveness of a new technology was attributed to the private risk and the probability of its commercial success was related to the market risk. For example, the efficacy of a laboratory drug is related to private risk and its product sales are subject to market risk. An NTBF in the early stages of its growth and before the production of its prototype involves the private risk. Therefore, to value an NTBF in the early stages of its growth, it is required to examine its private risk by measuring its success probabilities. In what follows, by reviewing the literature and using experts' opinions, the critical success factors in assessing the private risk are considered and determined.

Through the related previous studies, researchers used various criteria to measure the success or failure of NTBFs [56–61]. After preliminary adjustment of the criteria and obtaining experts' opinions, the 33 critical success factors were obtained. Finally, by considering the definition of private risk in the early growth stages of NTBFs and achieving experts' opinions, the factors related to private risk were summed up to 10 criteria, as shown in Table 1. These ten factors represent the bases for calculating private risk in the early growth

Table 1. Critical success factors related to private risk with the importance of each factor.

Critical success factors	Importance of each factor
The existence of a business plan at the beginning of formation	0.08
Patent ownership	0.1
Motivation, experiences, and capabilities of teamwork	0.2
The ability and capacity of firm directors for management and leadership	0.12
An integrated and cohesive team to transform an idea into a product	0.15
Risk of firm managers	0.15
Teamwork education level	0.04
The presence of required experts and consultants to convert an idea into a product	0.05
The availability of needed appliances, labs, and equipment to convert an idea into a product	0.07
Having strategic links with universities and research centers	0.04

stages of NTBFs and they can be applied to measure the probability of success in the DTA. It should be noted that in the event of failure in the early growth stages of NTBFs, the technological project will be terminated and investment in other stages will be abandoned. However, in the event of success in the early growth stages of NTBFs, the commercialization phase associated with market risk begins and they can be valued using the ROA. In Table 1, the significance of each factor was also determined by using the Analytical Hierarchy Process (AHP) and experts' opinions. This paper used AHP method as the simplest technique of ranking. However, over the past few years, there have been other competitive techniques for ranking alternatives such as Weighted Distance-Based Approximation (WDBA) and Distance-Based Approximation (DBA) method [62–64], Euclidean Distance-Based Approximation (EDBA) [65], Multi-Criteria Decision Making (MCDM), and Fuzzy Set Theory (FST) [66-68], Visekriterijumsko Kompromisno Rangiranje (VIKOR) MCDM method [69], FST and WDBA [70], Fuzzy-TOPSIS (F-TOPSIS) and TOPSIS method [71,72], Fuzzy Distance Based Approach (FDBA)' method [73], fuzzy-based matrix methodology [74], Fuzzy Complex Proportional Assessment (COPRAS) [75], Fuzzy Analytical Hierarchy Process (FAHP), COPRAS, VIKOR, WDBA [76], Hybrid MCDM methods [77], and fuzzy ELECTRE approach [78].

2.4. The growth stages of NTBFs

This paper considers the growth stages of NTBFs to distinguish the private risk from the market risk during these stages.

In a research study conducted by Ari and Vonortas [12], growth of NTBFs was divided into five stages: pre-seed, seed, start-up, mid-Life, and mature and the financing sources were defined depending on their growth stages. Bruno and Tyebjee [79] identified up to six stages and Gompers and Lerner [80] considered the growth stages of NTBFs.

In another study, Lukas et al. [81] divided the financing stages of VC into three main stages. The first stage is dedicated to financing the R&D phase, which deals with the period of converting an idea into the prototype, consisting of the market analysis and providing the business plan. This first stage is called seed phase. If there are no further barriers on the previous stage and product's market diffusion, the initial start-up stage of NTBFs begins. At this stage, an entrepreneur is ready to produce products, develop a market, create organizational structures, and provide production facilities. In the third stage, known as the commercialization stage, products are marketable. Thus, they need to be distributed so that their prevalence in the market can begin.

According to the characteristics of technology-based firms and based on clarity and simplicity of stages in the research of Lukas et al. [81], the current paper uses their categorization to distinguish between the growth stages of NTBFs. Regarding the definition of private and market risks, the first two stages are considered as the private risk and the commercialization stage is relevant to the market risk.

3. Methodology

3.1. Framework for technology valuation of NTBFs

Many scholars have introduced multi-step frameworks for valuing various projects and deciding to invest in them [19,82,83]; in addition, in the field of renewable energy, there is a specific framework for developing countries [84]. Although these frameworks apply to the consideration and valuation of different types of projects, they are not suitable for technology valuation of technological projects or NTBFs from an idea (seed) to commercialization, especially in the field of cleaner production. This paper proposed a ten-step framework, as shown in Figure 1, to eliminate that problem by reviewing the literature and demanding experts' opinions.

At the first step, the firm's technology life cycle is determined in the three mentioned growth stages based on experts' opinions. At the second step, following the commercialization stage of the technology-based firms, some of the options such as expansion, abandonment, and contraction are considered and determined by the option to choose during the option lifetime and based on the conditions reached by the firm. In a technology-based firm, it may be desirable to begin commercializing with the most likely production capacity; then, after considering the market condition, expansion, abandonment, or contraction of production capacity will proceed. Therefore, the salvage value of project abandonment, which equals the value of NTBFs' patent in some cases, should be considered in the option valuation calculations. Likewise, the amount and cost of expansion and contraction will be determined according to the favorable and unfavorable conditions of the market. At the third step, the principal variables related to income volatilities of the technology-based firm are identified by experts' opinions and they are used to determine the cash flows under three estimates of optimistic, most likely, and pessimistic. It is clear and should be remarked that the public policy variable has significant effect on income volatilities of such firms in the field of cleaner production. At the fourth step, according to the option lifetime of the technology-based firm during the commercialization stage and considering the NPVs of the firm's cash flows under three estimates of optimistic, most likely, and pessimistic, the annual volatility will be calculated using

