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SCIENCE COMMERCIALISATION WITHIN UNIVERSITY-INDUSTRY NEXUS

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Purpose: The current challenges science faces from the global market relate mainly to transferring knowledge, technical and scientific ideas to the economy, creating products, and developing processes and technologies promoting Social, Economic and Sustainable Development. Therefore, discussions regarding stimulating research commercialisation, along with university-industry cooperation as part of universities' third mission, persist. In light of these considerations, this research aimed to conceptualise and formulate a definition of research commercialisation in universities, while the second objective involved empirically verifying the incentives and barriers to R&D commercialisation within the university-industry nexus in Central and Eastern European country, Poland.

Design/methodology/approach: The commercialisation of scientific research is a complex process that involves multiple stages. It requires the implementation of tasks that are repeated at various points throughout the process. Hence, this research aims to answer the question: what is the approach model to universities' research commercialisation from enterprises' perspective? The study conducted systematic literature reviews and employed the SALSA (Search, Appraisal, Synthesis, Analysis) methodology. The second research question was phrased as: what are the incentives and barriers to R&D commercialisation in the university-industry nexus? Empirical research was employed to address this question through computer-assisted telephone interviews with 44 Polish companies. This qualitative study applied the methodologies which included data categorisation, contextualisation, preliminary within-case analysis, and cross-case analysis.

Findings: The research enhances our comprehension of universities' commercialisation process. The literature review enabled the formulation of a definition for science commercialisation and the graphical presentation of universities' commercialisation model. The study also confirmed that collaborating with highly qualified specialists, developing one's own staff during cooperation, exchanging knowledge, and achieving cost savings, e.g. on research and development expenses and acquiring new technologies, were the most significant benefits for respondents. In contrast, the most significant barriers were the lack of receptivity to industry needs, slow actions and decision-making during commercialisation, obsolete laboratories and equipment, as well as bureaucracy.

Research limitations: The research was not without constraints. Initially, a few respondents faced time constraints, and subsequently, the absence of visual and non-verbal cues that aid in situating the interviewee as observed in face-to-face interviews may have been lost.

Practical implications: The study enhances our comprehension of the process of commercialising research in universities and emphasises the most significant incentives and barriers to university-industry collaboration, as revealed by the respondents. Therefore, some recommendations for policymakers arise from this study, especially in the area of supporting university–industry cooperation.
Originality/value: The paper attempts to fulfil the research gap concerning the conceptual representation of universities' commercialisation process within university-industry nexus. In terms of theoretical implication, detailed literature studies about universities' research commercialisation and university – industry cooperation were preceded that allowed to answer the first research question. Additionally, empirical studies indicated incentives and barriers for university-industry cooperation. This research line contributes to management literature by complementing triple helix concept and knowledge spillover theory of entrepreneurship.
Keywords: science commercialisation, university-industry cooperation, triple helix concept, knowledge spillover theory of entrepreneurship.
Category of the paper: Research paper.

Introduction

The evolution of new technologies, digitization, and the growing diversity of customer needs has a significant impact on the development and implementation of various forms of innovations. This has heightened the importance of understanding the research commercialisation process. Despite the crucial role that the research commercialisation process plays in the advancement of regions and economies, the fragmented nature of scientific research on this matter has resulted in diverse and sometimes conflicting definitions of research commercialisation. This terminological inconsistency poses challenges both at the regulatory level, influenced by enacted legal measures and the overall implementation of the country's innovation policy, and at the practical level concerning the execution of scientific research in this domain.

Hence, the primary objective of this research was to formulate a comprehensive definition of the research commercialisation process, taking into consideration its intricate nature, potential commercialisation pathways, and the dynamic interactions between universities and industries. To progress in this investigation, a conceptual framework was developed, illustrating the research commercialisation model of universities from the perspective of enterprises. In formulating the commercialisation model for universities, emphasis was placed on principles closely associated with entrepreneurial universities and the triple helix, particularly in the context of university-industry collaboration and its importance for regions' development (Etzkowitz, Leydesdorff, 2000). To undertake this phase of the research, extensive literature reviews were conducted using a systematic literature review approach and the SALSA (Search, Appraisal, Synthesis, Analysis) methodology.

Drawing on the contingent model of research commercialisation, the second aim of this study was to determinate which factors are significant for the efficiency of commercialisation process, and which barriers are experienced by companies in Central and Eastern European country, Poland, in this process. To achieve this objective, multiple case study methodology and cross-case analysis covering 44 cases of university-industry cooperation through commercialisation process was applied. It was assumed that institutional and organizational conditions can impact research commercialisation process within the university-industry nexus. The objectives of the study emerged the following research questions: what is the model approach to universities' research commercialisation from the perspective of enterprises? and: what are the incentives and barriers to R&D commercialisation within university-industry nexus?

As numerous academic papers have shown, companies seek for new scientific knowledge and technological development opportunities, therefore often engage in licensing or purchasing academic research results or collaborative research opportunities (Thursby, Thursby, 2002). In the management science, of particular interest is the evidence that companies with direct research ties to universities significantly increase their innovation and competitive advantage (Fabrizio, 2009; Zucker et al., 2002), and universities serve as a major source of external knowledge for corporate world. As knowledge commercialisation serves as a catalyst for innovation in numerous companies and constitutes a crucial component of managing the innovation process, there remains considerable untapped potential for more targeted and conceptually driven research in this domain (Fini et al., 2019). As argues Kotlar et al. (2018), empirical data from the context of science commercialisation is underutilized in existing studies, and due to its multifaceted nature, there exists a gap in our theoretical comprehension of the process. With reference to this statement, the study posits that the research commercialisation process within the university-industry nexus involves the identification of opportunities arising from university research. This is viewed as a mechanism facilitating knowledge spillover to companies, aligning with the knowledge spillover theory of entrepreneurship described by Audretsch and Keilbach (2007).

Literature review

It is commonly expected that university research and its commercialisation should contribute towards solving grand challenges of our times, like global warming, climate change, biodiversity loss, pandemic or food security. The complexity, ambiguity and uncertainty of the commercialisation process require in-depth analysis but its main challenge is the fragmentation of knowledge in this area and the lack of a consistent definition of the commercialisation process (Perkmann et al., 2013).

