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Determination of Importance of Key Decision Points in the Technology Commercialization Process: Attitude of the US and German Experts

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Abstract: With the help of commercialization, inventions become marketable commodities that find new ways of solving problems. Turning technology into reality requires an excellent understanding of the development process from idea to market of the technology. The primary purpose of this article was to examine the commercialization process of inventions and divide the commercialization process into stages that culminate in decision points. Opinions of different authors and representatives of R&D organizations were compared concerning the content of technology commercialization, which is understood and named differently in the scientific and practical literature. Later, with the help of two groups of experts from the US and Germany, the importance of key decision points was determined. The research results were summarized using the MCDM method: the integrated Fuzzy Delphic–Eckenrode Likert-type Scale-based Rating Technique (FDELSRT). The results of this study can be applied in practice to making strategic decisions related to the allocation of efforts, limited time, and financial resources based on the determined importance of key decision points. Research in different countries and the comparison of results will identify areas and opportunities for further mutual learning and more intensive, mutually beneficial international cooperation in technology development.

Keywords: technology commercialization process; the importance of key decision-making points; MCDM methods

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1. Introduction

A popular idea is that the success of technology development depends on some creative magic. However, turning an invention into market requires having an excellent understanding of the development process. That process forces representatives of R&D organizations to think through every step to ensure that problems are solved properly, and that the necessary resources are secured [1,2] in order to prepare the technology for the market.

In the field of technology commercialization/transfer, early efforts were made for gauging the process of technology transfer. The quantitative measure was expected to be useful for economic planning, to aid program management, and for project evaluation and assessment [3,4]. A little later, a lot of attention was paid to the evaluation of technologies, in other words, to the evaluation of their commercial potential at an early stage of technology development [5–17]. Some technology commercialization and transfer models were analyzed in scientific articles in order to connect the understanding of the content of the technology commercialization process [15,18–20] and the content of the technology transfer process [21–24] to the concept. Allen's (2003) [25] and Cooper's (2006) [18] works have been the most prominent in examining the content of technology commercialization. Allen (2003) [25] presented a model for technology commercialization and argued that there are two crucial moments of self-determination in commercialization processes: first, whether intellectual property should be patented or not. At this stage, it is essential to answer the following questions: is it possible to develop the technology in the company? Is technology designed to meet the US Patent and Trademark Office requirements? Is the patent necessary for successful technology commercialization? The second major critical decision stage presents the inventor with three choices: (1) they claim license rights to manufacture and market existing businesses and to receive royalties tax, which is calculated from the product/service sales; (2) they may sell the technology directly to another company; (3) they can establish a company to produce and market their invention. These are very different solutions for scientists and inventors who work in a university environment, research institutes, and government laboratories. The creation of a firm may mean that it will be necessary to leave the current position and seek resources to maintain the start-up. In 2006, Cooper [18] proposed a unique Stage-Gate process specially tailored to the needs of technology development projects. This process consists of three stages and four gates, and feeds the front end of the typical new product process. The author also suggested scorecard and the use of tailored success criteria to rate and rank these technology projects. Articles on the topic of technology management examine such problems as the fit between technology management and technological capability and its impact on new product development performance, the effects of patent policy on outputs and the commercialization of academic patents, the causality between technological innovation and economic growth, and innovation influence for sustainability [26–29].

The technology commercialization process is broken down into stages in which vital decision-making points exist. Based on the motive related to the rational distribution of financial and time resources and efforts between commercialization stages, technology developers need guidance to understand the importance of technology commercialization stages and to compare them to each other. Previous studies, where the content of technology commercialization/transfer was examined [15,18–24,30], have shown that there have never been adequate studies aimed at determining the significance of commercialization stages.

In addition, earlier studies showed an apparent lack of research covering technology commercialization processes and processes that are alternative or related to the content of the technology development process, and led to the understanding that the conceptual analysis is insufficient to answer the questions. How are these processes related, and what are the differences? How can this process be broken down into stages culminating in decision points?

The motives listed above allowed for the formulation of the objective listed below:

- Analyze technology commercialization and transfer models used by different reliable organizations; link the concept of technology development with the content; determine key decision points; detect differences and interfaces between these models, following an analysis of the technology commercialization and transfer process models used in practice.
- Determine the importance of key decision points in the technology commercialization process based on the US and German experts.

Research in different countries and the comparison of results will identify areas and opportunities for further mutual learning and more intensive, mutually beneficial international cooperation in technology development [31].

2. An Overview of the Content and Decision-Making Points in the Technology Development Process

A few approaches to the concept of early technology development content exist in the scientific literature solving technology management problems. To avoid misunderstanding and to define the process under investigation, it is necessary to examine the models used in technology commercialization and transfer centers to connect the process of technology commercialization to the concept and identify key decision points.

The content of technology commercialization schemes can be decided considering the models currently in use in practice [32–38]. In order to connect the understanding of the content of the technology transfer process to the concept, technology transfer models currently in use were analyzed by different organizations responsible for technology transfer [39–41].

The technology transfer process matches all technology commercialization processes except the Goldsmith technology commercialization model [37]. The technology commercialization and transfer procedure usually starts with research and follows the disclosure of the invention and its assessment and legal protection. It ends with the transfer of ownership to a company willing and able to develop the technology and bring it to market. The overall successful procedure of technology commercialization and technology transfer is often divided into estimation and realization phases. The implementation decision depends on the estimation results. Many models of technology commercialization and technology transfer have a commercialization stage as the last stage of the process, which includes three possible choices. Some universities [37] use the Goldsmith technology commercialization schemes. If we compare it to other models, it is the most extensive, covering the entire R&D process, technology commercialization (and technology transfer), and product development processes. This model includes stages from discovery to the enterprise's optimization profit potential, which means that the process involving the stages from the initial stage to the moment return from end users can be assessed, called the post-lunch stage.