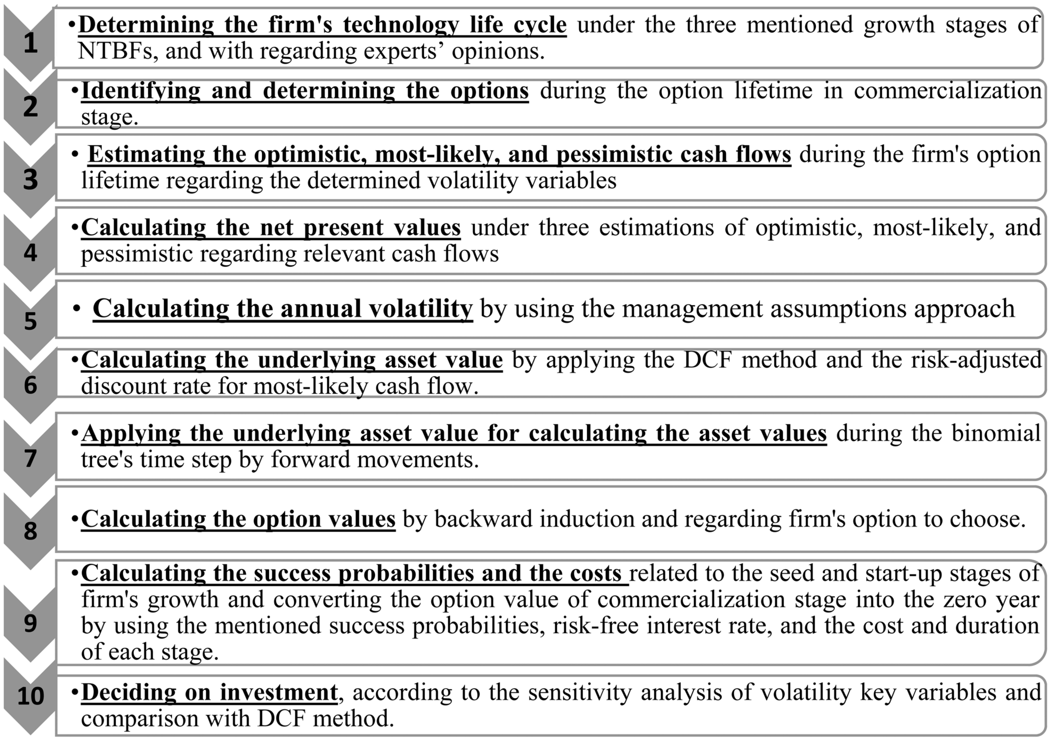

Figure 1. Ten-step framework for technology valuation of New Technology-Based Firms (NTBFs) from idea to commercialization.

the management assumption approach via Eq. (3). At the fifth step, the underlying asset value which is the NPV of most likely cash flows is taken by respecting the risk-adjusted discount. The risk-adjusted discount rate will be calculated by considering the real interest rate, the expected inflation rate, the hurdle rate of the investor, and the predicted risk [85]. At the sixth step, the asset values are calculated during the binomial tree's time step by moving from the left to the right side of the tree with upward and downward movements and based on the equations of option valuation section. At the seventh step, the option value will be calculated for each node by comparing the values of firms' option to choose with the value calculated by the backward induction equation, as demonstrated in the option valuation section. At this step, Real Option Value (ROV) is compared with the technology's NPV in the commercialization stage of the firm and the value added is determined. At the eighth step, the success probabilities and the costs related to the seed and start-up stages of firms' growth are determined. Then, the option value of commercialization stage will be converted into the zero year by using the mentioned success probabilities, risk-free interest rate, and the cost and duration of each stage. Note that the success probability of technology-based firms in the seed stage of their growth is estimated through the private risk factors in Table 1. Similarly, for measuring the success probability of firms' start-up stage and based on the characteristics of this stage, four factors such as the ability to produce, creation and development of the market, creation of an organizational structure, and provision of production facilities will be weighted and scored by experts. The ninth step involves examining the ROV of the overall stages in the zero year regarding sensitivity analysis of volatility key variables and deciding that the investor chooses to invest or not according to issues.

3.2. Option to choose and compound options

A real option in its simplest case is the right (not an obligation) to invest in a project in future. The deferral option is an American call option with the right to delay the start of a project or each stage of technology development. The option to expand is also an American call option that gives the right for project expansion to its owner. Abandonment and contraction options are the American put options and their owners have the right to abandon or reduce the scale of the project by selling all or parts of their assets. The idea behind this is that the option may be exercised and the project could be initiated, expanded, contracted, or abandoned. The option allows us to avoid the disadvantages of the negative risk while to take advantage of the positive risks at the same time. The option to choose combines and considers multiple different options as a single option. The reason for using the chooser name for this option is the reason why we can keep the option open and continue with the project, or choose one of the expansion, contraction, or abandonment options to exercise [19].

The deferral option is the best option for technologies whose owners have a monopoly and intellectual property rights, or entry barriers are so difficult that their owners do not lose their incomes by waiting during the option lifetime [19]. Therefore, due to the lack of full protection of intellectual property rights in Iran, the exercise of the deferral option was not possible to be covered in this paper; therefore, three options of expansion, contraction, and abandonment were utilized accordingly. Furthermore, at the second step of the valuation framework in Figure 1, given that NTBFs often do not start with full capacity, costs and incomes of the three above-mentioned options will be predicted for calculating the option values at the seventh step.

As mentioned earlier, in previous researches, the compound options have been used. In order to describe the compound options, it is explained that some of the investment projects have several decision-making stages, meaning that management can decide to extend, reduce, defer, or abandon the project after achieving new information to resolve the uncertainty. In consequence, the whole financing process can be divided into several stages so that the investor can benefit from the mentioned options at the end of each stage [19].

3.3. Option valuation

The binomial method is one of the most widely used methods for ROA and option valuation. It can be represented by the binomial tree for three stages, as shown in Figure 2. S_0 is the present value of the underlying asset value. In the first stage, the tree goes up and down and from there continues to go either up and down in the following stages. Movements up and down are shown by upward (u) and downward (d) factors, in which u is greater than one and d less than one and we assume $u = 1/d$. The values of these factors depend on the volatility of the underlying asset value over the option lifetime. In the first stage, the binomial tree has two points that represent the

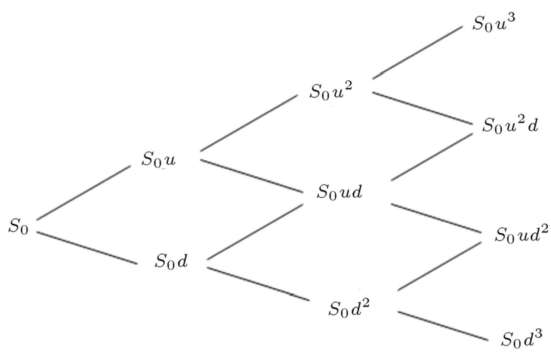

Figure 2. A binomial tree for three stages.

possible values for the asset (S_{0u}, S_{0d}) at the end of that time stage. Similarly, the second stage has three nodes and three different values for assets (S_0u^2, S_0ud, S_0d^2) and the third stage has four points and four different values for assets (S_0u^3, S_0u^2d, S_0ud^2, S_0d^3), and so on. The four last nodes at the end of the binomial tree indicate the possible range of asset values at the end of this option lifetime [19].

