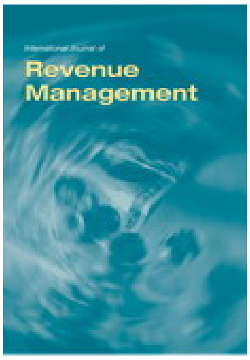

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Crop variety valuation for technology transfer through licensing: a systematic review

T.S. Stanishkar, Akriti Sharma, K.V. Praveen

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Crop variety valuation for technology transfer through licensing: a systematic review

T.S. Stanishkar

Department of Agricultural and Applied Economics,
Davis College of Agricultural Sciences and Natural Resources,
Texas Tech University,
Lubbock, USA
Email: stanishkarts8@gmail.com

Akriti Sharma*

Pusa Krishi,
ICAR-Indian Agricultural Research Institute,
Pusa, New Delhi-110012, India
Email: aakritinankur@gmail.com
*Corresponding author

K.V. Praveen

Division of Agricultural Economics,
ICAR-Indian Agricultural Research Institute,
Pusa, New Delhi-110012, India
Email: veenkv@gmail.com

Abstract: Poor valuation of crop varieties developed by research organisations and universities lead to windfall gains or abnormal losses in economic returns for different stakeholders in the tech-commercialisation chain. Most institutes follow thumb rules such as fixed rates based on crop type or fixed percentage of net present value to determine license fees. Hence, there is a paucity of scientific basis to validate the price or actual value of the crop variety developed through research. The research to develop a standardised framework for crop varieties valuation in the public system is also in its initial stage. This study aims to identify suitable techniques for the valuation of crop varieties through a systematic review of the extant literature. We studied the trends in the publications and the major approaches used in the literature. We identified the best-fit technology valuation methodologies for crop varieties by comparing the factors under consideration for valuation. A framework for crop variety valuation was developed by considering its variables and appropriate techniques to be applied. The study is the first of its kind and provides a critical review for developing crop variety valuation protocols by future researchers and university tech transfer offices for better crop variety commercialisation prospects.

Keywords: crop variety; technology valuation; non-exclusive licensing; technology transfer; real options; university technology transfer.

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Biographical notes: T.S. Stanishkar is a Graduate Research Assistant in the Department of Agricultural and Applied Economics at Davis College of Agricultural Sciences and Natural Resources, Texas Tech University, Lubbock, USA. He has completed his MSc Agriculture in Agricultural Economics from the Indian Agricultural Research Institute, New Delhi, and his Bachelor's in Agriculture from Kerala Agricultural University, Thrissur, Kerala. He is a very passionate and dedicated research scholar who has worked in the field of valuation of agricultural technologies.

Akriti Sharma is the CEO, Pusa Krishi and Senior Scale Scientist (Agribusiness Management) at ICAR-Indian Agricultural Research Institute widely known as PUSA Institute at New Delhi. She is carrying out research activities related to entrepreneurship management and technology commercialisation in the institute. Along with this, she is enabling the technologies reach from lab to farmers' land by the way of successful commercial business ventures. She is also engaged in providing mentorship to young entrepreneurs/ideas to formulate a proper business proposal and ultimately a viable business entity. She is also teaching and supervising Masters' and Doctoral students for various Agri-Business Management courses. She has handled eight externally funded projects, four books, 20 research articles, eight popular articles as publications of national and international repute. She has organised more than 50 training programs and multiple webinars for national and international participants. She has delivered 100+ sessions as an invited speaker.

K.V. Praveen is a Scientist in the Division of Agricultural Economics, ICAR-Indian Agricultural Research Institute, New Delhi. He holds Master's and Doctoral degrees in Agricultural Economics from the ICAR-Indian Agricultural Research Institute. He is currently involved in several in-house and externally funded projects running in the Division, besides teaching courses on Agricultural Economics for masters and doctoral students. Sustainable intensification of agricultural inputs forms the core of his research agenda. His research portfolio includes projects on impact assessment of technologies and policies, and markets and trade.

1 Introduction

Technology can be materialistic in the form of tangible products or non-materialistic such as software or practices, and technical know-how (Baek et al., 2007). Public and private research institutions are vital in technology development and dissemination. Technology transfer is done through various modes, i.e., licensing, contract research, and consultancy. In consultancy, two parties get involved in developing the technology, while in licensing, one party develops the technology, and another takes its production, selling, and distribution rights (Van and Eisenkot, 2017).

In the case of agricultural technologies, licensing is carried out by public research organisations (PRO) to private parties. The private companies pay a certain amount as licensing fees and royalty (depending upon the product sale) to the PRO and take the technology production and selling rights for a set duration. These rights must be surrendered to the PRO when the license expires. Licensing can be done through two modes, i.e., exclusive licensing, where the production rights are given to one company, and non-exclusive licensing, where the number of licensees is not restricted (Contreras, 2022). The mode of licensing is wisely chosen by the tech transfer office of the PRO after forecasting a clear impact of the technology in the market. Valuation of the technology is one metric that helps decide the mode of licensing and licensing fees.