Research commercialisation, viewed as an economic concept, is an intricate and diverse notion linked to a sequence of activities that result in conferring a commercial character to outcomes derived from scientific research. In this context, the university research commercialisation represents a multifaceted process that empowers creator to garner economic benefits through the practical application of his scientific research results. Recognizing both the scientific and market potential of an invention constitutes an integral aspect of the research commercialisation process. As a result, it is the economic ramifications of commercialisation, manifested in increased profits for individual companies or overall economic growth, that establishes a feedback loop wherein investment in innovation becomes a source of funding for various societal domains. Particularly significant in this context has been the creation of a new generation universities' knowledge that refers to the triple helix concept (Forliano et al., 2021; Etzkowitz, 2003). It is characterized by cooperation with the environment, manly with industry, government and society, as well as involvement of students and faculty members in various entrepreneurial activities, such as commercialisation process. Therefore, for the purpose of this study, research commercialisation definition was based on the assumption that knowledge exchange between university and industry becomes the source leading to the commercialisation process. In the accepted research context, science commercialisation spreads innovations within industries (Dosi et al., 2006) and also during this process innovations move from university research to commercial entities and then to public use (Van Norman, Eisenkot, 2017).

Additionally, according to previous studies referring to knowledge spillover theory of entrepreneurship, for legislative and organizational reasons, science commercialisation process was divided into direct (i.e. direct sell of research results) and indirect commercialisation (i.e. through creation of a spin-off, spin-out or start-up company) (Szulczewska-Remi, Nowak-Mizgalska, 2023). Also, the innovation process characteristics has been used to capture the complex, dynamic and adaptive relations among universities and private firms (Clayton et al., 2018). Eventually, taking into account the university-industry nexus, legislative and organizational conditions of the process, Table 1 summarizes various definitions of science commercialisation.

Table 1.
Definitions of science commercialisation within the university-industry nexus

Source	Definition
Dorf and Worthington (1987)	Technology commercialiation is the process of laboratory research results transformation into a marketable product
Mitchell and Singh (1996)	Research commercialisation is the process of acquiring new ideas, supplementing them with additional knowledge, developing and producing goods for sale and selling goods on the market
Jolly (1997)	Commercialisation is the transformation of knowledge and new (technological) solutions into money

Cont. table 1.

Zhao (2007)	Knowledge commercialisation is the process that involves new ideas and/or research results transformation into commercial products or services and their introduction to the market; it includes the transfer and development of intellectual property, as well as the provision of consulting services based primarily on technological innovation
Caerteling et al. (2008)	Technology commercialisation is a design, manufacture and marketing of products with developed technology, or technology transfer through licensing or other collaborative activities
Viale and Etzkowitz (2010)	Knowledge commercialisation occurs when knowledge generates added value from the economic point of view
OECD (2013)	Public research commercialisation refers to many ways in which knowledge from universities and public research institutions can be used by businesses to generate economic and social value as well as economic development
Perkmann et al. (2013)	Academic commercialisation implies market acceptance for outputs of academic research
Kirchberger and Pohl (2016)	Research commercialisation is the process of transferring a technological innovation from the technology creator to the organization that uses it and applies it in market products
Halilem et al. (2022)	Commercialisation can take several forms including IP-based commercialisation of science through patenting, licensing or spin-off creations

In most of the above presented definitions, commercialisataion process is primarily related to bringing research results to market (Kirchberger, Pohl, 2016; Perkmann et al., 2013; Caerteling et al., 2008; Zhao, 2007; Jolly, 1997; Mitchell, Singh, 1996; Dorf, Worthington, 1987). It is also the introduction and development of new products or services (innovations) that combines implementation of scientific research into economic practice (Kirchberger, Pohl, 2016; Zhao, 2007; Mitchell, Singh, 1996; Dorf, Worthington, 1987). Some definitions also refer to the added value generated by the commercialisation process (OECD, 2013; Viale, Etzkowitz, 2010) and its effects (patents, licenses, spin-off formation, other collaborative activities) (Halilem et al., 2022; Caerteling et al., 2008). Considering the above, the following definition was formulated: Science commercialisation is a process, in which scientific effects provided in the framework of university-business cooperation becomes the subject of market trading, and thus contribute to the added value generation for society and economy.

In addition to the above definition, conceptual framework of the study was constructed based on the innovation processes' models described in the literature. Utterback (1971) pioneered the modeling of the innovation process, delineating it as a sequence of activities: idea generation - technical problem resolution through invention - implementation leading to marketing - dissemination with a substantial impact on the economy. Subsequent developments in innovation process models are commonly framed through the lens of five distinct generations: 1. supply-side linear model of innovation propelled by science, 2. demand-side linear model of innovation driven by market forces, with a focus on consumer preferences (Žižlavsky, 2013), 3. third-generation nonlinear models, aiming to integrate demand and supply factors (e.g. Rothwell and Zegveld's (1985) coupled model or Cooper's (1990) phase-gate model). The subsequent two generations involve integrated and sequential models (Rothwell,

1992), emphasizing collaboration within R&D teams, involving suppliers and customers in the innovation process, and integrating R&D with production through R&D consortia. Traditional models were often modify into models that involved knowledge exchange and interaction with external entities through collaborative research like the Open Innovation Model (Chesbrough, 2003).

In the following study, also Guan and Chen (2010), Chen et al. (2018), as well as Yu et al. (2021) models were adopted, as they introduce two-stage approach to the innovation process comprises a research and development (R&D) stage and a subsequent commercialisation of R&D results. In this framework, research and experimental development (R&D) was defined as "creative and systematic work undertaken in order to increase the stock of knowledge – including knowledge of humankind, culture and society – and to devise new applications of available knowledge" (OECD, 2015). It was assumed, that research and development takes place within university-industry research collaboration that leads to commercialisation defined in previous section. The right-facing arrow points to commercialisation results that was described by Halilem et al. (2022) and Wang et al. (2022): number of R&D results including patents, new or improved products, services; number of licences, IP transfer agreements; number of spin-off/spin-out companies; number of collaborative research works (figure 1).

