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TECHNOLOGY ENTREPRENEURSHIP IN THE PROCESS OF FUNCTIONING OF ACADEMIC COMPANIES

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Purpose: The purpose of the present paper is to assess the impact of technology entrepreneurship on the entrepreneurial behavior of employees (which translates into the development of technology entrepreneurship of the organization) in the context of new present-day challenges.
Design/methodology/approach: The mentioned purpose was achieved by conducting qualitative research on selected photonics industry enterprises using the case study method. A comparative analysis of appropriately selected organizations allowed for formulating conclusions and recommendations concerning those organizations' further activity under conditions of heightened uncertainty.
Research limitations/implications: This paper contains the characteristics of technology entrepreneurship, academic firms, high-technology sector and case studies of three photonics firm in Poland. Finally, the conclusions and recommendations of discussed Polish photonic firm in Poland are evaluated.
Practical implications: The increased uncertainty resulted in a greater consolidation of employee teams, and also generated additional resources of entrepreneurial opportunities and behaviors, in addition, employees were inclined to build more flexible relations with employers.
Social implications: "Black swan"-type events forced the organizations to dynamic adaptation actions, which in turn intensified entrepreneurial activities both at the level of owners and employees. The senior management together with the owners of the companies was determined to undertake entrepreneurial activities in the area of reorganization of relations with employees.
Article Classification: Research article.

Keywords: technology entrepreneurship, academic companies, high-tech sector, photonic firms**.**

JEL classification: O3.

Introduction

Modern management is at a special moment. New, unprecedented challenges have overlapped with the existing conditions of increased uncertainty and risk. The coronavirus pandemic which swept the world in March 2020 and theoretically lasted until 2022 and whose the effects and manifestations we are still feeling, disrupted the operation of most organizations, including enterprises. The overheated supply chains and the numerous attendant consequences created an entirely new economic reality. On top of that, Russia's invasion of Ukraine in February 2022 and the ongoing full-scale conventional armed conflict has totally (and perhaps irrevocably) changed our perception of the world and economic reality. Returning to a relatively normal reality will be a process which will be drawn-out and very difficult, if at all possible.

A question which is of interest in this special context is to what extent enterprises operating in the high-tech sector are coping in the present time of extraordinary challenges. The phenomenon of technology entrepreneurship which has been gaining popularity for at least a decade makes it possible to evaluate the ways in which enterprises use technology opportunities resulting from development of science and technology and innovative technology solutions. An especially important role here is played by enterprises whose founders come from research and which are established for the commercial implementation of earlier scientific achievements (frequently the founders' own).

The objective of this paper is to evaluate the extent to which technology entrepreneurship, expressed through the entrepreneurial behaviors of the em0ployees and entire organizations, impacts the functioning of academic enterprises operating in the high-technology sector in the context of the challenges of the present day. It analyses the cases of three academic enterprises operating in the high-tech sector and representing the photonics industry. The research was conducted in 2022, after the Russian Federation's invasion of Ukraine. It attempted to answer the question of how the studied enterprises perceived these new conditions, and whether the change of the rules of the game constituted a threat or an opportunity for growth and operating more effectively in the totally changed conditions. The qualitative research performed using the case study method allowed for comparison of pairs of enterprises with origins in the academic sector and for capturing the influence of the organizations' and individual employees' entrepreneurial behaviors on the operations under specific conditions of new "rules of the game" in business activity.

Literature Review

Technology entrepreneurship and its conditions

In the conditions of the technological race and the shortening of product and technology life cycles, technology entrepreneurship is gaining particular importance as one of the key manifestations of entrepreneurship. Technology entrepreneurship is interdisciplinary and multi-faceted in character and can be considered both at the level of individual initiatives and innovative undertakings in the organizational dimension. It is a phenomenon that still arouses wide interest, both among theoreticians and researchers of management and quality science, as well as managers and practitioners (Chyba, 2021, pp. 62-67). Even though "Technology entrepreneurship" is a term which has been present in the world literature for over half a century (the first conference on the topic took place in 1970), the number of publications on the subject did not increase significantly until the second decade of the 21st century. The theoretical foundations of the concept appeared in "Technology Entrepreneurship," a special issue of Strategic Management Journal from 2012, edited by Ch. Beckman, K. Eisenhardt, S. Kotha, A. Meyer and N. Rajagopolan. (Beckman, Eisenhardt, Kotha, Meyer, Rajagopolan, 2012; Kordel, 2018, pp. 9-10). Attempts to define the concept were also presented by T. Bailetti (2012, pp. 2-25). The subject of technology entrepreneurship was also undertaken in many other papers, including by S. Muegge (2012, pp. 5-16), T. Bailetti et al (2012, pp. 28-34).