The basic methodology of this approach is to take advantage of risk-neutral probabilities, including risk adjusting the financial cash flows across the binomial tree with risk-neutral probabilities and discounting them at the risk-free interest rate. Regardless of the option to be valued, the binomial lattice that represents the value of the underlying asset can be described in Eqs. (1) and (2) [19]. The inputs required for forming a binomial tree and calculating the option value are σ, r, S_0, X, T, and δt that represent volatility factor, the risk-free interest rate, the present value of the underlying asset value, the cost of the option to exercise (the amount of investment), the life of the option, and the time step, respectively. The upward (u) and downward (d) factors are a function of the underlying asset volatilities and are calculated through Eqs. (1) and (2):

$$u = \exp\left(\sigma\sqrt{\delta t}\right), \tag{1}$$

$$d = \exp(-\sigma\sqrt{\delta t}), \tag{2}$$

where σ denotes volatility due to the variability of the total value of the underlying asset and it is related to the uncertainty of cash flows over the option lifetime. There are four principal methods for estimating the volatility as follows: logarithmic cash flow returns method, project proxy approach, market proxy approach, and management assumption approach. Three of them suffer from some serious weaknesses in estimating the volatility of new technological projects such as the inability for use in cases with negative cash flow, the absence of projects with similar market volatility, and the lack of similar firms with the closing stock price to the technology-based firm. However, in the proposed framework, the management assumption approach is used due to the mentioned reasons and the characteristics of NTBFs as a simple and practical method. In this approach, the manager or investor estimates optimistic (S_{opt}), pessimistic (S_{pes}), and most likely (average) (S_0) expected payoffs for project lifetime (t). Assuming that the payoff is followed by a lognormal distribution and by knowing any two of the three mentioned estimates, the volatility of the underlying asset value is calculated using one of Eq. (3) as follows:

$$\sigma = \frac{\ln\left(\frac{S_{opt}}{S_0}\right)}{2\sqrt{T}}, \ \sigma = \frac{\ln\left(\frac{S_0}{S_{pes}}\right)}{2\sqrt{T}}, \ \sigma = \frac{\ln\left(\frac{S_{opt}}{S_{pes}}\right)}{4\sqrt{T}}. \tag{3}$$

Risk-neutral probability (p) is defined according to Eq. (4), where r is the risk-free interest rate or rate of return on a riskless asset during the option lifetime. In fact, p is a mathematical intermediate, which allows for discounting the cash flows by using a risk-free interest rate.

$$p = \frac{\exp(r\delta t) - d}{u - d}. \tag{4}$$

The present value of expected free cash flow based on the calculation of DCF method indicates the underlying asset value that is calculated using the proposed framework and by utilizing the most-likely cash flows. The equations above are used to calculate the asset values with forward movements at each node of the binomial lattice, but for calculating the option values with backward induction, Eq. (5) is used. C is the discounted (at the risk-free rate) weighted average of potential future option values using the risk-neutral probability.

$$C = pC_u + (1-p)C_d] \exp(-r\delta t). \tag{5}$$

In the backward induction, calculated option values are compared with the values of the option to choose and we decide to exercise the options at each node of the binomial lattice.

4. Application of the proposed framework to a NTBF as the results and discussion

An Iranian technology-based firm that using a technology for production of nano anti-bacterial tiles was selected for applying the proposed framework. With the application of this technology, this firm can produce the ceramics usable for health and medical areas with antibacterial properties, which can eliminate the disease factors. By using the antibacterial materials on the nano scale during the process of production, it is feasible to produce the antibacterial ceramics for achieving completely clean and hygienic surfaces. This firm is at the stage of the idea (seed) and for its technology valuation, all of the ten steps are implemented as follows:

- First step: The firm's technology life cycle (from idea to commercialization) was determined to be eight years based on experts' opinions. According to the growth stages of the technology-based firm, the division of its technology life cycle is shown in Figure 3.
- Second step: To determine the option to choose, three options of abandonment, expansion, and contraction were considered during the commercialization stage of this firm. At any time during the five-year commercialization period, the firm can abandon the manufacturing operations by assigning the technology patent and selling the other properties for a salvage value of \$230,000 and expanding 35% by investing \$150,000 or contracting 30% of its current operations to save \$120,000.
- Third step: In this case study, by considering the experts, investors, and technology owners' opinions, the critical volatility variables of a relevant technology-based firm were determined to estimate the cash flows under three estimations of optimistic, most likely, and pessimistic. The results are shown in Table 2. Note that the most likely estimation is obtained from the mean of two optimistic and pessimistic estimates. During the process of determining the values of variables, the optimistic estimation is close to the proposals of the technology owner and the pessimistic estimation is close to the investor's proposals. Ultimately, the experts present the adjusting opinions for determining the final optimistic and pessimistic cash flows. Determined critical volatility variables are as follows:
  - New products (possibility to reveal new products and influence the market of a relevant firm's products);
  - Inflation (given the high exchange rate fluctuations in Iran, it is possible to increase inflation considerably);
  - Public policies (at the moment, the sale of technology-based products is supported and subsidies are granted to their sale; this support may increase or decrease during the commercialization stage).

It should be noted that for the calculation of a relevant firm' cash flows, in addition to considering the critical volatility variables, the market study was performed to achieve results, as shown in Table 2. In order ensure the success of the market study of nano anti-bacterial tiles as the product of the mentioned firm, the following elements were identified and considered: the number of imported products, projects under construction, and target markets such as hospitals and in particular their surgery rooms, emergency

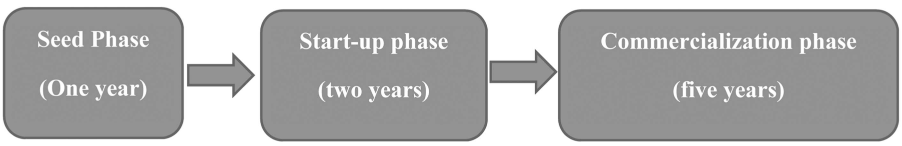

Figure 3. The division of the firm's technology life cycle in the growth stages.

Table 2. Critical volatility variables along with cash flows under three estimations, namely optimistic, most likely, and pessimistic.