Valuation allows the definition of a price, the determination of a form of payment, and the design of the best terms for the license for the tech transfer to interested companies (Cabrera and Arellano, 2019). It provides the total monetary value of a technology that can be exhausted during the life of the technology. It is a static measure assessed at a given time and is highly subjective based on the purpose of valuation. However, research is being done to bring more and more objectivity to the process to make it reliable and validated (Lagrost et al., 2010).In contrast, pricing is the value realised for the technology in the market through licensing. Technology can be sold at Par, at a price higher than the value or lower (World Intellectual Property Organization, 2015).The national governments are putting hefty amounts into technology development which may call for an appropriate valuation of the technology to realise its worth. Valuation does not always translate into licensing fees; instead, it displays the economic worth of the technology that could be realised by different stakeholders in the chain together.

Agri-based innovations foster any economy mainly in the form of technologies such as High yielding varieties, improved machinery, and other products that can uplift the efficiency of agriculture. The public sector's spending on research and development (R&D) in agriculture was about US$47 million in 2016 (Food and Agriculture Organization of the United Nations, 2022). In 2011, High-income nations accounted for around 55% of this spending on agricultural R&D, while middle-income nations like China, Brazil and India accounted for 43% (Pardey et al., 2016). In the last three years in India, the Indian Council of Agricultural Research (ICAR) has developed 765 field crop varieties, of which 578 are climate-resilient, 98 are resistant to drought and moisture stress, 41 are short-lived, and 47 are biofortified and suited for the establishment of alternative and lucrative cropping systems (ICAR, 2020). The public investment in agricultural research and education of agricultural gross value added in 2017–2018 amounted to INR 17,359 crores in India (Press Information Bureau, 2021).Thus agricultural R&D, which mainly relies on crop variety development, involves investments in R&D infrastructure, human labour, time, and many more factors. These massive investments are made to impact society and combat severe food and nutritional security problems (USDA, 2017).

There is a dilemma about the valuation of technology to avoid losses incurred due to overvaluation or undervaluation resulting from unscientific ways of deciding about the technology prices. Researchers have investigated various ways to identify the value of technology in other sectors, including defence, energy, automobile, etc. but a paucity of research was observed in the literature specifically dedicated to crop variety valuation (Rocha et al., 2021). Hence, this study attempted to understand various techniques of technology valuation in other sectors and make an analogy with crop variety valuation determinants to facilitate licensing deals.

Systematic reviews enable researchers and users of research to see beyond the limitations of particular studies and discover the similarities and differences across seemingly related studies (Munn et al., 2018; Zawacki-Richter et al., 2020). As a result, a level of cumulative knowledge of educational research is possible, which is typically lacking in the valuation of crop varieties as there are no standardised valuation techniques (Samuel et al., 2018). In this background, a systematic review of literature is done to address the following objectives:

1. identification of different techniques for the valuation of the technology from different sectors
2. to develop a framework of crop variety valuation to facilitate licensing deals.

This study explores a new area for crop variety valuation that future researchers may take up for empirical investigation on crop varieties and valuation model construction.

2 Methodology

The systematic literature review is an effective method to conduct a scientific overview of research activity in a specific field (Lame, 2019). In this section, we discuss the methodology followed for the systematic review. We first defined relevant keywords for searching the publications. The following search strings were formulated based on the objectives of study: ‘university + tech* + valuation’, ‘university + patent + valuation’, ‘technology + valuation’, and ‘agriculture + technology + valuation’. Although patents do not protect crop varieties, the techniques used for patent valuation may provide a reference for our review. To keep the review on track with the purpose of identification of a suitable technique for crop variety valuation for licensing deals, we applied the following inclusion criteria to select the studies collected from the sources:

- the technique for valuation shall be fully developed, explained, and demonstrated on a reference technology
- the reference technology shall be fully developed, not an early-stage project or a mid-stage technology
- the valuation shall be done to facilitate licensing deals.

Articles published from 2004 to 2023 were only considered for possible inclusion in our review because of limitations in the literature published before 2004.