Based on the analysis of technology commercialization and technology transfer models, the commercialization process in the literature and practice is understandable in three ways:

1. In the narrow sense, it starts with research or the disclosure of the intervention and ends with the transfer of intellectual property rights to a company;
2. In a broad sense, it covers the entire R&D process, or the technology commercialization (and technology transfer) and product development processes together (Goldsmith technology commercialization model) [37];
3. As the last stage of the technology commercialization/transfer process.

The first and third positions listed above were examined in the following stages of the research. Based on technology commercialization and transfer models analysis, a decision was made to consider the process in the first position as the most frequently used technology commercialization/transfer process and, in further research, to use the stages that culminate in decision points:

- The technology scouting;
- Technology and market assessment;
- Intellectual property protection and management;
- Intellectual property promotion;
- Negotiation;
- Commercialization;
- Market.

Everything starts from the results of the research. Observations and experiments during research activities lead to discoveries and inventions [40]: the new product, process, apparatus, or any new use thereof. In order to be patentable, an invention must be novel, involve an inventive step (i.e., not be evident to those with ordinary skill in the particular art of the invention), and be susceptible to the industrial application [42]. Suppose technology can solve problems in a particular area. In that case, the university's representatives must find the best way to disseminate and effectively exploit the research result to reach the market. The technology transfer process enables the socioeconomic use of humanistic, scientific, and technical knowledge through interaction with third parties in contracted research activities or collaborations, consulting and technical services, in the protection of the research results, licenses, rights of use, and in the creation of spin-offs, including technology transfer [43]. The Technology Transfer offices manage the knowledge transfer process.

Technology scouting is identifying new inventions and technologies and selecting and assessing the potential of innovative ideas. In the beginning, the inventor fills out a Technology Disclosure Form. A technology Disclosure (also called an Invention Disclosure) describes the invention or development. The disclosure should also list all research sponsors and any other information necessary to begin pursuing protection and commercialization activities.

Technology and Market Assessment. At this point, a technology and market assessment must be performed in which the TT Office reviews the invention disclosure, conducts patent searches, and analyzes the market and competitive technologies to determine the invention's market potential. This market assessment process is crucial to identifying the most appropriate business model and the most effective commercialization strategy. In order to identify commercial opportunities of technology, it is necessary to take into account several aspects: field of use; exclusivity or not; strength and breadth of the patent; commercial applications; perceived advantages and benefits; territoriality limitations; one market or multiple markets; single technology or bundle of technologies.

IP Protection and Management are essential for protecting investments, supporting business strategies, providing competitive advantages, and unlocking science and technology's potential. Three options exist: keep the invention a secret, publish it, or apply for a patent. If the invention is kept a secret, the inventor will not be able to publish anything about it. It will also be costly and challenging to keep a secret if there is an intention to make the invention commercially available. If the invention is published, any possibility to protect and prevent the invention from being used by third parties will be lost. If it is considered to fill a patent, no publication can occur before filing the patent request: any articles, press releases, blog entries, but also proceedings and posters. In Europe, any disclosure before filing destroys the patentability, while in the US, inventors have a grace period of 1 year for filing a patent after public disclosure. A patent is a type of intellectual property right granted for a technical invention by a country as a territorial right for a limited period of 20 years from the filing date of the first application. Rights conferred by patents are: to prevent others from making, using, selling, or importing infringing products in the country where the patent was granted; to sell these rights or conclude licensing contrast.

Suppose the decision is made to protect an invention. In that case, verifying whether the invention has all the requirements and conditions is necessary for the patent attorney to analyze the patentability. The patentability criteria require the invention to be novel, so no publication can occur before filing the patent application. In addition, an invention must be industrially applicable. An invention also does not require an outstanding breakthrough, but it should not be evident to a person specialized in the field. Thus, it should involve an inventive step, meaning it should be non-obvious to the expert on that specific technology [44]. If the results of this analysis are positive, then it is time to file the patent application.

IP Promotion. The designated countries for application are chosen based on the market assessment results. It covers relevant geographical markets. Once the IP strategy is defined, it is possible to launch a promotion activity to make the technology visible and accessible. Different marketing channels and instruments for promotion are possible to use. Usually used marketing instruments for promotion: publishing the technology on the institutional website; publishing the technology in the tech transfer database for the European Enterprise Network; publishing the technology in the marketplace; monitoring and engaging in open innovation platforms; presenting the innovation in conferences, or publishing it in industry-related and scientific periodicals; attending industry exhibitions. The promotional activity also concerns identifying potential customers and competitors, who can be easily verified online through some databases [40]. After establishing contact with potential investors/production representatives, an abstract of the technology is usually sent to explain the characteristics of the technology.

Negotiation. After the promotion and the identification of the interested party, a negotiation will be launched to arrive at the best possible deal. During the negotiation, the owner of the technology/inventor should consider several aspects. First, it is necessary to define the goal of the technology transfer deal very well: to maximize revenues, to increase the reputational impact of the research activities, or to keep control of the future development of technology. Secondly, it is essential to define confidentiality with the team, the organization, and the partners when negotiating the deal. During the negotiations, the conditions are discussed: geographical barriers to the development of the technology (broader geographical coverage) and the size of the royalty fee.