	Critical volatility variables: New products, inflation, and public policies								
	Investment and annual costs			**Income**			**Cash flows**		
Year	**Pessimistic**	**Most-likely**	**Optimistic**	**Pessimistic**	**Most-likely**	**Optimistic**	**Pessimistic**	**Most-likely**	**Optimistic**
2017	123,888	123,888	123,888	—	—	—	123,888	123,888	123,888
2018	214,973	168,938	122,902	258,233	354,960	451,687	43,260	186,023	328,785
2019	288,676	226,858	165,039	356,273	489,723	623,172	67,597	262,865	458,133
2020	321,758	252,855	183,952	365,101	501,858	638,614	43,343	249,003	454,662
2021	368,475	289,568	210,660	419,915	577,203	734,490	51,440	287,635	523,830
2022	369,766	290,583	211,399	445,248	612,025	778,802	75,482	321,443	567,403

rooms, health centers, industrial kitchens, hotels and restaurants, swimming pools, livestock and poultry slaughterhouses, industrial refrigerators of food products, home and public toilets, especially in educational and training centers, mosques and public places, etc.

- Fourth step: The NPVs of a firm's cash flows without taking risks and at a discount rate of 15% (central bank interest rate) were estimated in optimistic, most likely, and pessimistic modes during the commercialization stage.
  - Pessimistic NPV: \$52,418;
  - Most likely net present value: \$630,111;
  - Optimistic net present value: \$1,207,804.
- Fifth step: By incorporating the NPVs of the firm in optimistic and pessimistic modes and applying Eq. (3), based on the management assumptions approach, the annual volatility was calculated at about 35% as follows:

$$\sigma = \frac{\ln\left(\frac{S_{opt}}{S_{pes}}\right)}{4\sqrt{T}} = \frac{\ln\left(\frac{1,207,804}{52,418}\right)}{4\sqrt{5}} = 0.3507.$$

- Sixth step: In this step, by calculating the risk equal to 0.31 and taking into account the NPV of the firm in the most likely mode, the underlying asset value was obtained as follows:

Underlying asset value (risk-adjusted NPV)

$$= \frac{630,111}{(1+0.31)} = 481,001.$$

- Seventh step: The asset values and binomial tree were determined and depicted during the commercialization stage regarding the variables and calculations were demonstrated. It should be noted that the risk-free interest rate was considered a bit high in this research because, at the time of performing this study, the annual interest rate by the Central Bank of Iran was 15%. In Figure 4, the top numbers represent the asset values and the bottom italicized numbers represent the option values.

$S_0 = \$481000$
$\sigma = 35\%$
$Expansion\ Factor = 1.35$
$Contraction\ factor = 0.70$
$Salvage\ value = \$230000$
$u = \exp(\sigma\sqrt{\delta t}) = 1.419$
$T = 5$ Year
$r = 15\%$
$Cost\ of\ expansion = \$150000$
$Saving\ of\ contraction = \$120000$
$\delta t = 1$Year
$d = \frac{1}{u} = 0.705$
$p = \frac{\exp(r\delta t) - d}{u-d} = 0.640.$

- Eighth step: The option values were calculated by backward induction and based on the option to choose. At this step, to calculate the option value, there is an option to either continue the firm's current operation level and keep the option open for the future or:
  - To terminate the technology-based firm at a salvage value of \$230,000 which is equivalent to the value of patent assignment to rival applicants;
  - To invest \$150,000, for expanding by 35%;
  - To save \$120,000, for contracting by 30%.

It should be noted that the above numbers were estimated for the related case study. At this step, each node exercises one option that provides the maximum value for the technology-based firm. For example, at the node of S_0u^5 at the last time step, the expected asset value was \$2768300. Therefore, calculation of asset values for exercising each option is given below:

- Abandonment: \$230,000;

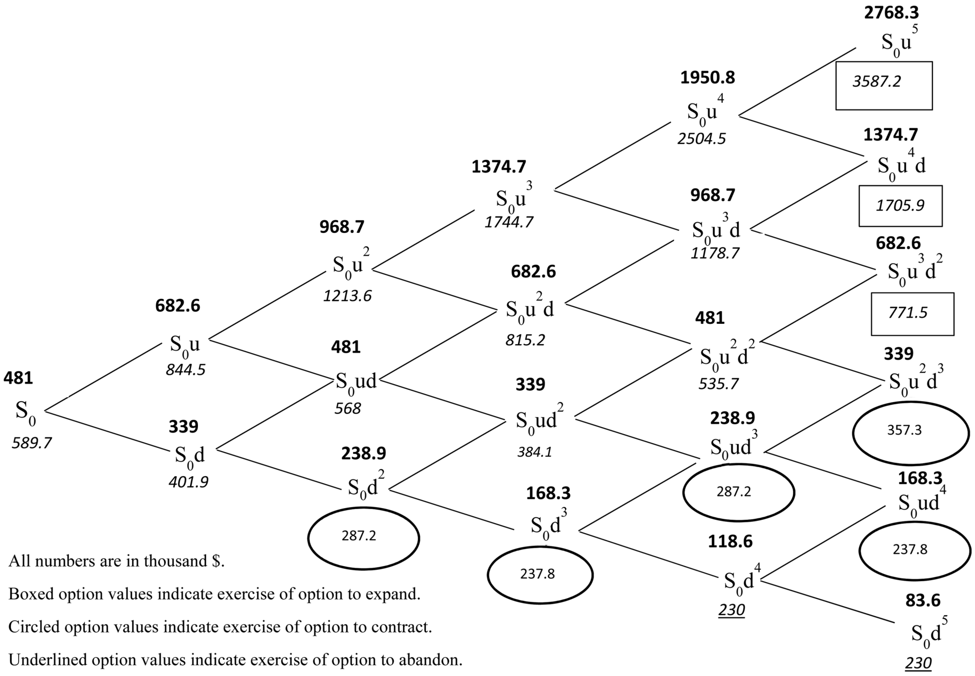

Figure 4. The binomial tree for the option to choice of case study.

- Expansion:

$$(1.35 * \$2768300) - \$150000 = \$3587200;$$

- Contraction:

$$(0.70 * \$2768300) + \$120000 = \$2057800.$$

The maximization shows that the option to expand would be exercised at this node; therefore, the option value here becomes $3587200. The same calculations were implemented for other nodes at this time step.

In the case of intermediate nodes, by moving one step away from the last time step, at node S_0u^4, the discounted (at the risk-free rate) weighted average of potential future option values using the risk-neutral probability will be obtained through Eq. (5) as follows:

$$C = pC_u + (1-p)C_d] \exp(-r\delta t)$$

$$= [0.640(\$3587200) + (1-0.640)(\$1705900)]$$

$$\times \exp(-0.15) = \$2504500.$$

Then, the asset value will be calculated for exercising each of the available options as follows:

- Abandonment: $230,000;
- Expansion:

$$(1.35 * \$1950800) - \$150000 = \$2483600;$$

- Contraction:

$$(0.70 * \$1950800) + \$120000 = \$1485600.$$

The maximization implies that the option would be kept open at this node; therefore, the option value here becomes $2504500. The same calculations were performed to show the option values for all the nodes in Figure 4.