In recent years there many publications on the topic have also appeared in Polish. The term "technology entrepreneurship" is defined differently by Polish authors. According to S. Flaszewska and S. Lachiewicz (2013, p. 18) et al. "technology entrepreneurship can be understood as a process combining elements of academic and intellectual entrepreneurship with entrepreneurship of commercial and business support organizations and with entrepreneurship of owners, managers and employees implementing new technologies and accompanying innovations in the sense of application and distribution of their effects in the market environment". According to W. Grudzewski and I. Hejduk (Grudzewski, Hejduk, 2008, p. 80) "technology entrepreneurship is a prerequisite for company success. It implies the process of new product development, using modern technologies, flexible response to changes taking place on the market, as well as introducing innovations in all areas of the company's operation, as well as its co-operators". According to P. Kordel (2018, p. 37) "the phenomenon of technology entrepreneurship occurs when scientific or engineering development creates a key element of an opportunity, which is later transformed into a new investment. A technological venture, based on the latest engineering knowledge, is a direct result of technology entrepreneurship". Still quoting the above-mentioned author (Kordel, 2015, p. 272), "technology entrepreneurship, by combining social dynamics with the dynamics created by the development of new technologies, gives a new perspective on the development of the economy,

especially that part of it which is composed of high technology enterprises and which is used to be called the knowledge-based economy".

Technology entrepreneurship should be considered in the broader context of an organization's strategy, especially a company's development strategy. Therefore, measures of efficiency and effectiveness of technology entrepreneurship can be those measures that relate to competitive advantage (share of market, profitability ratios, etc.) (Chyba, 2016, pp. 103-104). An overview of selected definitions of technology entrepreneurship is presented in Table 1.

Table 1.
Technology entrepreneurship. Overview of selected definitions

Authors	Definition
Ch. Beckman, K. Eisenhardt, S. Kotha, A. Meyer, N. Rajagopolan	Technological entrepreneurship occurs when advances in science or engineering create a key element of an opportunity that then forms the core of a new venture, product or service, enterprise or even an entire industry.
P. Kordel	The central role in the phenomenon of technological entrepreneurship is played by technological opportunity, i.e. an entrepreneurial opportunity based on the development of technology. The process of technological entrepreneurship consists of the stage of formulating a technological opportunity and the stage of its exploitation.
W. Grudzewski, I. Hejduk	Technological entrepreneurship is a prerequisite for the success of an enterprise. It signifies the process of creating new products, using modern technologies, reacting flexibly to changes on the market, as well as introducing innovations in all areas of the company's operation, as well as at its subcontractors.
S. Flaszewska, S. Lachiewicz	The process of ensuring greater practical utility of scientific research results through effective cooperation between research and research and development centers, capital market institutions and the surroundings of business, as well as enterprises involved in the production and sale of technologically advanced products or services.

Source: own development based on Beckman, Eisenhardt, Kotha, Meyer, 2015; Kordel, 2015, pp. 271-282; Grudzewski, Hejduk, 2008, p. 80; Flaszewska, Lachiewicz, 2013, p. 18.

The concept of technology entrepreneurship should be placed in the field of strategic management issues, including innovation theory and entrepreneurship theory. Technology entrepreneurship is most applicable to high-tech industries, although it can also be applied to traditional industries. It is a process consisting of entrepreneurial actions by an innovation leader, team members, and members of the entire organization. It is a special process that is characterized primarily by creative, collaboration-oriented activities or processes, innovation, a willingness to take risks, and a positive orientation on their results, primarily for social benefit.