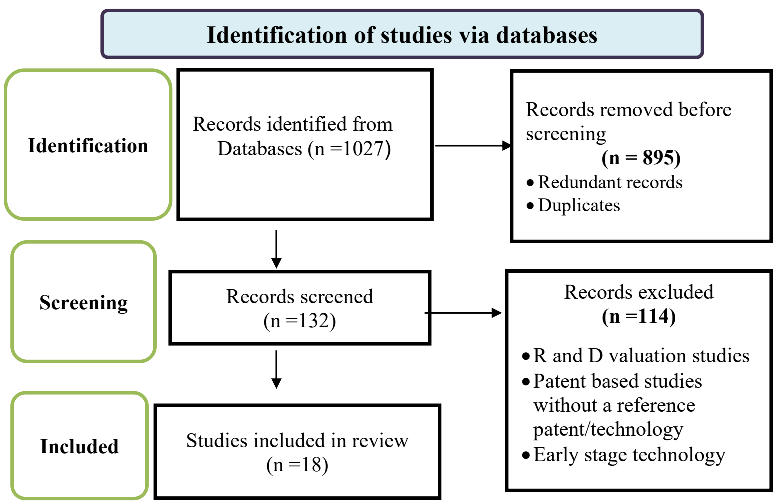
To ensure comparability among contributions, we include only scientific publications such as journal articles, conference proceedings, and book chapters.

The search strings were then applied to various databases such as Scopus, EbscoHost, ProQuest, and Google Scholar by two authors independently in December 2021 to May 2023 to arrive at the relevant studies. Also, cross-references were explored to elaborate the perspective of the study, and 1,027 studies were identified from the above databases (Table 1). As the first step, the title and abstract of the studies were analysed to remove the redundancy and duplicates. Next, we implied the technique’s specificity as the first criterion to filter the initial round of results. Many studies show the importance of valuation and its prospects in technology transfer which were irrelevant for this study. In the next stage, another round of filtering was done by reading the studies’ methodology, results, and implications. Patent-based studies without a reference technology, irrelevant technologies in the viewpoint of licensing, several non-technology-based valuation studies, early-stage technologies, and R&D investment-based valuation studies were removed. After applying all the inclusion criteria, 18 studies are included in this systematic review. The detailed methodology for conducting the review is explained in Figure 1.

Table 1 Search results obtained on EBSCOHOST, Proquest, Scopus and Google Scholar

Search strings	*Databases*	*No. of articles*
Agriculture + technology + valuation	Scopus, EBSCOhost, Proquest, Google Scholar	174
University + technology + valuation	Scopus, EBSCOhost, Proquest, Google Scholar	210
University + patent + valuation	Scopus, EBSCOhost, Proquest, Google Scholar	55
Technology + valuation	Scopus, EBSCOhost, Proquest, Google Scholar	588
Total		1,027

Figure 1 Review methodology schema (see online version for colours)



3 Results and discussion

There are three main approaches for valuation of technology: income, market, and cost. In the market approach, similar technology transactions are taken to assess the value, whereas the cost approach relies on the expenditure to reproduce or duplicate the technology under consideration. Market and cost-based approaches are not further classified in the literature and were found relatively simple to calculate compared to income-based approaches. At the same time, there are certain drawbacks reported in the literature for these two techniques. The market approach relied upon the comparative evaluation of an existing technology of similar nature which may already be undervalued or overvalued. Similarly, the cost-based approach does not take the potential of the technology into account while conducting valuation. The income approach estimates the future revenue of the particular technology throughout its useful life, and specific techniques such as discounted cash flow, and real options are used to value the technology within the income approach. The discounted cash flow (DCF) technique first subtracts expenses from the cash flow received from the usage of assets, and then this net cash flow is adjusted at a proper discount rate. Compared to DCF, real options analysis provides a much more precise valuation and is extremely useful when valuing projects with high levels of uncertainty (Banerjee et al., 2017; Cabrera and Arellano, 2019; Lou et al., 2010; Wirtz, 2012). A real option is different from a financial option as these assets are not traded in the market. Generally, three conditions are followed to find the suitability of the real options technique for the asset under consideration.

1 delay in investment that looks bad today may get better tomorrow, and having the proprietary right to that investment can still be valuable

2 an investment/asset which does not look good today but may give a chance to enter into a newer market/product tomorrow (expansion)

3 option to abandon the investment.

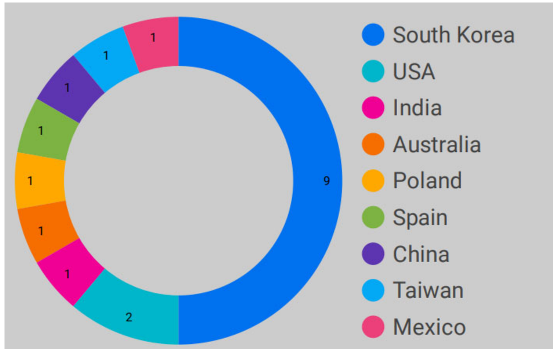
We studied the trend of the publications related to the valuation of the technology from 2004 to 2023. One to two articles were published yearly with the criteria (Table 2). South Korea contributed nearly half of the total studies related to the valuation (Figure 2).