The calculations show that the firm's NPV for the commercialization stage based on the risk-adjusted DCF method was $481,000 compared to the ROV of $589700. There is a significant difference valued at $108700, which is the value added due to the application of real options and so, the management or investor can consider it in making investment decisions. Figure 4 shows strategic values at different points of the option lifetime, during which decision-makers rely on the expected asset values to whether keep the option open and continue with this technology or to exercise any one of the options to expand, contract, or abandon. Note that in other cases, for technology valuation of NTBFs affairs, it is not required to use all these three options (abandonment, expansion, and contraction) at the same time and it suffices to use one or two of them, accordingly.

- Ninth step: At this step, according to the framework, the investment costs related to the seed and start-up stages of this firm were estimated as equal to 50 and 150 thousand dollars, respectively. Then, to calculate the success probability in the seed stage,

Table 3. Calculation of private risk according to the importance and experts' scoring to each factor.

Critical success factors	Factor's importance	Score of experts (1 to 100)
The existence of a business plan at the beginning of formation	0.08	70
Patent ownership	0.1	0
Motivation, experiences, and capabilities of teamwork	0.2	90
The ability and capacity of firm directors for management and leadership	0.12	80
An integrated and cohesive team to transform an idea into a product	0.15	90
Risk of firm managers	0.15	70
Teamwork education level	0.04	90
The presence of required experts and consultants to convert an idea into a product	0.05	85
The availability of needed appliances, labs, and equipment to convert an idea into a product	0.07	85
Having strategic links with universities and research centers	0.04	80
Success probability	0.742	
Failure probability	0.258	

the filling of Table 1 and the scoring were performed by the experts' opinions, as described in Table 3. Note that according to the conditions of other firms, the importance of the factors and the scoring of them may be changed. According to Kodukula and Papudesu [19], the discount rate was slightly higher than the risk-free interest rate 15% and was equal to 18%. Therefore, the technology-based firm's ROV up to the seed stage was calculated in terms of both market and private risks and the ROA and DTA methods were combined in the following.

By calculating the success probabilities, Figure 5 shows the performance of DTA. The success probability of this firm during the start-up stage was 0.854 and the details of the calculations were not presented in this paper. Figure 5 shows that if the technology-based firm cannot produce the prototype at the seed stage, then investors will not invest at the next steps and will proceed to terminate investment. Moreover, despite the success of the firm in the seed and start-up stages, the investor may not pursue the commercialization stage in case of the market uncertainty and a negative NPV. All calculations are given in Table 4.

According to the calculations in Table 4, finally, the firm's NPV in the seed stage is $83,108. With the application of this framework, in addition to achieving a value added equal to $108700 in the commercialization stage, the ability to perform the technology valuation of NTBFs was provided from idea (seed) to the commercialization stage, which has remained unanswered up to now. Moreover,

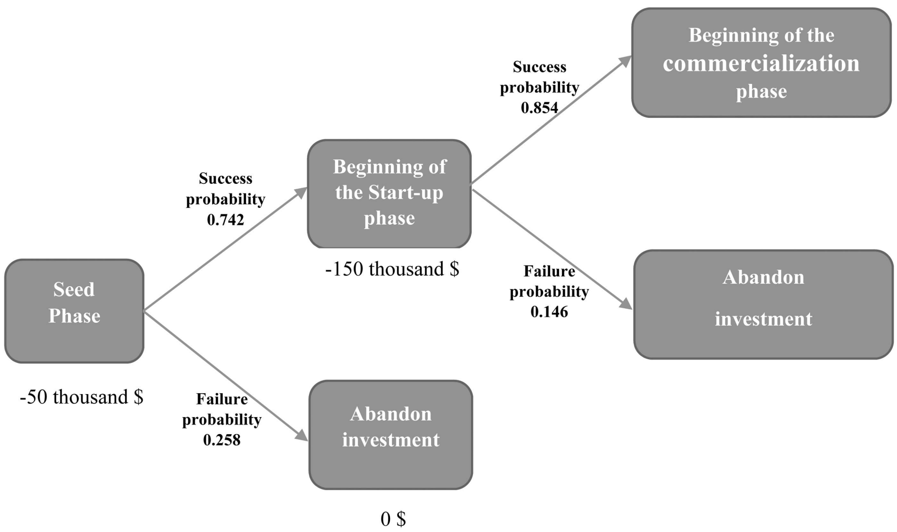

Figure 5. Decision tree for the early stages of the growth of case study.

Table 4. Decision tree calculations according to Real Options Analysis (ROA).

Input data	Values and calculations	
Discount rate in decision tree calculations	18%	
Seed phase duration	1 year	
Seed phase cost	$50000	
Probability of success in the seed phase	0.742	
Probability of success in the start-up phase	0.854	
Start-up phase duration	2 years	
Start-up phase cost	$150000	
Option value in the commercialization phase	$589700	
Start-up phase of technology-based firm		
Firm payoff at the end of year 3	0.854 ($589700)+ 0.146 ($0)	$503604
Firm's present value at the end of year 1	$503604 /(1+0.18)^2	$361680
Start-up phase cost		$–150000
Firm's NPV at the end of year 1	$361680-$150000	$211680
Seed phase of technology-based firm		
Firm payoff at the end of year 1	0.742 ($211680) + 0.258 ($0)	$157067
Firm's present value at the end of zero year	$157067 / (1+0.18)^1	$133108
Seed phase cost		$–50000
Firm's NPV at the end of zero year	$133108-$50000	$83108

in the absence of ROA in the commercialization stage and based on the NPV of $481000 at the end of the start-up stage and the beginning of commercialization stage, the final NPV at the seed stage will be obtained equal to $41185 instead of $83108. The $41923 difference is the value added to the technology valuation at the seed stage by applying the ROA to the commercialization stage.

- Step tenth: At this step, in addition to the above-mentioned value added, sensitivity analysis of the volatility key variables was performed, which was not needed and included in this paper because of the high value of NPV.

5. Conclusion

This study discussed the challenge of technology valuation of New Technology-Based Firms (NTBFs) in the field of cleaner production, especially in the idea (seed) stage of their growth. According to the literature review, appropriate methods for technology valuation of such New Technology-Based Firms (NTBFs) were selected and developed to include managerial flexibilities based on the uncertainties in public policy, systematically.