Among the factors influencing the technology entrepreneurship of an organization, internal determinants should be distinguished, i.e. the conditions of the internal environment of the organization (organizational culture, intellectual capital, etc.) and the technological potential of the company, including not only its technological portfolio, but also the creativity of employees, and in particular the effectiveness of R&D activities. Technological potential may or may not translate into technology entrepreneurship and market benefits for the enterprise. An important role should also be played by institutions in the company's environment that are set up to directly or indirectly support the entrepreneurial aspirations of the organization (scientific institutions, including: universities, R&D institutes, R&D units, as well as innovation and

entrepreneurship centers, training and consulting centers, etc.). When talking about technology entrepreneurship one should take into account the conditions of the internal environment and the organization's surroundings. Table 2 presents a list of determinants of technological entrepreneurship in a three-level perspective.

Table 2.
Technological entrepreneurship levels and their key determinants

Technological entrepreneurship levels	Key determinants
Environmental (external) determinants	Scientific institutions
	Centers supporting commercial implementation
	Commercial partners
Internal environment conditions	Organizational culture
	Intellectual capital
	Decision-making efficiency
Enterprise's technology potential	Technology portfolio
	R&D effectiveness
	Management's creativity and technology competences

Source: own development based on Chyba, 2015, pp. 87-96.

Technological entrepreneurship is strongly conditioned by the organization's environment, especially those entities that support the commercialization of new technology solutions. An important role is also played by the internal environment, including the specific characteristics and identity of the organization expressed by the created organizational culture, as well as the intellectual capital of the organization, with particular emphasis on its human capital. Also emphasized should be the importance of the technological potential of the company with its current portfolio (set) of technologies and the possibility of creating technologies thanks to the effectiveness of the R&D department and the creative activity of employees.

Determinants relating to the organization's internal environment play a significant role. Internal factors that determine technological entrepreneurship development include intellectual capital and organizational culture. The soft aspects of management, especially those mentioned above, are significant inputs into an enterprise's strategic resources. At the same time, the competences and resources at the disposal of enterprises are an important component of their technological potential. After all, it is difficult to build the technological potential of the company without the appropriate knowledge of employees, their technological competences, as well as creativity and commitment.

Barriers to the development of technological entrepreneurship can be both institutional and mental in nature. On the one hand, they result from the limitations of the political, legal and economic environment, and on the other hand, they are conditioned culturally and sociologically. Each country or region has its own specificity of entrepreneurship conditioned by history, culture, religion or finally resulting from local and family traditions. The limited volume of this article does not, in my opinion, allow for a broader development of these issues. However, it should be assumed a priori that such conditions play an important role.

Currently technological entrepreneurship is largely limited by the economic slowdown of the past several years. In such conditions, especially in the context of the idea of sustainable development of enterprises and the entire economy, the criteria for generating and implementing innovations undergo re-evaluation. According to the above idea, all innovations implemented should not only fulfil economic objectives by increasing revenue but also play a social and environmental-protection role. This means that technological entrepreneurship should also lead to the implementation of the goals outlined by the concept of sustainable development of enterprises. In crisis conditions, this is particularly difficult, taking into account the uncertainty and increased risks of business operations (compare Jafari-Sadeghi, Garcia-Perez, Candelo, Couturier, 2021, pp. 100-111; Mosey, Guerrero, Greenman, 2017, pp. 1-9; Giones, Brem, 2017, pp. 44-51; Bolzani, Munari, Rasmussen, Toschi, 2021, pp. 335-365).

Academic entrepreneurship and establishment of spin-offs

The concept of academic entrepreneurship appeared in Poland only relatively recently, mainly among people from the generally understood research and development sector and science administration, as an expression of new tasks and opportunities confronting the university sector, affecting the local, regional and global economy (Chyba, Grudzewski, 2011, pp. 108-109). The origins of this type of entrepreneurship in our country are connected with its political system transformation of the 1980s-1990s. According to W. Grudzewski and I. Hejduk (2000, p. 257), "academic entrepreneurship is defined as undertaking business activity by people involved in scientific activity and holding a specific position in academic circles. Academic entrepreneurship is conducted by people running a business on the basis of theoretical and applied research and development work". Academic entrepreneurship encompasses many areas and has a large impact on the development of innovative enterprises. It is the source of the most modern techniques and technologies transferred for practical industrial implementation (Grudzewski, Hejduk, 2000, pp. 257-258). The outcome of academic entrepreneurship is enterprises established by academics in order to commercialize earlier scientific and technological achievements (often their own). These enterprises are often referred to as spin-offs, spin-outs, or – when referring to newly established entities – start-ups. For a broader treatment on the concept and models of academic entrepreneurship, as we3ll as academic enterprises, see A. Kwiotkowska (2015), J. Korpysa (2016), A. Komarnicka (2020), K. Łobacz, P. Głodek (2020) and others.