Table 2 Articles published year-wise

Sl. no.	*Year*	*No of publications*
1	2004	1
2	2006	1
3	2007	1
4	2010	2
5	2013	1
6	2014	1
7	2015	2
8	2016	1
9	2017	1
10	2018	2
11	2019	2
12	2020	1
13	2022	2

Of the 18 articles, 16 were from different journals, and two were from conference proceedings. When we tried to classify the studies based on the journals they were published in, we identified that none showed specific dominance, and each paper was unique.

Figure 2 Origin of publications (country-wise) (see online version for colours)



The studies were classified based on the field of study for the technology in which a specific valuation technique was tested as a case study (Table 3). We found that industrial, agriculture-related, IT-based, and renewable energy technologies contribute about 50% of the total studies where the valuation is depicted. The biotechnology, pharmaceuticals, defence, and renewable energy sectors are also in the valuation studies.

Table 3 Classification of studies based upon field of study

Sl. no.	*Field of study*	*Number of publications*	*Authors and year of publication*
1	IT-based technology	4	Park and Park (2004), Jun et al. (2015), Novitzká et al. (2017) and Oh and Park (2022)
2	Agriculture-related technology	3	Wilson et al. (2015), Samuel et al. (2018) and Wynn et al. (2018)
3	Renewable energy	2	Jeon and Shin (2014) and Valdivia et al. (2020)
4	Industrial technology	2	Ma et al. (2019)
5	Pharmaceuticals	3	Wang (2016), Woo et al. (2019) and Kim (2022)
6	Defense related technology	2	Doerr et al. (2006) and Jang and Lee (2013)
7	Construction technology	1	Hong et al. (2010)
8	Laboratory instrument	1	Vega-González et al. (2010)

We initially attempted to classify the selected studies from different perspectives, such as income, cost, and market approaches (Table 4). The cost-based approach mainly relies on the expenditure made by the company/institute in the development of the technology. The market approach is the valuation approach based on making the comparison of the technology with other similar technologies and taking their prices in the market as reference. Finally, the income approach determines the current value of anticipated future revenue flow resulting from the relevant IP throughout its anticipated economic life. During the review, a hybrid approach also came into consideration which is an amalgamation of two or more of the above-mentioned approaches. This classification provides the popularity of income-based valuation techniques compared to the other approaches. Moreover, we found studies that used a hybrid approach, which means any combinations of the three traditional methods.

Table 4 Classification of studies based on approaches

Sl. no.	*Approach*	*Research findings*
		Income-based approach
1	Woo et al. (2019)	The study applied risk-adjusted net present value technique which employs the development attrition rate as a discount factor to represent risk throughout each development phase of the technology. Hence, it addresses the shortcomings of the current discounted cash flow method by considering market and technology risks.
2	Baek et al. (2007)	An objective web-based valuation model was developed based upon the Black Scholes method of real options valuation where expected returns from the technology, their volatility, technology contribution factor, additional investment for commercialisation, profit generation period, and risk-free interest rate is considered for getting the value of technology from the buyer's perspective.
3	Samuel et al. (2018)	The valuation of the production of chitin and chitosan from crustacean waste technology (fisheries technology) was done using the profit split method and royalty method. In the profit split technique, the licensee and the licensor split the actual profit expected from using intellectual property according to a mutually agreed-upon ratio. The relief from payment to the licensor by a third party for accessing IP is calculated in the royalty technique to value intellectual property. With the use of relevant risk factors (connected to both the technology and the industry), the present value of future royalties (cash flows) is computed.
4	Wynn et al. (2018)	The paper exhibited a mix of valuation methodologies on genetically modified (GM) wheat using risk premiums, Monte Carlo simulation, and real options analysis.
5	Wilson et al. (2015)	The study provided a stochastic real options-based model for valuing traits at different developmental stages and assessing the value of drought tolerance (DT) in wheat using GM technology.
6	Valdivia et al. (2020)	Techno-economic model for valuing the technologies related to renewable energy, was developed. In the first step, the model identifies the three aspects: uncertainty inherent to the technical aspects of the technology, long-term market conditions, and risks associated with the acceptance and maturity of the project. Based on these variables, cash flow is simulated.
7	Jang and Lee (2013)	The study presents a defence R&D technology valuation model based upon discounted cash flow technique. The major steps include estimating sales volume with a discount factor estimated using the weighted average cost of capital method (WACC). The technology contribution ratio for the technology is also calculated to derive the final value.
8	Park and Park (2004)	A detailed assessment is carried out to determine the life cycle, discount factor, and technology contribution ratio of the technology to arrive at the final value of the technology using income-based approach.