5.1. Novelty and contribution

A ten-step framework was proposed based on a combination of Real Options Analysis (ROA) and Decision Tree Analysis (DTA). This framework was applied to performing the technology valuation of such NTBFs from idea to the commercialization stage such that a comprehensive framework, especially in the early growth stage of the firm, was not presented before this research. Furthermore, unlike the previous researches that utilized the compound options in several stages of financing, an option to choose was used to apply investors' flexibilities during the commercialization stage at the second step of the proposed framework, matching the characteristics of NTBFs.

In this paper, a case study related to the technology valuation of Iranian NTBFs in the field of cleaner production was presented. Iranian NTBFs were in the seed stage and a technology for production of nano anti-bacterial tiles was utilized in terms of the dimensions of the proposed framework encompassing all three options of abandonment, expansion, and contraction and all of ten steps were taken. However, to value the technology of other NTBFs, depending on which stage of growth the firm is, it may not be possible to use all steps of this framework. Therefore, if a firm is in the commercialization stage of growth, then the DTA and private risk assessment will be ignored during the process of the framework. Moreover, depending on the circumstances and valuation status of the firm, one, two, or all of three options may be applied.

5.2. Implications for industrial engineers

As already discussed in the case study, the application of ROA led to a significant value added to the value of the technology-based firm both at the commercialization and seed stages. In this way, by comparing the value of technology in the commercialization stage of $589700 and its value at seed stage of $83108, the investors may find sufficient motivation to invest in the early stages of firms, which turns to be a real-world engineering application. Moreover, using this framework, a manager, investor, or venture capitalist has the right to invest in the later growth stages of such firms or terminate his investment by considering the implementation or non-implementation of public policies in the future. With the application of this approach to valuation and participation, it may result in encouraging the investors and increasing their participation in the early stages of such NTBFs, leading to fostering the development of innovation and technology in the field of cleaner production. In addition, the application of the ROA instead of traditional methods such as Discounted Cash Flow (DCF) or Net Present Value (NPV) can help industrial engineers who are active in the field of project management to consider flexibilities and uncertainties in the feasibility study of projects.

5.3. Limitations and future scope

In the section on assessing the private risk and determining the success probability, it may be possible to apply better methods to future research and also it is needed to measure the impact of utilizing this framework on encouraging the investors to invest in the early growth stages of NTBFs. Additionally, this research should be extended to include game theory for determining the option price during the technology valuation.

References

1. Stokes, D. and Wilson, N., *Small Business Management and Entrepreneurship*, Cengage., 6th Edn. (2010).
2. Yagüe-Perales, R.M. and March-Chorda, I. "Performance analysis of NTBFs in knowledge-intensive industries: Evidence from the human health sector", *Journal of Business Research*, **66**(10), pp. 1983–1989 (2013).
3. Jensen, A. and Clausen, T.H. "Origins and emergence of exploration and exploitation capabilities in new technology-based firms", *Technological Forecasting & Social Change*, **120**, pp. 163–175 (2017).
4. Camisón-Haba, S., Clemente-Almendros, J.A., and Gonzalez-Cruz, T. "How technology-based firms become also highly innovative firms? The role of knowledge, technological and managerial capabilities, and entrepreneurs' background", *Journal of Innovation & Knowledge*, **4**(3), pp. 162–170 (2019).
5. Phan, P.H., Siegel, D.S., and Wright, M. "Science parks and incubators: observations, synthesis and future research", *Journal of Business Venturing*, **20**(2), pp. 165–182 (2005).
6. Stucki, T. "Which firms benefit from investments in green energy technologies? -The effect of energy costs", *Research Policy*, **48**(3), pp. 546–555 (2019).
7. Yabar, H., Uwasu, M., and Hara, K. "Tracking environmental innovations and policy regulations in Japan: case studies on dioxin emissions and electric home appliances recycling", *Journal of Cleaner Production*, **44**, pp. 152–158 (2013).
8. Guerzoni, M. and Raiteri, E. "Demand-side vs. supply-side technology policies: Hidden treatment and new empirical evidence on the policy mix", *Research Policy*, **44**(3), pp. 726–747 (2015).
9. Amankwah-Amoah, J. and Hinson, R.E. "Contextual influences on new technology ventures: A study of domestic firms in Ghana", *Technological Forecasting and Social Change*, **143**, pp. 289–296 (2019).
10. Quindlen, R. "Confessions of a venture capitalist: Inside the high-stakes world of start-up financing", *Business Plus*, May 1st (2001).
11. Cumming, D. and Dai, N. "Fund size, limited attention and valuation of venture capital backed firms", *Journal of Empirical Finance*, **18**(1), pp. 2–15 (2011).
12. Ari, G.B. and Vonortas, N.S. "Risk financing for knowledge-based enterprises: mechanisms and policy options", *Science and Public Policy*, **34**(7), pp. 475–488 (2007).
13. Engel, D. and Keilbach, M. "Firm-level Implications of early stage venture capital investment: An empirical investigation", *Journal of Empirical Finance*, **14**(2), pp. 150–167 (2007).
14. Hochberg, Y.V., Ljungqvist, A., and Lu, Y. "Networking as a barrier to entry and the competitive supply of venture capital", *Journal of Finance*, **65**(3), pp. 829–859 (2010).
15. Gompers, P., Kovner, A., Lerner, J., et al. "Performance persistence in entrepreneurship", *Journal of Financial Economics*, **96**(1), pp. 18–32 (2010).
16. McKaskill, T., *Raising Angel & Venture Capital Finance*, Melbourne: Breakthrough Publications (2009).
17. Meyer, T. "Venture capital in Europa - Mehr Pep für Europas Wirtschaft", *Deutsche Bank Research*, Frankfurt (2006).
18. Dixit, A.K., Dixit, R.K., Pindyck, R.S., et al., *Investment Under Uncertainty*, Princeton University Press (1994).
19. Kodukula, P. and Papudesu, C., *Project Valuation Using Real Options: A Practitioner's Guide*, Fort Lauderdale, Florida: J. Ross Publishing (2006).
20. Bagheri, R., Rezaeian, A., and Fazlaly, A. "A mathematical model to evaluate knowledge in the knowledge-based organizations", *Scientia Iranica, Transaction E, Industrial Engineering*, **22**(6), pp. 2716–2721 (2015).
21. Daum, J. "How to better exploit intangible asset to create value", The New Economy Analyst Report, **6** (2001).
22. Kamiyama, S., Sheehan, J., and Martinez, C. "Valuation and exploitation of intellectual property", *OECD Directorate for Science, Technology and Industry*, STI Working Paper 2006/5 (2006).