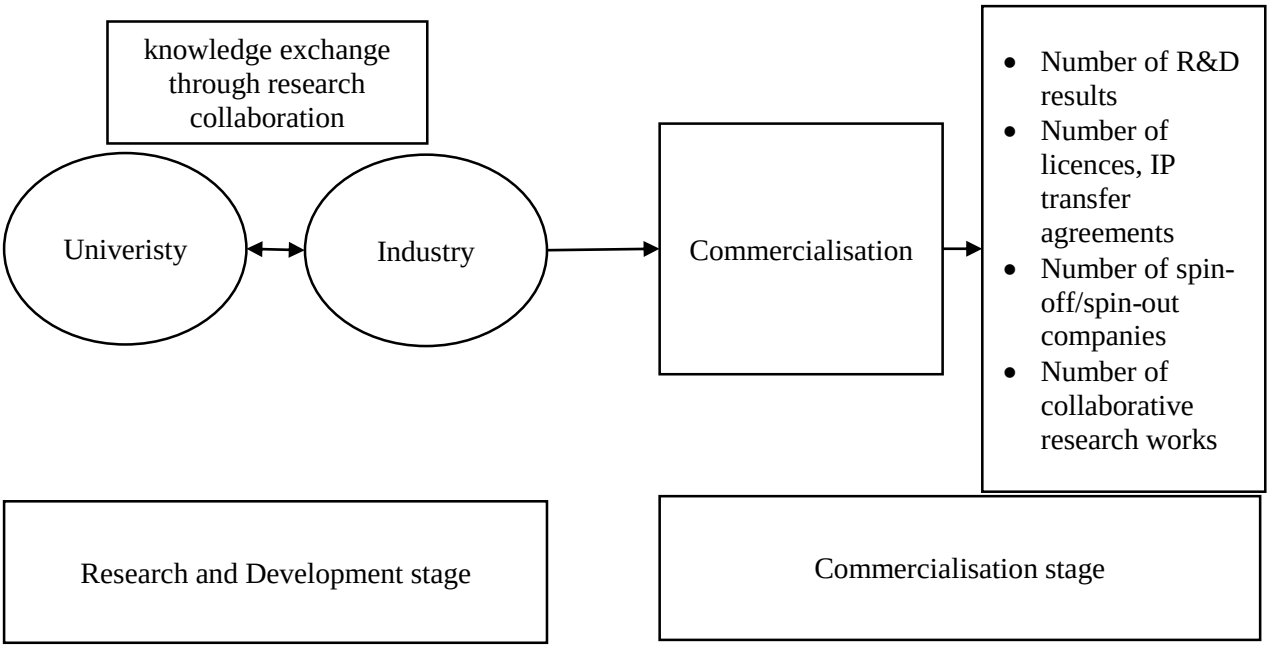

Figure 1. Conceptual framework of the study – universities' research commercialisation model from the perspective of enterprises.

Source: own development.

Methods

To explore research commercialisation, firstly extensive literature studies were conducted using systematic literature review and SALSA (Search, AppraisaL, Synthesis, Analysis) methodology (Booth et al., 2016), which aimed to provide research commercialisation definition and characteristics of research commercialisation models within the university-industry nexus. A preliminary literature search in Scopus electronic database collected 691 items, which were used to establish the criteria that guided the selection of literature in the full-text search (keywords, followed by inclusion and exclusion criteria). Items selected on the basis of analysis of abstracts and titles of articles and post-conference publications were allocated for full-text analysis (n = 32). In addition, a snowball sampling technique was used when reviewing the bibliography of each of these items (Jalali, Wohlin, 2012) and searching through citation indexes to obtain additional relevant articles (n = 35). In a further stage, data were synthesized by organizing them into logical categories: 1. research commercialisation definition, 2. research commercialisation in the context of the innovation process taking place in enterprises. In addition, an analysis of data from each item within the identified categories was applied (Petticrew, Roberts, 2006).

In order to accomplish the research objectives, empirical investigations was employed and a methodology involving multiple case studies, as outlined by Yin (2018). This approach facilitated a thorough examination of each case, enabling the identification of contingency variables that differentiate one case from another. Additionally, the adoption of multiple-case studies aimed to provide insights into explanatory processes through cross-case analysis, thereby externally validating the findings obtained from individual case studies. Data collection was carried out using computer-assisted web interviews triangulated with other documents like legislative acts on university research commercialisation, reports and data bases of the Ministry of Education and Science, Polish Agency for Enterprise Development or the National Center for Research and Development. A group of academics with the required qualifications and experience conducted the interviews during which they were able to clarify questions, summarize the questionnaire and very the accuracy of interpretations. The questionnaires remained accessible and were designed in a conversational manner, allowing respondents to articulate their comments and opinions. Therefore, the method used in the presented studies corresponded to both confirmatory methods, focusing on the conceptual representation of the research commercialisation process, and exploratory methods, examining the role of university-industry cooperation enhancing science commercialisation performance. Qualitative research was chosen for its ability to describe, understand and interpret phenomena, facilitating a comprehensive understanding of various factors (Merriam, 2009).

In order to select the companies, the aggregated profitability index was constructed and principal component analysis (PCA) was selected as it reduces the dimensionality of a dataset while preserving the maximum amount of information (IBM, 2021). The above procedure resulted in having companies from 19 different sectors (ranged from the most profitable company, to the least profitable one within a sector). Next, from each sector 3 companies were included in the study: one representing high-profitability companies, one representing average-profitability, and one representing low-profitability. Accordingly, 57 companies were initially included, representing all the sectors studied and all the profitability levels established. As there were not too many companies cooperating with universities, most of the interviews were not completed (Szulczewska-Remi, 2023). Therefore, in the second step of this study, other 44 companies were interviewed based on the companies' selection identified by Polish commercialisation intermediary institutions (Technology Transfer Offices and Special Purpose Vehicles) as cooperated with universities. This part of the empirical research took place in the first and the second quarter of 2023. Characteristics of companies operating in Central and Eastern Europe, Poland, taking part in the second round of empirical study are presented in Appendix 1.