Table 4 Classification of studies based on approaches (continued)

Sl. no.	*Approach*	*Research findings*
		Income-based approach
9	Novitzká et al. (2017)	The authors developed a valuation model for the software at the early implementation stage through an income approach using discounted cash flow method. In addition, a sales forecast was projected using scenario analysis to get future cashflows.
10	Hong et al. (2010)	The study identified critical factors that determine construction technology's valuation and provided guidelines for the valuation by simple discounted cash flow technique using the case study of bridge piers.
11	Doerr et al. (2006)	The study involves the analysis of the cost and benefits of radio frequency identification/micro electro mechanical system (RFID/MEMS) technology for the management of ordnance factories. The valuation approach combines a multi-criteria tool for evaluating qualitative factors and assessing returns on investment. The sensitivity analysis for identifying major risk factors and the Monte Carlo simulation was carried out to incorporate uncertainties in valuation.
12	Kim (2022)	The article focuses at the theoretical as well as the practical aspects of the income approach's valuation techniques and procedures that are helpful for valuing intellectual property. The profit approach, which relies exclusively on the business plans and financial statements of domestic companies, is applied to value intellectual property.
13	Oh and Park (2022)	The study developed a modified income method called 'innotech' that incorporates industry and innovation characteristics into the valuation framework. The challenges associated with mathematical modelling and the dependence of variables like risk premium, anticipated cash flows, and contributing fees are streamlined using this approach.
		Market-based approach
1	Jun et al. (2015)	The study proposed an objective technology valuation model using quantitative patent analysis. Text mining, social network analysis, technology clustering, and descriptive statistics was carried out using the patent documents for the valuation of technology transfer in big data marketing.
2	Samuel et al.	Depicted the valuation of technology that helps in the extraction of chitin and chitosan from crustacean waste using market transactions of similar intellectual property assets.
		Cost-based approach
1	Samuel et al. (2018)	The valuation of technology that helps in the extraction of chitin and chitosan from crustacean waste were done mainly by adding the expenditures for the R&D, such as the personnel salary, patent cost, and other indirect costs.

Table 4 Classification of studies based on approaches (continued)

Sl. no.	*Approach*	*Research findings*
		Hybrid approach
1	Wang (2016)	The study has implications for existing valuation techniques used in Taiwan universities. Based on the survey findings and past studies, they have developed a valuation framework based on the three approaches and applied them for valuing the vaccines for duck viral hepatitis.
2	Vega-González et al. (2010)	A hybrid valuation model using a cost, market, and income approach was developed based on specific value points in the product cycle for pre-commercialised technology, a scanning probe microscope.
3	Ma et al. (2019)	An objective valuation of patents with a long supply chain, such as a Petroleum-based industry, was carried out. It is based on the Value Capture Theory, which combines the cost and benefits method that incorporates the technical characteristics of the petroleum industry.
4	Jeon and Shin (2014)	Valuation of the renewable energy sector using system dynamics that incorporates complex interactions between the variables and the Monte Carlo Simulation, which accounts for long-term uncertainties.

4 Suitability of techniques to crop varieties

We tried to make an analogy with critical variables identified in each study with crop varieties that help in valuation studies. Baek et al. (2007) suggested the real options method using the Black-Scholes equation for the valuation of fully developed technology that uses variables such as expected returns of the technology, technology contribution ratio, profit generation period, an additional investment made for commercialisation, and the volatility of expected returns from the technology. When compared with crop varieties, expected returns can be estimated by discounting the future cash flows after the commercialisation of the technology. In the case of the technology contribution ratio, the study used the sector-agnostic matrix to derive the value. In contrast, in crop variety-specific valuation, the level of innovation that contributes to the real value of the technology based on crop variety-specific parameters, including yield, quality, disease resistance, etc. may be used for deriving technology contribution. The remaining variables, such as additional investment made for commercialisation, profit generation period for the commercialised technology, and volatility of the expected returns, is identical to the crop variety scenario.

In the case of real options, investment options are given for the companies, contingent upon the license to commercialise the particular crop varieties from the licensing agency in the public-private partnership (PPP) mode of commercialisation through exclusive and non-exclusive licensing. In the first case, for new technology, the licensee is unaware of how the market will respond, or for old technology, they perceive that it may go well in the market. Hence, they delay the investment in commercialisation after taking due precautions by just getting the license gives them an option to produce the technology in the future after looking at the pros and cons in the market. Hence, this investment may give them a better chance to enter the market. Moreover, the licensee can observe the market and technology (maybe at a pilotscale) and learn about the profits and losses. It can make the stepwise investment of going full-fledged in the market. Secondly, it can start commercialisation immediately after taking the license, giving it the first-mover's advantage in the market (in case of non-exclusive licensing). Thirdly, the prospective licensee may delay taking the license and thus observe the market trends. It can be possible only if that company has a good market share and supply chain facilities to distribute the commercialised product so that they can overcome the delay of taking the license. The scenarios discussed here imply how the options are extended to the field of crop variety valuation. The essence of the real options approach is to incorporate the market and income risks that technology faces in the commercialisation period, a limitation of traditional discounted cash flow approaches. The cost component during the pre-commercialisation period is not considered in this approach. However, it can be used as a yardstick to check whether the valuation method using real options undervalues or overvalues the crop variety.