23. Hanel, P. "Intellectual property rights business management practices: A survey of the literature", *Technovation*, **26**(8), pp. 895–931 (2006).

24. Smith, G.V. and Parr, R.L., *Intellectual Property: Valuation, Exploitation, and Infringement Damages*, Hoboken/N.J. Wiley (2005).

25. Hsieh, C.H. "Patent value assessment and commercialization strategy", *Technological Foracasting & Social Change*, **80**(2), pp. 307–319 (2013).

26. Loop, D. and Lipfert, S., *Patentbasierte Unternehmensfinanzierung* , Bankpraktiker 12/2006, pp. 594–599 (2006).

27. Reilly, R.F. and Schweihs, R.P., *Valuing Intangible Assets*, Boston, McGraw Hill Professional (1998).

28. Battersby, G.J. and Grimes, C.W., *Licensing Royalty Rates*, *Licensing Royalty Rates*, Aspen Publishers Online (2012).

29. Roman, V.B., LOPES, M., Marques, A., et al. "Technologies valuation methods applicable to technology transfer in Brazilian universities: a review", In *International Conference on Industrial Engineering and Operation Management*, Valladolid, Spain (2013).

30. Shane, S.A., *Academic Entrepreneurship: University Spin-Offs and Wealth Creation*, Edward Elgar Pub, New York (2004).

31. Stewart, T.A., *The Wealth of Knowledge: Intellectual Capital and the Twenty-First Century Organization*, Crown Business (2007).

32. Hall, G. "Lack of finance as a constraint on the expansion of innovatory small firms", In: Barber, J.L., Metcalfe, J.S., Porteous, M., Eds., *Barriers to Growth in Small Firms*, Routledge, London (1989).

33. Storey, D.J., *Understanding the Small Business Sector*, 1st. Ed., Cengage Learning EMEA (1994).

34. Blackburn, R.A. "High-technology new firms: variable barriers to growth", *International Small Business Journal*, **13**(3), pp. 103–105 (1995).

35. Festel, G., Wuermseher, M., and Cattaneo, G. "Valuation of early stage high-tech start-up companies", *International Journal of Business,* **18**(3), p. 216 (2013).

36. Wang, Z. and Tang, X. "Research of investment evaluation of agricultural venture capital project on real options approach", *Agriculture and Agricultural Science Procedia*, **1**, pp. 449–455 (2010).

37. Razgaitis, R., *Valuation and Dealmaking of Technology-Based Intellectual Property: Principles, Methods, and Tools*, John Wiley & Sons, Hoboken (2009).

38. Hunt, F., Mitchell, R., Phaal, R., et al. "Early valuation of technology: real options, hybrid models and beyond", *Journal of The Society of Instrument and Control Engineers*, **43**(10), pp. 730–735 (2004).

39. Kjaerland, F. "A real option analysis of investments in hydropower-The case of Norway", *Energy Policy*, **35**(11), pp. 5901–5908 (2007).

40. Lee, S.C. and Shih, L.H. "Renewable energy policy evaluation using real option model - The case of Taiwan", *Energy Economics*, **32**, pp. 67–78 (2010).

41. Batista, F.R.S., de Melo, A.C.G., Teixeira, J.P., et al. "The carbon market incremental payoff in renewable electricity generation projects in Brazil: a real options approach", *IEEE Transactions on Power Systems*, **26**(3), pp. 1241–1251 (2011).

42. Lee, S.C. "Using real option analysis for highly uncertain technology investments: the case of wind energy technology", *Renewable and Sustainable Energy Reviews*, **15**(9), pp. 4443–4450 (2011).

43. Boomsma, T.K., Meade, N., and Fleten, S.E. "Renewable energy investments under different support schemes: a real options approach", *European Journal of Operational Research*, **220**(1), pp. 225–237 (2012).

44. Detert, N. and Kotani, K. "Real options approach to renewable energy investments in Mongolia", *Energy Policy*, **56**, pp. 136–150 (2013).

45. Martinez-Cesena, E.A., Azzopardi, B., and Mutale, J. "Assessment of domestic photovoltaic systems based on real options theory", *Progress in Photovoltaics: Research and Applications*, **21**(2), pp. 250–262 (2013).

46. Abadie, L. and Chamorro, J. "Valuation of wind energy projects: a real options approach", *Energies*, **7**(5), pp. 3218–3255 (2014).

47. Kim, K.T., Lee, D.J., and Park, S.J. "Evaluation of R & D investments in wind power in Korea using real option", *Renewable and Sustainable Energy Reviews*, **40**, pp. 335–347 (2014).

48. Kroniger, D. and Madlener, R. "Hydrogen storage for wind parks: a real options evaluation for an optimal investment in more flexibility", *Applied Energy*, **136**, pp. 931–946 (2014).

49. Jeon, C., Lee, J., and Shin, J. "Optimal subsidy estimation method using system dynamics and the real option model: photovoltaic technology case", *Applied Energy*, **142**, pp. 33–43 (2015).

50. Weibel, S. and Madlener, R. "Cost-effective design of ring wall storage hybrid power plants: a real options analysis", *Energy Conversion and Management*, **103**, pp. 871–885 (2015).

51. Zhang, M.M., Zhou, P., and Zhou, D.Q. "A real options model for renewable energy investment with application to solar photovoltaic power generation in China", *Energy Econ*, **59**, pp. 213–226 (2016).

52. Martín-Barrera, G., Zamora-Ramírez, C., and González-González, J.M. "Application of real options valuation for analyzing the impact of public R&D financing on renewable energy projects: A company's perspective", *Renewable and Sustainable Energy Reviews*, **63**, pp. 292–301 (2016).

53. Chen, S.H., Xu, S.H., Lee, C., Xiong, N.N., and He, W. "The study on stage financing model of IT project investment", *The Scientific World Journal*, **2014**, pp. 1–6 (2014).

54. Chu, H., Ran, L., and Zhang, R. "Evaluating CCS investment of China by a novel real option-based model", *Mathematical Problems in Engineering*, **2016**, pp. 1–15 (2016).

55. Wang, J., Wang, C.Y., and Wu, C.Y. "A real options framework for R&D planning in technology-based firms", *Journal of Engineering and Technology Management*, **35**, pp. 93–114 (2015).

56. Stuart, R. and Abetti, P.A. "Start-up ventures: towards the prediction of initial success", *Journal of Business Venruring*, **2**(3), pp. 215–230 (1987).