The qualitative analysis was structured based on the methodologies outlined by Yin (2018), incorporating data categorization, data contextualization, preliminary within-case analysis, and cross-case analysis. The author used theory as a filter to organize the collected information as recommended in the previous works (Yin, 1994). The research methodology employed in the semi-structured interviews consisted of 11 substantive questions (Appendix 1 and 2). In the line with the findings in the literature (Langridge, Hagger-Johnson, 2009), six of these questions were open-ended, providing respondents with the opportunity to elaborate freely. Alongside the substantive questions were covering 18 statements where the respondents were required to indicate the strength of their agreement/disagreement with each statement on a 5-point Likert-type scale where 5 means strongly agree. The data analysis procedure aligned with both the confirmatory and exploratory requirements of the study. In the confirmatory aspect, the data were analyzed to provide additional validation for the theoretical model depicting the science commercialisation process. On the exploratory front, the data served to address knowledge gaps related to the role of university-industry cooperation in enhancing comercialisation process. The study population exhibited homogeneity, with precisely structured and focused research content, allowing the saturation point to be reached after 44 interviews.

The research was not free of limitations. First, some of the respondents experienced time pressure. Secondly, all the visual and non-verbal clues that can facilitate contextualizing the interviewee as seen in face-to-face interviews might be lost.

Results and discussion

Commercialisation of scientific discoveries is a complex process that involves commitment from and interaction with a myriad of organizational support and institutions. A special example of such cooperation is a university-industry collaboration that facilitate the direct translation of universities' research to the marketplace (Rothaermel et al., 2007). Still, the research on science commercialisation, especially from Central and Eastern European countries remains scare, and as Cunningham et al. (2017) postulate more studies from this region is needed for further contribution to the field, providing insights into different contextual approaches and practices.

Since science commercialisation is characterized by multifaceted interactions and the terminology in this area remains fragmented, the first objective of this study was to develop a comprehensive definition of the research commercialisation process. Based on literature studies, the following definition was formulated: Science commercialisation is a process, in which scientific effects provided in the framework of university-business cooperation becomes the subject of market trading, and thus contribute to the added value generation for society and economy. Relying on this definition, conceptual framework of the study was developed based on the two-stage innovation process described in the literature as a research and development stage and a commercialisation of R&D results stage (figure 1). It was assumed, that research and development takes place within university-industry research collaboration that leads to commercialisation. Hence, this part of research corresponds to the first research question.

Complementary to this study, empirical investigations was employed to provide insights into commericalisation process within the university-industry nexus. Firstly, respondents' experience in commercialisation was analyzed. At the organizational level, most of the respondents confirmed separated research and development (R&D) department within their companies' structure (n = 27). As it was commented by respondent 43: "The company is engaged in research and development activities in a wide range of fields (…)", respondent 37: "We established an R&D department with highly qualified specialists in 2019 for innovations in the production process", respondent 12: 'We have our own R&D department because we need to react quickly to market changes - our products are related to an industry where technology is aging very quickly, so we decided to conduct R&D internally to react faster and have full control over processes", respondent 5: "We are a manufacturing company. An R&D department is necessary for new product development and technological development. Outsourcing R&D to external parties would not be effective in our case". One respondent declared R&D carried out by another company belonging to the same capital group and some companies outsourced R&D to external entities (n = 6), which was explained by respondent 44: "We are a startup employing 8 people, that is why we outsource some of the work". In some cases (n = 10) R&D department was not implemented.

Transforming scientific research into technological development, product or process leading further to commercialisation often required patenting activities aimed at supporting commercialisation process (Shin et al., 2023). Patents are useful in understanding innovation trends and forecasting future technologies (Ernst, 1997), for that reason respondents were asked about their patenting experience. Most of them did not hold any patents and did not use any patents through a licence granted by another entity (n = 28), some held national (n = 11), international patents (n = 8) and/or used patents through a licence granted by another entity (n = 3). Respondents commented on the need for patent protection: "National patents were necessary to secure the formula on which the company manufactures, the basis of its business" (respondent 42), "Many proprietary and very clever functional food products require a patent claim" (respondent 40). During considered period, eleven companies received national and/or international patents, six companies were granted with licences, IP transfer agreements, seven sold their technologies, eleven companies performed contract R&D and seven set-up a spin-off/spin-out companies.

In relation to experience in R&D commercialisation within university-industry nexus, most of the companies were on one occasion cooperating with universities or other scientific institutes (n = 33, with the caveat that it was a one occasion collaboration with different universities, scientific institutes), some regularly cooperated with universities/scientific institutes (n = 14) and some did not cooperate with universities/scientific institutes (n = 11). Companies were mainly cooperating with universities (n = 20) and universities of technology (n = 13), followed by universities of economics (n = 7), scientific institutes (n = 6) and Polish Academy of Science (n = 5), medical universities (n = 3), universities of agricultural and life science (n = 3), universities of arts (n = 3). In one example, the cooperation was dictated by the academic experience of the founders: "The staff comes from universities and has the knowledge and ambition for additional R&D activities in addition to typical production activities. They know how to raise external funds. They are aware that this allows the company to stand out internationally and allows to distinguish itself from the competition. By focusing on new solutions, the company has the opportunity to offer them to its customers and thus access a wider market" (respondent 39).

Most respondents claimed commercial research works as an effect of cooperation with universities/scientific institutes (n = 14) and R&D results implementation (n = 13). It was commented by respondent 30: "A cheaper and better solution. We can't afford high-level experts on staff, and this is how we benefit and pay 'per use'. In addition, entities such as universities can efficiently tap into the intellectual resources of other experts that are too difficult for us to reach". Two respondents also mentioned licenses, IP transfer agreements and one spin-off/pin-out company formation as results of university-industry collaboration. The following opinions also appeared in relation to cooperation with universities/scientific institutes: "High specialization requires constant adaptation" (respondent 28), "The company's

object is largely research and development, hence much of its business is geared toward this type of activity, both for its own needs and those of external parties" (respondent 32).

With regards to the second research question, the incentives and barriers to R&D commercialisation within university-industry nexus are summarized in table 2, which is organized in line with the recommendations of Johnson et al. (2023). The level of significance of individual incentives and barriers was determined by the average score of respondents' agreement/disagreement strength. The results are listed in order from most significant to least significant.