The financial conditions will refer to the number of royalties the university will receive. Moreover, they may vary concerning all the conditions of the license. In some instances, a royalty-free license can indeed be granted. Compensation in kind can also be envisaged for the licensor.

Commercialization. When trying to reach the market, we have three options: selling the patent application, licensing the technology, or making a spin-off [38,45]. Australian Government IP Austria names several additional ways of commercialization: Direct in-house use of IP; Franchising; Mergers and acquisitions (M&As); Joint venture (JV) [46]. However, Gbadegeshin (2017) [47] very carefully examined and developed methods of technology commercialization.

Selling: One way of transferring technology is the outright sale, assigning all IP rights to the other entity. The outright sale would be without any restrictions. The new owner will have all rights over the IP assets. This ownership is transferred, and the seller has no further claim on it [47].

Licensing: The most commercial route for academic innovation is licensing to the industry. License agreements grant the licensee the right to use a particular piece of intellectual property rights owned by the licensor, while the ownership of intellectual property rights remains with the licensor.

Creation spin-off or start-up company: The university will license the technology to a newly formed company specifically created to produce the technology. The company will use the technology, and the university will receive patent royalties in exchange for investment in research work. These two forms differ slightly in terms of the source of funding. A spin-off is a company created by a university, with technologies owned by the university and financed by the university [40]. A start-up is a company created outside the university with technologies licensed to the start-up by the university and financed by outside funders. Creating a start-up or spin-off company is relevant when the technology is specific, and it is not easy to find a buyer who could invest in it and create a new market [47]. The success of a spin-off depends very much on sufficient financial resources and good managerial skills.

Market. Once the decision to create start-ups has been made, funding is needed to cover the cost of manufacturing locations, materials, and other initial expenses, such as the direct running costs that include payroll and various operating expenses. The inventor can use resources or search for funding from a Business Angel, Venture Capitalist, crowdfunding end, etc. The inventor can also receive funding through participation in start-up competitions.

3. Materials and Methods: Determination of Importance of Key Decision Points in the Technology Commercialization Process

R&D business managers need a variety of experience and knowledge to address challenges of increasing complexity so that they can operate effectively and make the right and reliable decisions, both locally and internationally [48]. They need models of group decisions that gather experience and experts' reactions. Based on experience (such as facts, similar examples, and others), the experts decide on the values and significance of evaluated elements. Making a decision is a process where alternatives are assessed to choose or take action to achieve desired goals and objectives. A suitable decision-making process can be essential for organizational success [49]. The MCDM method defines the structure of this research and was used to summarize the results of the expert study. This method's choice is based on a motive related to the evaluation purpose [50]—to determine the importance of key decision points in the technology commercialization process among US and German experts. The set of key decision points is the foundation for determining their importance based on the multi-criteria decision-making (MCDM) methods of the determination of weights. There are many different subjective approaches for assessing weights: AHP [51,52], ANP [53], expert method [54], SWARA [55], and the integrated Fuzzy Delphic–Eckenrode Likert-type Scale-based Rating Technique (IFDELSRT) [56]. The FDELSRT was chosen, considering the ranking technique used to collect the primary data from experts. Mathematician specialists have developed many different models of multi-criteria discrete optimization. In this case, the researched model proposes using multi-criteria decision-making (MCDM) methods as universal and reliable solving intermediaries to classify important key decision points and choose the best options. This study uses a methodology consisting of a subjective expert assessment and a three-step Delphi study to evaluate key decision points in the technology commercialization process:

1. It formulates an expert panel to help stakeholders solve a problem. Experts were selected from the US and German R&D organizations according to the following criteria: (1) experience in the process of technology commercialization or the process of the development of products/services or research, the subject of which is the process of technology commercialization, or the development of products/services; (2) positions of the person in organizations and institutions responsible for the technology commercialization, development of products/services, or scientific research in the field of R&D. The R&D experts who agreed to participate in the research were: employees of university technology transfer centers; representatives of start-ups, spin-offs, and large companies; several scientists studying the R&D process in the US and Germany. A total of 60 experts participated in the study: 30 from the US and 30 from Germany.
2. The next step in determining the importance of key decision points is creating the elements for evaluation—a set of the key decision points. The set of elements is the foundation for establishing the weight of elements and the meanings of factors' values, which are essential elements in evaluating multi-criteria decision-making (MCDM). In this case, a set of key decision points was developed based on the models currently in use in practice.
3. The last round of research aimed to measure the weights of key decision points and performs fuzzy MCDM analysis, i.e., to determine the opinion of experienced experts on the importance of the key decision points in the set. The direct expert evaluation of the significance was applied, and a seven-point scale was used. Experts were asked to express their opinion on the importance of key decision points. In this case, the most significant element receives the highest point, whereas the least important receives the lowest.

Delphi's nominal group technique [57,58] helps solve problems requiring experts' opinions and assessments. In this case study, the Eckenrode rating technique [59] integrated with the Delphi technique is used. The basis of the Delphi study is that the decisions of a structured panel of experts are more reliable than individual or unstructured assessments. The main methodological features of Delphi are the multifaceted nature of the procedure, the anonymity and independence of the specialist. This Delphi study helped to select the primary evaluation elements and assess the relative importance of these elements. The above-described method proved valuable in solving prioritization problems in the presence of many fuzzy predetermined requirements [60,61].