The concept of spin-off as such does not raise any interpretative controversies (Chyba, Grudzewski, 2011, pp. 116-118). It is used to define an entity established as a result of a spin-off/separation from the parent organization (corporation) in order to undertake activities that would be difficult or even impossible to carry out within that organization. There is no major problem with the interpretation of the term spin-off when it is related to entities emerging as, so to speak, satellite of large corporations, intended mainly for the implementation of new, often high-risk technology projects. Spin-off companies (so-called university spin-offs) are the

principal stream of academic entrepreneurship and one of the main mechanisms of technology transfer and commercial implementation (Tamowicz, 2006, p. 9). Academic entrepreneurship, especially in Poland, is identified not only with spin-off companies, but also with the business activity of university students and graduates (Matusiak, 2005, p. 131). The broadest interpretation of the term spin-off includes "all types of transfer of technological knowledge from the company that developed the know-how to the entity that is to apply it in practice". The creation of such a spin-off is most often associated with the separation of the assets of an already existing enterprise. There are also spin-offs which do not involve establishing a new organizational unit. In corporate terms, a spin-off is a company created by separating a team, branch, department from another organization. A special type of spin-off companies are enterprises originating from universities and research and development institutions, increasingly called spin-outs (Guliński, Zasiadły, 2005, p. 18).

N. Nicolaou and S. Birley not only developed a flexible definition of the term spin-off but went further (Chyba, Grudzewski, 2011, pp. 120-122). Recognizing the considerable diversity of this phenomenon, they defined three types of spin-offs that differ in the way they engage and link key factors (human, scientific institution, ownership links) (Nicolaou, Birley, 2003, p. 340):

- orthodox – where the spinout involves both the academic inventor(s) and the technology spinning out from the institution;
- hybrid – which involves the technology spinning out and the academic(s) (all or some of those involved in the project) retaining their university position, but holding a directorship, membership of the scientific advisory board or other part time position within the company;
- technology – which involves the technology spinning out but the academic maintaining no connection with the newly established firm, although they may own shares or provide advisory services (Birley, 2002, p. 137).

The degree of differentiation, as well as the common elements of various approaches to definitions, are best reflected in studies conducted by the OECD in the late 1990s. Among the five factors characterizing spin-off companies, three elements distinguishing these entities were most often indicated:

- the founders include employees of a scientific research organization,
- the organization operates based on a licensed technology,
- the organization received capital support (in the form of an ownership stake aquis8ition) from the public sector.

Despite the convergence of components that are part of support programs for spin-off companies in different countries, they often differ in the way they are organized and the intensity of involvement of the public sector (STI Review, 2000, p. 17). From this perspective, in Europe for instance it is possible to distinguish four models of support:

- top-down (vertical) model – based on public agencies disbursing government funds for various purposes and programs; this model this model works best when launching large (national) programs during the initial development of the spin-off sector,
- network model – more horizontal and differentiated in terms of ownership; it is based on cooperation between private and public institutions,
- organic development model (termed "incremental" in the literature) assumes a slow, organic development of individual – mainly infrastructural – elements of the support system,
- „technopoly" – this model assumes the creation of a specific infrastructure that triggers strong impulses that change the internal culture of a scientific organization (Guliński, Zasiadły, 2005).

Another classification can be made, based on the criterion of the goal and resources assigned to a given support system. Three models of incubation of spin-off enterprises can be distinguished:

- the "weak selection" model based on low-level resources (infrastructure, finance) with the aim for launching as many projects/entities as possible; the effect is usually a large number of economically weak entities (with quantity dominating over quality),
- the "supportive" model, which supports the creation of spin-offs, understood as an alternative to the sale of licenses; since the point of reference is the benefit obtained from trading licenses, an important parameter in this model (which also determines the allocation of support) is the economic efficiency of the spin-off project,
- the "incubation" model which focuses on seeking the optimum moment for the spin-off entering the market.