Table 2.
Incentives and barriers to R&D commercialisation within university-industry nexus

Theoretical dimensions	Importance for respondents	Illustrative examples from respondents
Incentives to R&D commercialisation		
Opportunity to cooperate with highly qualified specialists	thirty respondents indicated this incentive as very important and twelve as somewhat important (average of all responses: 3.77)	"The development of new products, based on current experience, required the qualified personnel for the further development of functional foods" (respondent 40)
Own staff development during cooperation, exchange of knowledge	nineteen respondents indicated this incentive as very important and sixteen as somewhat important (average of all responses: 3.50)	"R&D work is carried out within the Technical Department and cooperation with University of Technology. This allows engineers to develop comprehensively in the areas of design and technology" (respondent 34)
Savings e.g. on research and development expenditures	fifteen respondents indicated this incentive as very important and other fifteen as somewhat important (average of all responses: 3.50)	"Such a solution is cost-optimal for us and allows us to benefit from external funds" (respondent 16)
Acquisition of new technologies	twenty four respondents indicated this incentive as very important and eight as somewhat important (average of all responses: 3.45)	"Greater access to all sorts of technology" (respondent 44)
Access to knowledge and research results	twenty four respondents indicated this incentive as very important and six as somewhat important (average of all responses: 3.41)	"We are innovating in the field of technology for the production of vegan dairy products and dietary supplements, so we are working with universities to continuously improve our products' offer" (respondent 9)
Access to research infrastructure	twenty one respondents indicated this incentive as very important and thirteen as somewhat important (average of all responses: 3.34)	"Lack of funds to finance a research center operating within the company's structure" (respondent 5)
Prestige of cooperation	eight respondents indicated this incentive as very important and nineteen as somewhat important (average of all responses: 2.93)	"The co-owners of the company are scientists employed at the University which increases the prestige of cooperation between these institutions" (respondent 3) "We outsource all of our research to R&D centers and university companies" (respondent 21)

Cont. table 2.

Barriers to R&D commercialisation		
Lack of openness to the industries' needs	twenty one respondents indicated this incentive as very important and ten as somewhat important (average of all responses: 3.70)	"We would be interested in marketing research in the field of functional food development in Poland and Europe or research in the field of communication with the consumer (modern channels of reaching the customer both B2B and B2C)" (respondent 40) "We would be interested in research targeting opportunities to increase sales volume and identifying customer market preferences that determine the choice of a particular service/product provider" (respondent 36) "We would be interested in market analyses and opinions, analysis of business risks with specific projects, improvement of management" (respondent 23)
Lack of rapid actions and decision-making during commercialisation	eighteen respondents indicated this incentive as very important and eleven as somewhat important (average of all responses: 3.66)	"The organization is very large and the scope of the commercialisation manager does not allow to carry out activities well" (respondent 29)
Outdated laboratories and equipment	ten respondents indicated this incentive as very important and thirteen as somewhat important (average of all responses: 3.61)	"We don't cooperate with universities. In a chemical company, there is no other solution than to build its own labo, which plays a research and development role" (respondent 35)
Bureaucracy	twenty one respondents indicated this incentive as very important and thirteen as somewhat important (average of all responses: 3.57)	"The company is engaged in a wide range of research and development activities, and due to the problems with universities' cooperation (e.g. bureaucracy), we do most of the research ourselves" (respondent 43)
Lack of offers or insufficient information on cooperation opportunities	sixteen respondents indicated this incentive as very important and seventeen as somewhat important (average of all responses: 3.48)	"We don't know what kind of offerings the e.g. economic university has (…)" (respondent 39)
Problem with valuing technology and royalties	thirteen respondents indicated this incentive as very important and fifteen as somewhat important (average of all responses: 3.48)	"Problem with valuing technology and royalties appears especially in commercialisation in international markets" (respondent 28)
Problem of financing such initiatives	twenty one respondents indicated this incentive as very important and twenty as somewhat important (average of all responses: 3.41)	"We do research in research in the area of AI for which it is difficult to find funding" (respondent 44)
Lack of specialized units responsible for external cooperation	eighteen respondents indicated this incentive as very important and eleven as somewhat important (average of all responses: 3.34)	"We would like to cooperate with departments of mechanical and power engineering" (respondent 34) "We would be interested in cooperating on commercialisation and implementation of technologies from the life-sciences industry" (respondent 32)
Lack of adequate commercialisation procedures (e.g., bylaws and unified contracts)	twelve respondents indicated this incentive as very important and eight as somewhat important (average of all responses: 3.32)	"It is a barrier for us and that is why our company designs and develops its product offerings itself. The founders are scientists" (respondent 41)

Cont. table 2.

Imperfection of legal regulations	ten respondents indicated this incentive as very important and twelve as somewhat important (average of all responses: 3.11)	"Insufficient protection of intellectual property at a rather high cost of protection" (respondent 32) "Lengthy patent process vs high rate of product change" (respondent 13) "Patent protection does not work in our case - the process is too time-consuming, and the need for new solutions occurs too quickly" (respondent 12)
Lack of specialized knowledge among university representatives, especially in the area of intellectual property protection and public aid	eight respondents indicated this incentive as very important and seven as somewhat important (average of all responses: 3.11)	"We do cooperate with universities but IP protection is a problem. That is why we do not use patents, it is better for us to use third-party software instead" (respondent 44)

Source: own development.

University-industry cooperation refers to interaction between universities' scientists, students and companies, which exchange their knowledge and/or developed technologies (Parmentola et al., 2021). The study examines this interaction by developing theoretical background through science commercialisation definition and conceptual model. The research also reveal the incentives and barriers of such cooperation in Central and Eastern European country, Poland. As main incentives in research commercialisation, respondents indicated opportunity to cooperate with highly qualified specialists, own staff development during cooperation, exchange of knowledge (as indicated in conceptual framework of this study), savings e.g. on research and development expenditures and acquisition of new technologies. In relation to barriers of such cooperation, respondents were pointing out lack of openness to the industries' needs, lack of rapid actions and decision-making during commercialisation, outdated laboratories and equipment, as well as bureaucracy. In another study, Portuguese researchers listed lack of procedures for such cooperation, lack of contacts with industry, lack of funding for such cooperation and analyzed (Moutinho et al., 2016), which were also barriers in Polish university-industry collaboration.