Experts rated importance of each element using ranks on a scale of 1 to 7. Weight w_{cj} for element c computed based on the given rank, as follows:

$$w_{cj} = p_{cj} / \sum_{c=1}^{m} p_{cj}, \tag{1}$$

The final elements weights (KDP) w_c were summarized based on the following formula:

$$w_c = \sum_{j=1}^{n} w_{cj} / \sum_{j=1}^{n} \sum_{c=1}^{m} w_{cj}. \tag{2}$$

4. Results

First, the experts were asked to express their opinion based on the MCDM method, the technique of the determination of ranks. Ranked key decision points were changed with points of importance ((number of criteria +1) − (rank number)). In this case, the most critical key decision points in the technology commercialization process receive the highest point, whereas the less important points received a lower score. After the research, sixty correctly completed questionnaires/tables of the importance of key decision points were received: thirty questionnaires from R&D organizations in the US and thirty from R&D organizations in Germany. Tables 1 and 2 provide the initial research results that provided ranks for key decision points in the technology commercialization process. Tables 3 and 4 provide the importance of key decision points obtained after modifying the ranked ones. Abbreviations used in the table: technology scouting—TS; Technology and market assessment—TMA; Intellectual property protection and management—IP PM; Intellectual property promotion—IP P; Negotiation—NG; Commercialization—COM; Market—MR; KDP—key decision points in the technology commercialization process.

Table 1. Ranks of key decision points in the technology commercialization process by USA experts.

No	KDP	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16	E17	E18	E19	E20	E21	E22	E23	E24	E25	E26	E27	E28	E29	E30	Sum of Ranks	Rank
1	TS	7	6	6	4	7	6	7	6	6	7	4	7	7	4	6	4	7	6	7	6	6	7	4	7	7	4	6	6	6	4	177	7
2	TMA	1	2	3	1	2	2	2	2	2	2	1	1	3	1	1	1	2	2	2	2	2	2	1	1	3	1	1	2	3	1	52	1
3	IP PM	3	3	2	2	3	1	1	1	7	3	2	5	2	3	2	2	3	1	1	1	7	3	2	5	2	3	2	3	2	2	79	2
4	IP P	5	7	4	7	5	4	4	5	1	5	7	6	6	7	4	7	5	4	4	5	1	5	7	6	6	7	4	7	4	7	156	5
5	NG	4	4	5	3	4	7	5	4	5	4	3	4	4	6	4	3	4	7	5	4	5	4	3	4	4	6	4	4	5	3	131	4
6	COM	2	1	1	6	1	3	3	3	3	1	6	2	1	2	3	6	1	3	3	3	3	1	6	2	1	2	3	1	1	6	80	3
7	MR	6	5	4	5	6	5	6	7	4	6	5	3	5	5	7	5	6	5	6	7	4	6	5	3	5	5	7	5	4	5	157	6

Table 2. Ranks of key decision points in the technology commercialization process by German experts.

No	KDP	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16	E17	E18	E19	E20	E21	E22	E23	E24	E25	E26	E27	E28	E29	E30	Ranks′ Sum	Rank
1	TS	3	5	4	5	5	5	7	4	7	7	4	6	6	5	7	6	6	6	7	7	2	7	6	6	7	4	5	7	4	6	166	7
2	TMA	2	2	2	2	2	2	2	1	1	3	1	1	2	2	2	2	2	3	2	2	6	2	2	7	2	1	2	2	1	1	64	1
3	IP PM	1	3	1	1	1	7	5	2	5	2	3	2	3	7	5	3	3	2	5	3	1	1	1	2	3	2	7	5	3	2	91	3
4	IP P	7	6	5	4	6	1	3	6	6	6	7	4	7	1	3	7	7	4	3	5	4	4	5	1	5	7	1	3	7	4	139	4
5	NG	4	4	7	7	4	6	4	3	4	4	6	4	4	6	4	4	4	5	4	4	7	5	4	5	4	3	6	4	6	4	140	5
6	COM	6	1	3	3	3	3	1	7	2	1	2	3	1	3	1	1	1	1	1	1	3	3	3	3	1	6	3	1	2	3	73	2
7	MR	5	7	6	6	7	4	6	5	3	5	5	7	5	4	6	5	5	4	6	6	5	6	7	4	6	5	4	6	5	7	162	6

Table 3. Weights/importance of key decision points in the technology commercialization process by USA experts.

No	KDP	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16	E17	E18	E19	E20	E21	E22	E23	E24	E25	E26	E27	E28	E29	E30	Sum of Weights	Rank	Weights of KDP
1	TMA	7	6	5	7	6	6	6	6	6	6	7	7	5	7	7	7	6	6	6	6	6	6	7	7	5	7	7	6	5	7	188	1	0.222
2	IP PM	5	5	6	6	5	7	7	7	1	5	6	3	6	5	6	6	5	7	7	7	1	5	6	3	6	5	6	5	6	6	161	2	0.190
3	COM	6	7	7	2	7	5	5	5	5	7	2	6	7	6	5	2	7	5	5	5	5	7	2	6	7	6	5	7	7	2	160	3	0.189
4	NG	4	4	3	5	4	1	3	4	3	4	5	4	4	2	4	5	4	1	3	4	3	4	5	4	4	2	4	4	3	5	109	4	0.129
5	IP P	3	1	4	1	3	4	4	3	7	3	1	2	2	1	4	1	3	4	4	3	7	3	1	2	2	1	4	1	4	1	84	5	0.099
6	MR	2	3	4	3	2	3	2	1	4	2	3	5	3	3	1	3	2	3	2	1	4	2	3	5	3	3	1	3	4	3	83	6	0.098
7	TS	1	2	2	4	1	2	1	2	2	1	4	1	1	4	2	4	1	2	1	2	2	1	4	1	1	4	2	2	2	4	63	7	0.074
																																848		1.000

Table 4. Weights/importance of key decision points in the technology commercialization process by German experts.