57. Doutriaux, J. "Emerging high tech firms: how durable are their comparative sturt-up advantages?", *Journal of Business Venturing*, **7**(4), pp. 303–322 (1992).

58. Cooper, R.G. and Kleinschmidt, E.J. "Benchmarking the firm's critical success factors in new product development", *Journal of Product Innovation Management:* An International Publication of the Product Development & Management Association , **12**(5), pp. 374–391 (1995).

59. Kakati, M. "Success criteria in high-tech new ventures", *Technovation,* **23**(5), pp. 447–457 (2003).

60. Chorev, S. and Anderson, A.R. "Success in Israeli high-tech start-ups; Critical factors and process", *Technovation*, **26**(2), pp. 162–174 (2006).

61. Sadeghi, A., Azar, A., and Rad, R.S. "Developing a fuzzy group AHP model for prioritizing the factors affecting success of High-Tech SME's in Iran: A case study", *Procedia - Social and Behavioral Sciences*, **62**, pp. 957–961 (2012).

62. Jain, D., Garg, R., Bansal, A., et al. "Selection and ranking of E-learning websites using weighted distance-based approximation", *Journal of Computers in Education*, **3**(2), pp. 193–207 (2016).

63. Garg, S.R. and Kumar, R. "Computational MADM evaluation and ranking of cloud service providers using distance-based approach", *International Journal of Information and Decision Sciences*, **10**(3), pp. 222–234 (2018).

64. Amit, G., Ramesh, K., and Tewari, P.C. "Ranking of inventory policies using distance based approach Method", *World Academy of Science, Engineering and Technology, International Science Index 86, International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering*, **8**(2), pp. 395–400 (2014).

65. Sandhya, S. and Garg, R. "Implementation of multi-criteria decision making approach for the team leader selection in IT sector", *Journal of Project Management*, **1**(2), pp. 67–75 (2016).

66. Garg, R. and Jain, D. "Prioritizing e-learning websites evaluation and selection criteria using fuzzy set theory", *Management Science Letters*, **7**(4), pp. 177–184 (2017).

67. Garg, R. "Optimal selection of e-learning websites using multiattribute decision-making approaches", *Journal of Multi-Criteria Decision Analysis*, **24**(3–4), pp. 187–196 (2017).

68. Garg, R., Sharma, R., and Sharma, K. "MCDM based evaluation and ranking of commercial off-the-shelf using fuzzy based matrix method", *Decision Science Letters*, **6**(2), pp. 117–136 (2017).

69. Garg, R. and Arora, S. "Performance evaluation and selection of financial fraud detection models using MCDM approach", *International Journal of Recent Research Aspects*, **4**(2), pp. 172–178 (2017).

70. Bansal, A., Kumar, B., and Garg, R. "Multi-criteria decision making approach for the selection of software effort estimation model", *Management Science Letters*, **7**(6), pp. 285–296 (2017).

71. Garg, R. "Performance evaluation and selection of software effort estimation models based on multi-criteria decision making method", *International Journal of Recent Research Aspects*, **4**(3), pp. 252–257 (2017).

72. Jain, D., Garg, R., and Bansal, A. "A parameterized selection and evaluation of E-learning websites using TOPSIS method", *International Journal of Research & Development in*, **22**(3), pp. 12–26 (2015).

73. Garg, R., Sharma, R., and Sharma, K. "Ranking and selection of commercial off-the-shelf using fuzzy distance based approach", *Decision Science Letters*, **5**(2), pp. 201–210 (2016).

74. Garg, R.K., Sharma, K., Nagpal, C.K., et al. "Ranking of software engineering metrics by fuzzy-based matrix methodology", *Software Testing, Verification and Reliability*, **23**(2), pp. 149–168 (2013).

75. Garg, R., Kumar, R., and Garg, S. "MADM-based parametric selection and ranking of E-learning websites using fuzzy COPRAS", *IEEE Transactions on Education*, **99**, pp. 1–8 (2018).

76. Garg, R. and Jain, D. "Fuzzy multi-attribute decision making evaluation of e-learning websites using FAHP, COPRAS, VIKOR, WDBA", *Decision Science Letters*, **6**(4), pp. 351–364 (2017).

77. Zavadskas, E.K., Antucheviciene, J., Turskis, Z., et al. "Hybrid multiple-criteria decision-making methods: A review of applications in engineering", *Scientia Iranica, Transaction A, Civil Engineering*, **23**(1), p. 1 (2016).

78. Jasemi, M. and Ahmadi, E. "A new fuzzy ELECTRE based multiple criteria method for personnel selection", *Scientia Iranica*, **25**(2), pp. 943–953 (2018).

79. Bruno, A.V. and Tyebjee, T.T. "The entrepreneur's search for capital", *Journal of Business Venturing*, **1**(1), pp. 61–74 (1985).

80. Gompers, P.A. and Lerner, J., *The Venture Capital Cycle*, MIT press (2004).

81. Lukas, E., Mölls, S., and Welling, A. "Venture capital, staged financing and optimal funding policies under uncertainty", *European Journal of Operational Research*, **250**(1), pp. 305–313 (2016).

82. Antikarov, V. and Copeland, T., *Real Options: A Practitioner's Guide*, Texere, New York (2003).

83. Herath, H.S. and Park, C.S. "Multi-stage capital investment opportunities as compound real options", *Eng Econ*, **47**(1), pp. 1–27 (2002).

84. Kim, K., Park, H., and Kim, H. "Real options analysis for renewable energy investment decisions in developing countries", *Renewable and Sustainable Energy Reviews*, **75**, pp. 918–926 (2017).

85. Property, WIPO_World Intellectual, *Valuation of Early Stage Technologies: How to Reach a Starting "Price" for Negotiating a TT Agreement*, Noordwijk, Holanda (2011).

Biographies

Komeil Fattahi has been trained in the field of Management of Technology at Iran University of Science and Technology. His PhD research focuses on technology valuation of technology-based firms. His research interests include venture capital, technology valuation, contract theory, and mechanism design.

Ali Bonyadi Naeini is a Faculty Member at the Business Department of Iran University of Science and Technology (IUST). He has taught a variety of courses such as marketing & innovation management, so far. Furthermore, he has presented several conference papers and scholarly journal papers, mostly focused on quantitative decision-making techniques.

Seyed Jafar Sadjadi finished his PhD at the University of Waterloo, Canada. His research interest is focused on solving different classes of optimization problems in industrial engineering areas such as supply chain management, portfolio optimization, optimal pricing, etc. He has been serving at Iran University of Science and Technology since 2001.