Conclusions

The primary scientific challenges pertain to the transfer of research results to the economy and society. Consequently, discussions persist concerning effective means of commercialising knowledge and technology. Thus, the research aimed to conceptualise and define the commercialisation of university research as its first objective. The second objective aimed to empirically verify incentives and barriers to R&D commercialisation within the university-

industry nexus. This step forward enhances our understanding of science commercialisation in Central and Eastern Europe, specifically in Poland.

Through the research, collected data allowed to answer original research questions on the model approach to universities' research commercialisation from the perspective of enterprises. The model is derived from the definition of research commercialisation in universities and comprises of two stages, namely R&D phase, where the outcomes are produced via knowledge sharing between university and industry, and commercialisation phase. The study confirmed that the chance to collaborate with highly skilled professionals, improve staff development, exchange knowledge, and benefit from cost savings on research and development expenditures, as well as gaining access to new technologies, were the most significant benefits reported by respondents in their collaborations with universities. In contrast, the absence of receptiveness to the requirements of industries, delayed actions and decision-making throughout commercialisation, obsolete laboratories and equipment, as well as the bureaucracy posed the most significant obstacles to collaboration with universities. These findings has policy implications; strengthening the incentives outlined above and removing the identified barriers to university-industry cooperation can lead to effective science commercialisation, resulting in added value for society and the economy. This research line complements the triple helix concept and knowledge spillover theory of entrepreneurship in management literature.

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References

1. Audretsch, D.B., Keilbach, M. (2007). The theory of knowledge spillover entrepreneurship. *Journal of Management Studies, 44(7),* 1242–1254.
2. Booth, A., Sutton, A., Papaioannou, D. (2016). *Systematic Approaches to A Successful Literature Review*. London: Sage Publications.
3. Caerteling, J., Halman, J.I.M., Dore´e, A.G. (2008). Technology commercialization in road infrastructure: How government affects the variation and appropriability of technology. *Journal of Product Innovation Management, 25,* 143–161.

4. Chen, X., Liu, Z., Zhu, Q. (2018). Performance evaluation of China's high-tech innovation process: Analysis based on the innovation value chain. *Technovation, 74-75,* 42–53.
5. Chesbrough, H.W. (2003). *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Harvard Business Press.
6. Clayton, P., Feldman, M., Lowe, N. (2018). Behind the scenes: intermediary organizations that facilitate science commercialisation through entrepreneurship. *Academy of Management Perspectives, 32(1),* 104-124. doi:10.5465/amp.2016.0133.
7. Colen, L., Belderbos, R., Kelchtermans, S., Leten, B. (2022). Reaching for the stars: When does basic research collaboration between firms and academic star scientists benefit firm invention performance? *Journal of Product Innovation Management, 39,* 222–264. doi: 10.1111/jpim.12607.
8. Cooper, R.G. (1990). Stage-gate systems: a new tool for managing new products. *Business Horizons, 33(3),* 44–54.
9. Dorf, R.C., Worthington, K.K.F. (1987). Models for commercialization of technology from university and research laboratories. *The Journal of Technology Transfer, 12,* 1-8.
10. Dosi, G., Llerena, P., Labini, M.S. (2006). The relationships between science, technologies and their industrial exploitation: An illustration through the myths and realities of the so-called 'European Paradox'. *Research Policy, 35(10),* 1450-1464.
11. Ernst, H. (1997). The use of patent data for technological forecasting: the diffusion of CNC-technology in the machine tool industry. *Small Business Economics, 9,* 361–381.
12. Etzkowitz, H. (2003). Research groups as "quasi-firms": the invention of the entrepreneurial university. *Research Policy, 32(1),* 109–121. Retrieved from: https://doi.org/10.1016/S0048-7333(02)00009-4
13. Etzkowitz, H., Leydesdorff, L. (2000). The dynamics of innovation: from national systems and 'mode 2' to a triple helix of university-industry-government relations. *Research Policy, 29,* 109–123.
14. Fabrizio, K.R. (2009). Absorptive capacity and the search for innovation. *Research Policy, 38(2),* 255–267.
15. Fini, R., Rasmussen, E., Wiklund, J., Wright., M. (2019). Theories from the Lab: How Research on Science Commercialization can Contribute to Management Studies. *Journal of Management Studies, 56,* 5. doi:10.1111/joms .12424.
16. Forliano, C., De Bernardi, P., Yahiaoui, D. (2021). Entrepreneurial universities: A bibliometric analysis within the business and management domains. *Technological Forecasting & Social Change, 165*. doi:10.1016/j.techfore.2020.120522.
17. Guan, J., Chen, K. (2010). Measuring the innovation production process: A cross-region empirical study of China's high-tech innovations. *Technovation, 30,* 348–358.
18. Halilem, N., De Silva, M., Amara, N. (2022). Fairly assessing unfairness: An exploration of gender disparities in informal entrepreneurship amongst academics in business schools. *Technological Forecasting & Social Change, 174*. doi:10.1016/j.techfore.2021.121295.