No	KDP	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16	E17	E18	E19	E20	E21	E22	E23	E24	E25	E26	E27	E28	E29	E30	Sum of Weights	Rank	Weights of KDP
1	TMA	6	6	6	6	6	6	6	7	7	5	7	7	6	6	6	6	6	5	6	6	2	6	6	1	6	7	6	6	7	7	176	1	0.208
2	COM	2	7	5	5	5	5	7	1	6	7	6	5	7	5	7	7	7	7	7	7	5	5	5	5	7	2	5	7	6	5	167	2	0.198
3	IP PM	7	5	7	7	7	1	3	6	3	6	5	6	5	1	3	5	5	6	3	5	7	7	7	6	5	6	1	3	5	6	149	3	0.176
4	IP P	1	2	3	4	2	7	5	2	2	2	1	4	1	7	5	1	1	4	5	3	4	4	3	7	3	1	7	5	1	4	101	4	0.120
5	NG	4	4	1	1	4	2	4	5	4	4	2	4	4	2	4	4	4	3	4	4	1	3	4	3	4	5	2	4	2	4	100	5	0.118
6	MR	3	1	2	2	1	4	2	3	5	3	3	1	3	4	2	3	3	4	2	2	3	2	1	4	2	3	4	2	3	1	78	6	0.092
7	TS	5	3	4	3	3	3	1	4	1	1	4	2	2	3	1	2	2	2	1	1	6	1	2	2	1	4	3	1	4	2	74	7	0.088
																																845		1.000

Table 5 compares the importance of key decision points in the technology commercialization process. The similarities between the research results conducted in the US and Germany were quite surprising. In principle, even the evaluation ranks of the three decision-making points coincided: Technology and market assessment (TMA) appeared in the first position, Market (MR) was in the sixth position, and technology scouting (TS) was last in the seventh position.

Table 5. Weights/importance of key decision points in the technology commercialization process by German experts.

Key Decision Points in the Technology Commercialization Process	Abbreviations Used in the Table	US		German	
		Rank	Criteria Weights	Rank	Criteria Weights
The technology scouting	TS	7	0.074	7	0.088
Technology and market assessment	TMA	1	0.222	1	0.208
Intellectual property protection and management	IP PM	2	0.190	3	0.176
Intellectual property promotion	IP P	5	0.099	4	0.120
Negotiation	NG	4	0.129	5	0.118
Commercialization	COM	3	0.189	2	0.198
Market	MR	6	0.098	6	0.092

The experts' opinions differ insignificantly on Intellectual property protection and management (IP PM); it appeared in the second position based on the opinions of US experts and in the third position based on the opinions of German experts. According to US experts, intellectual property promotion (IP P) took the fifth position, and according to German experts, fourth. Negotiation (NG) received the fourth rank from US experts and fifth from Germany. Commercialization (COM) appeared in the third position according to US experts and second according to the opinion of German experts. In general, the differences between the assessments are insignificant, which shows the similarity between the US and German R&D processes.

5. Discussion and Conclusions

Scientific research promotes the emergence of new technologies and innovations, contributes to high-added-value creation, and influences the country's economic growth. With the help of the commercialization of scientific research, ideas become products that find new ways of solving problems, destroy existing ones, and transform old or create new markets. Turning technology into reality requires an excellent understanding of the development process from idea to market. This paper examines the commercialization process of inventions, highlighting the most critical stages of the commercialization process.

The earlier studies showed an apparent lack of research covering technology commercialization processes and processes that are alternative or related to the content of the technology development process, and led to the understanding that the conceptual analysis is insufficient to answer the questions. How are these processes related, and what are the differences? How can this process be broken down into stages culminating in decision points? The technology commercialization process is broken down into stages in which vital decision-making points exist. Based on the motive related to the rational distribution of financial and time resources and efforts between commercialization stages, technology developers need guidance to understand the importance of technology commercialization stages and to compare them to each other. Previous studies, where the content of technology commercialization/transfer was examined [15,18–24,30], have shown that there have never been adequate studies aimed at determining the significance of commercialization stages.

Different authors' opinions and R&D organizations were compared concerning the content of technology commercialization, which, in the scientific and practical literature, is understood and named differently. Based on the analysis above, the commercialization process was divided into stages that culminate in decision points. With the help of two groups of experts from the US and Germany, the importance of these key decision points was determined. The quantitative results of the research were summarized using the MCDM method: the integrated Fuzzy Delphic-Eckenrode Likert-type Scale-based rating technique (FDLSRT). Based on the analysis of the technology commercialization process, the main decision-making points were defined; with the help of experts, the significance of these stages was determined. Expert evaluations in the US and Germany showed that the most important decision-making points are considered to be: 1—Technology and market assessment (TMA), based on both groups of experts; 2—Intellectual property protection and management (IT PM) based on US experts; 2—Commercialization (COM) based on German experts; 3—Commercialization (COM) based on US experts; 3—Intellectual property protection and management (IP PM) based on German experts. In the last position, the key decision point, the technology scouting (TS), appeared and, here, the opinions of both expert groups coincided.