Park and Park (2004) suggested an income-based valuation consisting of adjusting and discounting the income flow generated by the technology. It mainly consists of five modules:

1 assessment of intrinsic and application factors of the technology.

2 value of market factors (VOM)

3 calculation of adjusting factor using the value of technology (VOT) factors (weighted sum method)

4 adjusting the income flow generated from the VOM module

5 the income flow is discounted to the present value.

The first module mainly involves the assessment of the intrinsic and application factors of the technology. The intrinsic factors are the proprietary position, level, type of technology, and life of technology. The proprietary position means the degree of protection to use that technology which is 100% in the case of crop variety under licensing. The level of technology implies the technical superiority of the technology of similar kinds. The proprietary position and level of technology are normally measured in scores. The author tried to list its product or process nature in the type of technology. The crop variety can be considered as a product type with incremental innovation from the existing crop varieties. In the case of application factors, the scope of application, technology contribution ratio, and degree of completeness were considered. The scope of application is the extent of application in different sectors specific to industrially applied technology. The technology contribution ratio may give the percentage of cash flow purely attributed to the varietal technology, and completeness is usually expressed in the score, which is the maximum for varietal technology since it is a fully developed technology. Using these factors in the first module, the weighted sum method estimates the adjusting factor. The second module furnishes the market aspects of subjected technology with the income flow based on the type of technology (profit-generating or cost-saving). If it is a profit-generating technology, the market share assessment estimates net profit, whereas the net cost saving flow is estimated from the total cost saved from production. Net profit or net cost saving flow is determined by multiplying the technology contribution ratio with the total cost/total profit flow. The income flow and duration are estimated and discounted to the present value. Then the discounted value is adjusted using the factor derived from the technical factors in the 1st module. This process can be applied in crop varieties because of its possibility to estimate future returns after commercialisation, and most of the technology factors can be derived from the perspective of the variety.

Samuel et al. (2018) estimated the monetary worth of technology using the cost, market, and income approach. The cost approach used R&D expenses, salary components, patent costs, and other indirect costs to derive the technology's final value, which can be easily applied for the crop variety commercialised under PPP. Since most of the varieties may be developed under different research projects that maintain records related to this R&D expenditure, it is amicable to get this information. The market approach does the valuation by comparing the sales of similar technology in the market, which is the general practice in the Indian market for identifying the licensing fees of crop varieties. However, this method is criticised due limitations such as reliability of current market prices and comparability of one crop variety with the other as every new variety is developed due to market gaps. Different methods such as royalty rate, profit split method, and incremental profits are used for the income approach. The relief from royalty technique, the most often used approach, works by adding up the discounted cash flow or net present value of the expected royalties over the first four or five years to determine the worth of the intellectual property. In the profit split approach, the licensee and the licensor split the expected profit from using an IP in a mutually agreed ratio. The standard ratio between the licensee and the licensor is 3:1. For the useful life of the intellectual property, the net present value of the proportion of net profit (often 25%) must be determined. Finally, the incremental profit method involves the excess profit generated by the entity with and without the IP. The royalty method can be successfully implemented in crop varieties since a fixed royalty may be calculated based upon breeder seed to certified seed conversion ratio. Also, the profit split method for the licensor can be derived if there is any contract for the profit split between the licensor and licensee. The incremental method is limited in the case of crop varieties since the profits obtained by the specific variety cannot be exactly predicted because of the limitation to comparing the scenario with and without the technology as interactions of different market variables determine profits.

Jang and Lee (2013) used discounted cash flow techniques to evaluate the technology. The economic life cycle of the technology, estimated sales volume, free cash flow over the period, discount rate, and technology contribution were the critical variables identified in the study, which could be identified for the crop variety as well. Hong et al. (2010) also used the same technique to value construction-based technology but the difference was that the study used the weighted average cost of capital to estimate the discount factor. The weighted average cost of capital (WACC) approach theoretically computes the discount rate by calculating the compensation provided to the capital provider in exchange for using the capital.

Vega-González and Velasco (2016) and Wang (2016) used the mixed approach that uses cost, market, and income as a part of the expected return analysis and comprise the market value of the pre-commercialised technology. The methodology estimates the base, intermediate and final technology value of the specific technology. In the case of crop varieties, cost variables such as direct tangible and project costs can be used to derive the base value. The cash flow (income) simulation can be carried out to reach the intermediate value range of the variety. Finally, the total expected average sales of the variety can be calculated to derive the upper range value of the technology using the scoring and pragmatic approach.