19. IBM (2021). *Principal component analysis (PCA)*. https://www.ibm.com/docs/en/db2oc?topic=procedures-principal-component-analysis-pca.
20. Jalali, S., Wohlin, C. (2012). *Systematic Literature Studies: Database Searches vs. Backward Snowballing*. Proceedings of the 2012 ACM-IEEE International Symposium on Empirical Software Engineering and Measurement, 1-9. https://doi.org/10.1145/2372251.2372257.
21. Johnson, D., Gianiodis, P.T., Harrison, R.T., Bock, A.J. (2023). From laboratory to clinic: science commercialization within university-centered entrepreneurial ecosystems. *R&D Management, 53(1),* 3-23. doi:10.1111/radm.12535.
22. Jolly, V.K. (1997). *Commercializing New Technologies: Getting from Mind to Market*. Boston, MA: Harvard Business School Press.
23. Kirchberger, M.A., Pohl, L. (2016). Technology commercialization: a literature review of success factors and antecedents across different contexts. *The Journal of Technology Transfer*, *41*, 1077–1112. doi:10.1007/s10961-016-9486-3.
24. Kotlar, J., Massis, A., Wright, M., Frattini, F. (2018). Organizational goals: antecedents, formation processes and implications for firm behavior and performance. *International Journal of Management Reviews*, *2*, S3-S18.
25. Langridge, D., Hagger-Johnson, G. (2009). *Introduction to Research Methods and Data Analysis in Psychology*. Harlow: Pearson.
26. Merriam, S. (2009). *Qualitative Research: Guide to Design and Implementation*. Hoboken, NJ: Wiley.
27. Mitchell, W., Singh, K. (1996). Survival of businesses using collaborative relationships to commercialize complex goods. *Strategic Management Journal*, *17(3)*, 169–195.
28. Moutinho, R., Au-Yong-Oliveira, M., Coelho, A., Manso, J. (2016). Determinants of knowledge-based entrepreneurship: an exploratory approach. *International Entrepreneurship and Management Journal*, *12*, 171–197.
29. OECD (2013). *Commercialising Public Research: New Trends and Strategies*. OECD Publishing. https://doi. org/10.1787/9789264193321‑en.
30. OECD (2015). *Frascati Manual 2015. Guidelines For Collecting and Reporting Data on Research and Experimental Development*. OECD Publishing. https://www.oecd-ilibrary.org.
31. Parmentola, A., Ferretti, M., Panetti, E. (2021). Exploring the university-industry cooperation in a low innovative region. What differences between low tech and high tech industries? *International Entrepreneurship and Management Journal*, *17*, 1469–1496. doi:10.1007/s11365-020-00671-0.
32. Perkmann, M., Tartari, V., McKelvey, M., Autioa, E., Broströmc, A., D'Este, P., Fini, R., Geuna, A., Grimaldif, R., Hughes, A., Krabel, S., Kitsong, M., Llerenai, P., Lissoni, F., Salter, A., Sobrero, M. (2013). Academic engagement and commercialisation: a review of

the literature on university–industry relations. *Research Policy*, *42(2),* 423-442, doi: 10.1016/j.respol.2012.09.007.

33. Petticrew, M., Roberts, H. (2006). *Systematic reviews in the social sciences: A practical guide*. Oxford: Wiley-Blackwell. Retrieved from: http://www.wiley.com/WileyCDA/ WileyTitle/productCd-1405121106.html.
34. Rothwell, R. (1992). Successful industrial innovation: critical factors for the 1990s. *R&D Management, 22(3),* 221-239.
35. Rothwell, R., Zegveld, W. (1985). *Reindrustralization and Technology*. Longman.
36. Shin, H., Woo, H.G., Sohn, K., Lee, S. (2023). Comparing research trends with patenting activities in the biomedical sector: The case of dementia. *Technological Forecasting & Social Change*, *195*. doi:/10.1016/j.techfore.2023.122790.
37. Szulczewska-Remi (2023). Pomiar działalności innowacyjnej przedsiębiorstw (The measure of companies' innovation performance). In: C. Kochalski (eds). *Analiza ekonomiczna przedsiębiorstw w warunkach niepewności (Economic analysis of companies under uncertainty)*. Poznań: Wydawnictwo UEP.
38. Szulczewska-Remi, A., Nowak-Mizgalska, H. (2023). Who really acts as an entrepreneur in the science commercialisation process: the role of knowledge transfer intermediary organisations. *Journal of Entrepreneurship in Emerging Economies*. doi:10.1108/JEEE-09-2020-0334.
39. Thursby, J.G., Thursby, M.C. (2002). Who is selling the ivory tower? Sources of growth in university licensing. *Management Science*, *48(1)*, 90–104.
40. Utterback, J.M. (1971). The process of technological innovation within the firm. *Academy of Management Journal*, *14(1)*, 75–88.
41. Van Norman, G.A., Eisenkot, R. (2017). Technology Transfer: From the Research Bench to Commercialization: Part 2: The Commercialization Process. *JACC: Basic to Translational Science, 2(2),* 197–208.
42. Viale, R., Etzkowitz, H. (2010). *The Capitalization of Knowledge*. Cheltenham: Edward Elgar Publishing.
43. Wang, Y., Wu, D., Li, H. (2022). Efficiency measurement and productivity progress of regional green technology innovation in China: a comprehensive analytical framework. *Technology Analysis & Strategic Management*, *34(12),* 1432–1448. doi:10.1080/09537325.2021.1963427.
44. Yin, K.R. (1994), *Case Study Research and Applications: Design and Methods.* Thousand Oaks, CA: Sage Publishing.
45. Yin, K.R. (2018), *Case Study Research and Applications: Design and Methods.* Thousand Oaks, CA: Sage Publishing.
46. Yu, A., Shi, Y., You, J., Zhu, J (2021). Innovation performance evaluation for high-tech companies using a dynamic network data envelopment analysis approach. *European Journal of Operational Research, 292*, 199–212.

47. Zhao, F. (2007). Commercialization of research: a case study of Australian universities. *Higher Education Research & Development, 23(2)*, 223-236.
48. Žižlavsky, O. (2013). Past, Present and Future of the Innovation process. International *Journal of Engineering Business Management*. doi:10.5772/56920.
49. Zucker, L.G., Darby, M.R., Armstrong, J. (2002). Commercializing knowledge: university science, knowledge capture, and firm performance in biotechnology. *Management Science, 48(1)*, 138–153.

Appendix 1

Table 3.
Characteristics of respondents taking part in the second round of empirical study (n = 44)