The similarities between the research results conducted in the US and Germany were quite surprising. In principle, even the evaluation ranks of the three decision-making points coincided: Technology and market assessment (TMA) appeared in the first position, Market (MR) was in the sixth position, and technology scouting (TS) was last in the seventh position. The experts' opinions differed insignificantly on Intellectual property protection and management (IP PM); it appeared in the second position based on the opinions of US experts and in the third position based on the opinions of German experts. According to US experts, intellectual property promotion (IP P) took the fifth position, and according to German experts, fourth. Negotiation (NG) received the fourth rank from US experts and fifth from German. Commercialization (COM) appeared in the third position according to US experts and second according to the opinion of German experts. In general, the differences between the assessments are insignificant, which shows the similarity between the US and German R&D processes.

In this study, both groups of experts unanimously decided on the most significant key decision point. Technology and Market Assessment (TMA) is in the most significant position. There are many vital decision-making points in the technology development process; however, only one Technology and Market Assessment (TMA) determines whether other vital decision points will be reached. The importance of this stage is confirmed not only by the results of the study but also by the attention of scientists to this issue in the scientific literature. This stage in academic literature is often called evaluation of commercial potential, invention or technology evaluation, and identification of commercial opportunities. Based on the identification results, large-scale investments are made. The decision at this stage determines whether or not a project will have a successful return on investment. The identification of commercial opportunities is also usually carried out at the initiative of interested third parties who desire essential information about the technology situation. The identification and selection activities are especially critical from the point of view of decision-making, as they are usually framed in the processes of strategic and technological planning, thereby defining future lines of development, as well as the fundamentals for their scientific and economic competitivity and sustainability.

The second and third positions are shared among themselves: Intellectual property protection and management (IP PM) and Commercialization (COM). According to experts, Intellectual property protection and management (IP PM) decisions are related to the risk that the invention will be disclosed and will later no longer be possible to protect or that someone will use it and the value of the technology will be lost. Commercialization (COM) covers three very different alternatives and the risks associated with them. Here, both the inventor and the representatives of the technology transfer center have to very carefully evaluate and weigh their options. Of course, in this case, the situation can change very quickly depending on the current situation in the market or the changed position in the negotiations.

Several limitations of the research need to be mentioned. It established a lack of previous studies in the research area and identified the literature gap and the need for further development in the area of study. Attempts to find studies dedicated to determining the importance of key decision points in the technology commercialization process in science were unsuccessful. In addition, after applying specific technology development promotion instruments, it is difficult to determine the effectiveness of these measures.

The research was carried out by interviewing the US and German R&D experts; the goal was achieved, and the importance of key decision points in the commercialization process was identified. However, we cannot claim that the research reflects the opinion of US and German experts, due to the geographical limitations of the research. The US study was conducted in R&D organizations in San Francisco and Los Angeles, while in Germany, the study was conducted at the Hannover Messe 2022 technology fair. If the limited ability to access a more comprehensive geographic range of participants could have been avoided, results mirroring those of the US and Germany may have been obtained.

Future research should include a detailed analysis of the product development process that follows the technology commercialization process; a determination of key decision points in the product development process; broader and more specific studies in decision-making and determining indicators for product development projects.

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References

1. Biodesign Innovation Process | Stanford Byers Center for Biodesign | Stanford Medicine. Available online: https://biodesign.stanford.edu/about-us/process.html (accessed on 26 January 2022).
2. Mohamed, M.M.A.; Liu, P.; Nie, G. Are Technological Innovation and Foreign Direct Investment a Way to Boost Economic Growth? An Egyptian Case Study Using the Autoregressive Distributed Lag (ARDL) Model. *Sustainability* **2021**, *13*, 3265. [CrossRef]
3. Fan, Y.-K.; Yu, W.-Y. Gauging the Process of International Technology Transfer. *J. Technol. Transf.* **1983**, *7*, 45–51. [CrossRef]
4. Jolly, C. The Technology Transfer Process: Concepts, Framework and Methodology. *J. Technol. Transf.* **1977**, *1*, 77–91. [CrossRef]
5. Jolly, D. The Issue of Weightings in Technology Portfolio Management. *Technovation* **2003**, *23*, 383–391. [CrossRef]
6. Gray, A.; Boehlje, M.; Amanor-Boadu, V.; Fulton, J. Agricultural Innovation and New Ventures: Assessing the Commercial Potential. *Am. J. Agric. Econ.* **2004**, *86*, 1322–1329. [CrossRef]
7. Sohn, S.Y.; Moon, T.H. Structural Equation Model for Predicting Technology Commercialization Success Index (TCSI). *Technol. Forecast. Soc. Chang.* **2003**, *70*, 885–899. [CrossRef]
8. Galbraith, C.S.; DeNoble, A.F.; Ehrlich, S.B.; Kline, D.M. Can Experts Really Assess Future Technology Success? A Neural Network and Bayesian Analysis of Early Stage Technology Proposals. *J. High Technol. Manag. Res.* **2007**, *17*, 125–137. [CrossRef]
9. Price, C.; Huston, R.; Meyers, A.D. A New Approach to Improve Technology Commercialisation in University Medical Schools. *J. Commer. Biotechnol.* **2008**, *14*, 96–102. [CrossRef]
10. Kim, W.; Han, S.K.; Oh, K.J.; Kim, T.Y.; Ahn, H.; Song, C. The Dual Analytic Hierarchy Process to Prioritize Emerging Technologies. *Technol. Forecast. Soc. Chang.* **2010**, *77*, 566–577. [CrossRef]
11. Thokala, P.; Duenas, A. Multiple Criteria Decision Analysis for Health Technology Assessment. *Value Health* **2012**, *15*, 1172–1181. [CrossRef]
12. Cho, J.; Lee, J. Development of a New Technology Product Evaluation Model for Assessing Commercialization Opportunities Using Delphi Method and Fuzzy AHP Approach. *Expert Syst. Appl.* **2013**, *40*, 5314–5330. [CrossRef]
13. Yu, P.; Lee, J.H. A Hybrid Approach Using Two-Level SOM and Combined AHP Rating and AHP/DEA-AR Method for Selecting Optimal Promising Emerging Technology. *Expert Syst. Appl.* **2013**, *40*, 300–314. [CrossRef]