Woo et al. (2019) proposed the risk-adjusted net present value technique as the alternative for discounted cash flow and the real options-based technique in the biopharmaceutical industry. The major variables used to derive the value are the Development period of drugs in each phase, the likelihood of approval, probability of entering into each development phase, cash flow after release, development cost at each phase, discount rate, and the period until the expiration of the patent. The varieties are also developed, tested, approved, and released in phases like drugs. However, these development phases do not account for heavy economic inputs, unlike the drug development case. Hence, the emphasis on the phase-wise development variables may not play as big role as it plays in the case of drug valuation. The rest of the factors adopted under discounted cash flow method used in this paper may be retained for crop variety valuation.

Wilson et al. (2015) and Wynn et al. (2018) valued genetically modified wheat for drought tolerance in Australia and the USA using the real options-based method with Monte Carlo simulation, which helped justify the investments in these projects. They did valuation based upon the ex-ante valuation of trait, risk premium, trait efficiency, technology's life after commercialisation, and phase-wise investments. The yield of any variety may be evaluated by simulating the farm budget data and estimating potential outcomes of an unknown event using Monte Carlo simulation as presented in the study. The yield, drought coverage, costs of seeds, fertiliser, and chemicals may be used among the random variables used for the simulation. An increase in yield due to any trait (disease resistance etc.) as a result of the application of the technology may be applied as the specific contribution of the technology (also referred by Baek et al., 2007), and by combining with phase-wise development data, the valuation may be estimated.

Jeon and Shin (2014) proposed system dynamics with Monte Carlo simulation for the valuation of renewable energy-based technologies. System dynamics (SD) mainly structures the complex interactions between micro and macro variables. The variables for SD were under the three sections as economy, environmental and energy sections. The economic variables are sales, cost, and investment related to the technology. In the case of the environmental section, tax policies and regulations by the government are included, whereas, the energy section included the prices of the technical variables constituted in the project. Similarly, the three sections described here can be applied to the field of crop variety valuation since the tech commercialisation involves economy-related variables (investments, market aspects, sales), governmental interventions, which can be included in environmental variables, and finally the technical variables for the production of crop variety which may constitute the last section. Monte Carlo simulation does probabilistic valuation by incorporating the long-term uncertainties and helps in the dynamic distribution of NPV of the technology for the economic life of the commercialised technology. These simulations are applicable for the crop varieties because of the uncertainties that the commercialised technology faces in the market. The application of SD may be limited for the agricultural system because of its dependency on long-term data for each variable to address its trends.

We eliminated those studies that were irrelevant to crop variety valuation based upon the variables considered and listed them in Table 5 with justification for their inapplicability.

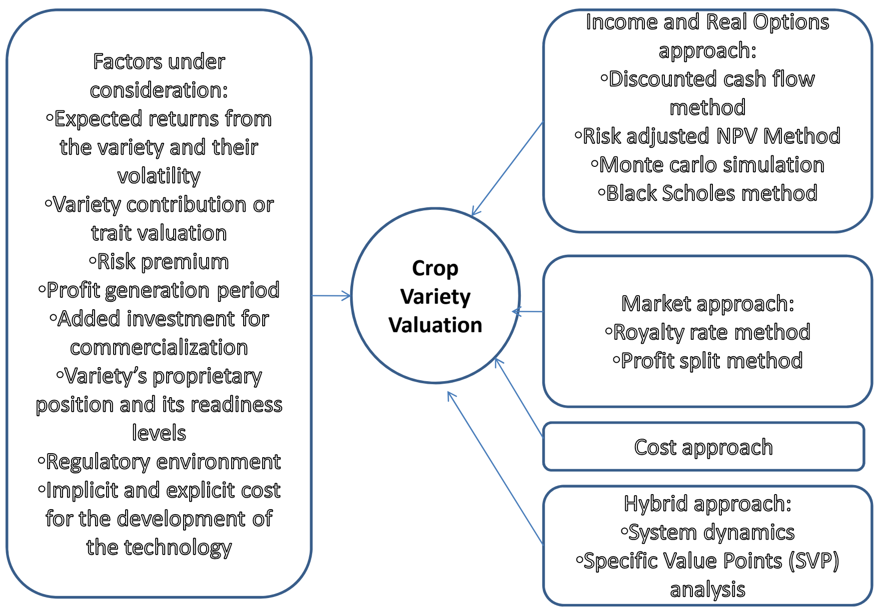
Table 5 Techniques that are inapplicable to crop varieties