Respondent	The level of company's internationalization	Ownership form	Average annual employment volume
1	Low (purely domestic operations)	Polish	Up to 1001-7000 employees (full time employment)
2	Medium (international operations)	Polish	Up to 11-50 employees (full time employment)
3	Low (purely domestic operations)	Polish	Up to 10 employees (full time employment)
4	Medium (international operations)	Polish	Up to 10 employees (full time employment)
5	Medium (international operations)	Polish	Up to 51-250 employees (full time employment)
6	Medium (international operations)	Polish	Up to 10 employees (full time employment)
7	Low (purely domestic operations)	Polish	Up to 51-250 employees (full time employment)
8	Medium (international operations)	Polish	Up to 10 employees (full time employment)
9	Medium (international operations)	Polish	Up to 11-50 employees (full time employment)
10	Medium (international operations)	Polish	Up to 11-50 employees (full time employment)
11	Medium (international operations)	Polish	Up to 11-50 employees (full time employment)
12	High (mainly international operations)	Polish	Up to 251-1000 employees (full time employment)
13	High (mainly international operations)	Polish	Up to 11-50 employees (full time employment)
14	High (mainly international operations)	Polish	Up to 11-50 employees (full time employment)
15	Low (purely domestic operations)	Polish	Up to 10 employees (full time employment)
16	Low (purely domestic operations)	Polish	Up to 10 employees (full time employment)
17	Low (purely domestic operations)	Enterprise with majority of Polish capital	Up to 251-1000 employees (full time employment)
18	Low (purely domestic operations)	Polish	Up to 10 employees (full time employment)
19	Medium (international operations)	Polish	Up to 11-50 employees (full time employment)
20	High (mainly international operations)	Polish	Up to 11-50 employees (full time employment)
21	Low (purely domestic operations)	Polish	Up to 11-50 employees (full time employment)
22	Medium (international operations)	Enterprise with predominantly foreign capital	Up to 251-1000 employees (full time employment)
23	Low (purely domestic operations)	Polish	Up to 51-250 employees (full time employment)
24	Medium (international operations)	Polish	Up to 11-50 employees (full time employment)
25	Low (purely domestic operations)	Foreign	Up to 51-250 employees (full time employment)

Cont. table 3.

26	Medium (international operations)	Polish	Up to 51-250 employees (full time employment)
27	High (mainly international operations)	Foreign	Up to 11-50 employees (full time employment)
28	High (mainly international operations)	Enterprise with majority of Polish capital	Up to 51-250 employees (full time employment)
29	Medium (international operations)	Polish	Up to 1001-7000 employees (full time employment)
30	Medium (international operations)	Polish	Up to 11-50 employees (full time employment)
31	Low (purely domestic operations)	Polish	Up to 51-250 employees (full time employment)
32	Medium (international operations)	Polish	Up to 10 employees (full time employment)
33	Medium (international operations)	Enterprise with majority of Polish capital	Up to 51-250 employees (full time employment)
34	High (mainly international operations)	Polish	Up to 11-50 employees (full time employment)
35	High (mainly international operations)	Polish	Up to 251-1000 employees (full time employment)
36	Medium (international operations)	Polish	Up to 11-50 employees (full time employment)
37	High (mainly international operations)	Polish	Up to 11-50 employees (full time employment)
38	High (mainly international operations)	Polish	Up to 51-250 employees (full time employment)
39	Medium (international operations)	Polish	Up to 11-50 employees (full time employment)
40	Low (purely domestic operations)	Polish	Up to 51-250 employees (full time employment)
41	High (mainly international operations)	Polish	Up to 10 employees (full time employment)
42	High (mainly international operations)	Polish	Up to 51-250 employees (full time employment)
43	Low (purely domestic operations)	Polish	Up to 10 employees (full time employment)
44	Low (purely domestic operations)	Polish	Up to 10 employees (full time employment)

Source: own development.

Appendix 2

Table 4.
Research protocol

Experience in R&D commercialisation
1. Does your company have formal research and development (R&D) department? • Yes, we do have dedicated R&D department • No, but R&D is carried out by another company belonging to the same capital group • No, R&D is outsourced to external entities (if this answer is selected, please specify which external entities) • No, we do not carried out R&D If one out of the first three answers is indicated, please specify reasons for this solution
2. Does your company holds patents protecting its inventions? (multiple answer options) • Yes, our company holds national patents • Yes, our company holds international patents • No, our company uses patents through a license granted by another entity (if this answer is selected, please specify which entity) • No, our company does not hold any patents and do not use any patents through a license granted by another entity Please specify reasons for the company particular patent management solution
3. Previous experience in R&D commercialisation in the last five years (2017-2022) (multiple answer options) • Number of patents granted (national and international) • Number of licences granted, IP transfer agreements • Number of technologies sold • Number of contract R&D • Number of spin-off/spin-out companies • Number of start-ups companies • Other (if this answer is selected, please specify) • Our company has no experience in commercialising R&D
Experience in R&D commercialisation within university-industry* nexus
4. Does your company have any experience in cooperation with universities in the last five years (2017-2022) • Yes, our company regularly cooperated with universities • Yes, our company on one occasion cooperated with universities • No, our company does not cooperate with universities
5. Please specify which universities and other research institutions did your company cooperate in the last five years (2017-2022) (multiple answer options) • University • University of Technology • Medical University • University of Economics • University of Agricultural and Life Sciences • University of Pedagogy • University of Arts • University of Physical Education • Maritime University • Military Higher Education Institution (HEI) • Government Service Higher Education Institution (HEI) • Polish Academy of Science • Scientific Institute • Other (if this answer is selected, please specify which entity)
6. Previous experience in R&D commercialisation in cooperation with universities: • Number of R&D results implementation • Number of licences, IP transfer agreements • Number of spin-off/spin-out companies • Number of commercial research works

Cont. table 4.

Incentives and barriers to R&D commercialisation within university-industry nexus

Incentives to R&D commercialisation within university-industry nexus.

Please indicate the strength of your agreement/disagreement with each statement on a 5-point Likert-type scale where 5 means strongly agree.

	1	2	3	4	5
access to knowledge and research results					
access to research infrastructure					
acquisition of new technologies					
opportunity to coopearte with highly qualified specialists (e.g., on a consulting basis)					
savings e.g. on research and development expenditures					
prestige of cooperation					
own staff development during cooperation, exchange of knowledge					
other (please specify)					

Barriers to R&D commercialisation within university-industry nexus.

Please indicate the strength of your agreement/disagreement with each statement on a 5-point Likert-type scale where 5 means strongly agree.

	1	2	3	4	5
problem of financing such initiatives					
imperfection of legal regulations					
lack of specialized knowledge among university representatives, especially in the area of intellectual property protection and public aid					
lack of adequate commercialisation procedures (e.g., bylaws and unified contracts)					
bureaucracy					
problem with valuing technology and royalties					
lack of offers or insufficient information on cooperation opportunities					
lack of specialized units responsible for external cooperation					
lack of rapid actions and decision-making during commercialisation					
lack of openness to the industries' needs					
outdated laboratories and equipment					
other (please specify)					

* in each case of university-industry, reference is made to universities and scientific institutes.

Source: own development.