14. Dereli, T.; Altun, K. A Novel Approach for Assessment of Candidate Technologies with Respect to Their Innovation Potentials: Quick Innovation Intelligence Process. *Expert Syst. Appl.* **2013**, *40*, 881–891. [CrossRef]
15. Kirchberger, M.A.; Pohl, L. Technology Commercialization: A Literature Review of Success Factors and Antecedents across Different Contexts. *J. Technol. Transf.* **2016**, *41*, 1077–1112. [CrossRef]
16. Rahal, A.D. Assessment Framework for the Evaluation and Prioritization of University Technologies for Licensing and Commercialization. Ph.D. Thesis, University of Central Florida, Orlando, FL, USA, 2005.
17. Bandarian, R. Evaluation of Commercial Potential of a New Technology at the Early Stage of Development with Fuzzy Logic. *J. Technol. Manag. Innov.* **2007**, *2*, 13.
18. Cooper, R.G. Managing Technology Development Projects. *Res.-Technol. Manag.* **2006**, *49*, 23–31. [CrossRef]
19. Dehghani, T. Technology Commercialization: From Generating Ideas to Creating Economic Value. *IJOL* **2015**, *4*, 192–199. [CrossRef]
20. Fasi, M.A. An Overview on Patenting Trends and Technology Commercialization Practices in the University Technology Transfer Offices in USA and China. *World Pat. Inf.* **2022**, *68*, 102097. [CrossRef]
21. Tseng, A.A.; Raudensky, M. Performance Evaluations of Technology Transfer Offices of Major US Research Universities. *J. Technol. Manag. Innov.* **2014**, *9*, 93–102. [CrossRef]
22. Van Norman, G.A.; Eisenkot, R. Technology Transfer: From the Research Bench to Commercialization. *JACC Basic Transl. Sci.* **2017**, *2*, 197–208. [CrossRef]
23. Khabiri, N.; Rast, S.; Senin, A.A. Identifying Main Influential Elements in Technology Transfer Process: A Conceptual Model. *Procedia-Soc. Behav. Sci.* **2012**, *40*, 417–423. [CrossRef]
24. García-Vega, M.; Vicente-Chirivella, Ó. Do University Technology Transfers Increase Firms' Innovation? *Eur. Econ. Rev.* **2020**, *123*, S0014292120300209. [CrossRef]
25. Allen, K.R. *Bringing New Technology to Market*; Pearson: Upper Saddle River, NJ, USA, 2003; ISBN 978-0-13-093373-7.
26. Ma, Q.; Wu, W.; Liu, Y. The Fit between Technology Management and Technological Capability and Its Impact on New Product Development Performance. *Sustainability* **2021**, *13*, 10956. [CrossRef]
27. Gu, J. Effects of Patent Policy on Outputs and Commercialization of Academic Patents in China: A Spatial Difference-in-Differences Analysis. *Sustainability* **2021**, *13*, 13459. [CrossRef]
28. Mohamed, M.M.A.; Liu, P.; Nie, G. Causality between Technological Innovation and Economic Growth: Evidence from the Economies of Developing Countries. *Sustainability* **2022**, *14*, 3586. [CrossRef]
29. Chaudhuri, R.; Chatterjee, S.; Vrontis, D.; Chaudhuri, S. Innovation in SMEs, AI Dynamism, and Sustainability: The Current Situation and Way Forward. *Sustainability* **2022**, *14*, 12760. [CrossRef]
30. Bagheri, S.K.; Goodarzi, M.; Mahdad, M.; Ali Eshtehardi, M.S. Popularity of Patent Commercialization Policies: Iran as a Case. *World Pat. Inf.* **2021**, *66*, 102063. [CrossRef]
31. Abramson, H.N. *Technology Transfer Systems in the United States and Germany: Lessons and Perspectives*; National Academies Press: Washington, DC, USA, 1997; p. 5271. ISBN 978-0-309-05530-7.
32. Technology Commercialization Process | UCOP. Available online: https://www.ucop.edu/knowledge-transfer-office/innovation/training-and-education/technology-commercialization-process.html (accessed on 11 July 2022).
33. Science and Technology Commercialization. Available online: https://polsky.uchicago.edu/tech-commercialization/ (accessed on 11 July 2022).
34. Technology Commercialization Process | Research | Michigan Tech. Available online: https://www.mtu.edu/research/innovation/commercialize-technology/process/ (accessed on 26 January 2022).
35. OSU Technology Commercialization Process-Oklahoma State University. Available online: https://cowboyinnovations.okstate.edu/for-innovators/osu-technology-commercialization-process.html (accessed on 26 January 2022).
36. Technology Commercialization Process | UTRGV. Available online: https://www.utrgv.edu/research/for-partners/tech-comm-process/index.htm (accessed on 26 January 2022).
37. Goldsmith Technology Commercialization Model. Available online: https://www.unomaha.edu/nebraska-business-development-center/technology-commercialization/goldsmith-technology/index.php (accessed on 26 January 2022).
38. The Commercialisation Process. Available online: https://www.ed.ac.uk/edinburgh-innovations/for-staff/commercialisation-routes/commercial-process (accessed on 11 July 2022).
39. Technology Transfer Process | Technology Transfer and Commercialization. Available online: https://www.jsums.edu/technologytransfer/technology-transfer-process/ (accessed on 26 October 2021).
40. JRC E-Learning Course on Knowledge Transfer. Available online: https://ec.europa.eu/assets/jrc/knowledge-transfert-course/story_html5.html (accessed on 26 January 2022).
41. Technology Transfer Process | LSU Innovation & Technology Commercialization. Available online: https://www.lsu.edu/innovation/faculty/techtransferprocess.php (accessed on 26 October 2021).
42. European Patent Office Glossary. Available online: https://www.epo.org/service-support/glossary.html#:~{}:text=Invention%3A%20New%20product%2C%20process%20or,be%20susceptible%20of%20industrial%20application (accessed on 11 July 2022).
43. Carvalho, L.C.; Madeira, M.J. (Eds.) *Global Campaigning Initiatives for Socio-Economic Development*; Advances in Electronic Government, Digital Divide, and Regional Development; IGI Global: Hershey, PA, USA, 2019; ISBN 978-1-5225-7937-3.