Author	*Technique*	*Justification*
Valdivia et al. (2020)	Return on investment with uncertainty	The model incorporates technical, market, financial uncertainty, and long-term maturity such as renewable energy, environmental, and conventional energy projects. This model is applicable for capital intensive, long term projects, and hence may be discouraged for crop variety valuation. Since, it deals with discounting of future cash flows after simulation, this part can be adopted for crop variety valuation.
Jun et al. (2015)	Quantitative patent analysis	This valuation method has wholly relied on the patent databases and it is limited in the case of crop varieties.
Novitzká et al. (2017)	Scenario analysis income-based approach	Discounted cash flow can be adapted to the crop varieties, but scenario analysis of the software-based technologies has limited application for crop variety commercialisation. It's mainly due to the limited possibility of developing various scenarios for the purchase of the crop varietal technology from the inventor.
Ma et al. (2019)	Value capture theory	It applies only to patents characterised by a long supply chain, such as petroleum-based industries, and is limited to crop varieties.
Doerr et al. (2006)	Qualitative technique (multifactorial model) with Monte Carlo simulation for unanticipated financial factors)	A multifactorial model was used to estimate the unanticipated benefits of the radio frequency identification technology/microelectromechanical system (MEMS) which is limited to the defence technologies as they are longer term technologies (15–20 years) and not carrying any impact on ultimate consumers in direct sense.

5 Conclusions towards a crop variety valuation framework

The purpose of our study was to provide a clear picture of valuation techniques and critically evaluate the existing literature. This study highlighted the advantages and disadvantages of the cost, market, and income valuation approach with a perspective of crop variety valuation. It also tried to see the best fit of each valuation methodology in the case of crop variety valuation. Through this review, we arrive at a crop variety valuation framework (Figure 3) that denotes the variables to be taken under consideration while valuing crop varieties and techniques that can be applied. The income-related variables and their volatility, technology's sole contribution to the expected returns, and for how much time these returns will be there, along with additional investment incurred to commercialise the variety, are essential parameters to be considered for income and real options-based valuation approach. These variables can also be looked into while conducting valuation through a hybrid approach. Although varieties are entirely proprietary, valuing any variety for licensing may take its proprietary position and readiness level as an essential parameter for income, real options, and hybrid approach. The environmental factors may be considered necessary from the perspective of enforcement of new seed or crop-based regulations in a specific jurisdiction which may affect the market and variety adoption. These regulations may also relate to the export and subsidy offered on any specific kind of crop family of variety. These are considered in the hybrid approach's systems dynamics method. The implicit and explicit cost incurred for developing the variety may be considered while valuing the crop variety through a cost-based and hybrid approach. The framework also highlights the most suitable techniques which could be adopted for crop variety commercialisation.

Figure 3 Crop variety valuation framework (see online version for colours)



6 Theoretical contribution and future research areas

The study highlights the paucity of research in this important domain of technology transfer. It is a first attempt to summarise different methodologies concerning crop variety valuation and derive a framework. Our findings will be useful for future researchers to understand and conduct the valuation of crop varieties using these methodologies. Consequently, our study provides an initial step for further advancing technology valuation research, serving as a scientific knowledge base for guiding and encouraging future research efforts. The study is novel from the perspective of technology valuation of the crop varieties, and further developments can be made in the approach to value the crop varietal technology. The future income (cash flow) from commercialisation is the base of developing the value of the technology, especially in crop varieties, since market and cost approaches have inapplicability in the valuation scenario of crop varieties. Future research shall be done in this perspective to identify an objective model for the valuation of crop varieties. The study also contributes to the methodology of review articles by analysing existing literature for a possible application in a newer area.

7 Practical utility

It is necessary to calculate the value of technology as part of the transfer process to have an idea of how much it is worth. This is valuable information to offer appropriate terms to potential buyers or licensees. Cabrera and Arellano (2019) highlighted the lack of knowledge about valuing technologies as a significant hindrance for public system tech transfer offices. Majorly, the tech transfer offices work on the rule of thumb for valuation, which causes either overvaluation or undervaluation of the technology. Both of these cases seriously ill affect technology transfer and market adoption. The study poses significant practical implications by sensitising and making the tech transfer offices understand different valuation methodologies narrated in the literature. Incubators can play an important role in licensing/transferring the crop varieties to startups working in similar areas and also to encourage incremental innovation on variety traits. This could serve as a wonderful way of PPP to inculcate a culture of innovation and simultaneously development of the entrepreneurial ecosystem in a region. The tech transfer offices in the universities, specifically agricultural universities, will benefit greatly from the study and devise their valuation protocols based on the framework derived in the paper.

8 Limitations

The study is limited to the crop valuation scenario in which the public sector plays a major role in developing and disseminating technology through licensing. It is also limited to fully developed crop variety valuation rather than the valuation at the time of different development points.

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