44. European Patent Office. Patentability Requirements. Available online: https://www.epo.org/law-practice/legal-texts/html/guidelines/e/g_i_1.htm (accessed on 11 July 2022).
45. Hamano, Y. Commercialization Procedures: Licensing, Spin-Offs and Start-Ups (WIPO). Available online: https://www.wipo.int/edocs/mdocs/aspac/en/wipo_ip_han_11/wipo_ip_han_11_ref_t7b.pdf (accessed on 11 July 2022).
46. Australia, I.P. Choose Your Commercialisation Vehicle Option. Available online: https://www.ipaustralia.gov.au/understanding-ip/commercialise-your-ip/choose-your-commercialisation-vehicle-option (accessed on 11 July 2022).
47. Saheed, A. Gbadegeshin Stating Best Commercialization Method: An Unanswered Question from Scholars and Practitioners. *Int. J. Soc. Behav. Educ. Econ. Bus. Ind. Eng.* **2017**, *11*, 1088–1094. [CrossRef]
48. Zolfani, S.H.; Zavadskas, E.K.; Turskis, Z. Design of Products with Both International and Local Perspectives Based on Yin-Yang Balance Theory and Swara Method. *Econ. Res.-Ekon. Istraživanja* **2013**, *26*, 153–166. [CrossRef]
49. Haddad, M.; Sanders, D. Selection of Discrete Multiple Criteria Decision Making Methods in the Presence of Risk and Uncertainty. *Oper. Res. Perspect.* **2018**, *5*, 357–370. [CrossRef]
50. Palomo-Domínguez, I.; Zemlickienė, V. Evaluation Expediency of Eco-Friendly Advertising Formats for Different Generation Based on Spanish Advertising Experts. *Sustainability* **2022**, *14*, 1090. [CrossRef]
51. Saaty, T.L. *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*; McGraw-Hill International Book Co: New York, NY, USA; London, UK, 1980; ISBN 978-0-07-054371-3.
52. Turskis, Z.; Lazauskas, M.; Zavadskas, E.K. Fuzzy Multiple Criteria Assessment of Construction Site Alternatives for Non-Hazardous Waste Incineration Plant in Vilnius City, Applying ARAS-F and AHP Methods. *J. Environ. Eng. Landsc. Manag.* **2012**, *20*, 110–120. [CrossRef]
53. Saaty, T.L. *Decision Making with Dependence and Feedback: The Analytic Network Process*; RWS Publications: Pittsburgh, PA, USA, 1996; Volume 4922.
54. Erdogan, S.A.; Šaparauskas, J.; Turskis, Z. Decision Making in Construction Management: AHP and Expert Choice Approach. *Procedia Eng.* **2017**, *172*, 270–276. [CrossRef]
55. Keršulienė, V.; Zavadskas, E.K.; Turskis, Z. Selection of Rational Dispute Resolution Method by Applying New Step-wise Weight Assessment Ratio Analysis (SWARA). *J. Bus. Econ. Manag.* **2010**, *11*, 243–258. [CrossRef]
56. Turskis, Z.; Dzitac, S.; Stankiuviene, A.; Šukys, R. A Fuzzy Group Decision-Making Model for Determining the Most Influential Persons in the Sustainable Prevention of Accidents in the Construction SMEs. *Int. J. Comput. Commun.* **2019**, *14*, 90–106. [CrossRef]
57. Delbecq, A.L.; Van de Ven, A.H. A Group Process Model for Problem Identification and Program Planning. *J. Appl. Behav. Sci.* **1971**, *7*, 466–492. [CrossRef]
58. Turoff, M.; Linstone, H.A. The Delphi Method-Techniques and Applications. 2002. Available online: http://www.foresight.pl/assets/downloads/publications/Turoff_Linstone.pdf (accessed on 30 August 2022).
59. Eckenrode, R.T. Weighting Multiple Criteria. *Manag. Sci.* **1965**, *12*, 180–192. [CrossRef]
60. Turskis, Z.; Goranin, N.; Nurusheva, A.; Boranbayev, S. Information Security Risk Assessment in Critical Infrastructure: A Hybrid MCDM Approach. *Informatica* **2019**, *30*, 187–211. [CrossRef]
61. Turskis, Z.; Goranin, N.; Nurusheva, A.; Boranbayev, S. A Fuzzy WASPAS-Based Approach to Determine Critical Information Infrastructures of EU Sustainable Development. *Sustainability* **2019**, *11*, 424. [CrossRef]