Academic enterprises operate mostly in the high-technology sector. It is in this sector that technology entrepreneurship seems to bring about the most spectacular effects. This does not mean that traditional industries should be disregarded or underestimated, as academic spin-off/spin-out entities also operate successfully in them (see also El-Awad, 2022, pp. 1-14; Vekić, Daković, Borocki, Sroka, 2020, pp. 533-550; Nikoforou, Zabara, Clarysse, Gruber, 2018).

The importance of advanced technologies

A special role among the many different types of technology is played by advanced or high technology. This term has been used in science for several decades (Chyba, 2021, pp. 46-50). It is difficult to pinpoint the person who was the first to use it, although credit for popularizing the concept is usually given to R. Metz, the author of one of the most popular regular columns in the New York Times – "Market Place" which appeared during 1966-1982, attracting large numbers of readers (Skala, 2014, pp. 111-113). In informal terms, this signified those products (and then entire sectors of the economy) that were based on the latest achievements in science and technology. This conception remains generally valid; however, problems arise when it is necessary to precisely define what is classified as "high technology" and what is not.

The high-technology or high-tech enterprise sector is difficult to define precisely since many enterprises classified as high-tech go beyond the boundaries of industries identified according to the accepted classifications. These industries are frequently considered to arise at the intersection of science and industry and are founded on the processing of scientific research results in industry. This is also frequently the case with the academic enterprises which were the subject of the present research. According to A. Adamik and A. Zakrzewska-Bielawska (2014, pp. 12, 17) "a high technology enterprise is defined as an entity operating in the field recognized as high technology, combining the features of an innovative and knowledge-based enterprise and using modern information and communication technologies to a large extent".

The first attempts to attempts to systematize this area of the economy were made in the 1970s. The results of the first were published by the Organization for Economic Co-operation and Development (OECD, 1980, SITC/80.48), which followed the American classification and covered only foreign trade in high-tech products. This made it possible to make the first comparisons of countries in terms of the development of this sector of the economy. However, due to the excessive number of references to the US economy, the proposal was considered unsatisfactory. The subsequent classification conducted by the OECD concerned the dozen or so highly-developed countries for which data were available. The basic distinguishing criterion was the intensity of expenditure on research and development, i.e. the level of expenditure on research and development as a portion of the value of sales, which resulted in distinguishing three industry classes depending on the advancement of the technological level: high technology, medium technology and low technology. After a decade this approach was revised, with the number of categories increased to four (high technology, medium-high technology, medium-low technology and low technology) and the so-called Product approach being introduced, enabling enterprises to be included in the high-tech group based on their products, and not just belonging to the sector (OECD, 1984, DSTI/SPR/84-49). Based on data from over a dozen of the most developed countries, a list of initially 10, and then nine product groups was created, showing the level of technical advancement of the companies that create them.

As a result, according to the first "sectoral" criterion, the high-tech group includes entities that carry out their activities within two divisions and one subclass of the European NACE classification (Nomenclature Statistique des Activites economiques dans la Communaute Europeenee), which find their equivalents in the Polish Classification of activities (EKD):

- Division 21: Manufacture of basic pharmaceutical products and pharmaceutical preparations;
- Division 26: Manufacture of computer, electronic and optical products;
- Subclass 30.3: Manufacture of air and spacecraft and related machinery.

According to the "product" criterion, there are nine groups of high-tech products: products related to the aerospace industry; computers; electronic and telecommunications products; pharmaceuticals; scientific and research apparatus; electric machines; chemical products; non-electric machines; and weapons and ammunition.

Both the above criteria have their limitations and disadvantages. In the first case, some enterprises declare belonging to the high-tech sector, although in fact they do not manufacture products that fall within the high-tech category. On the other hand, some enterprises from other sectors do fulfill this condition. On the other hand, there are enterprises representing other sectors that fulfill this condition. The consequence of this may be an overestimation of technological intensity in some sectors with a simultaneous underestimation in others.

Two additional criteria are used to make the process of classifying enterprises as high-tech more credible. These criteria are used more locally than globally due to the lack of sufficient data for international comparisons. The first criterion is obtaining patents by the company or signing license agreements in areas recognized as high-tech. The second criterion is the level of employment of highly qualified research and technical personnel. According to the OECD, due to the lack of such data in a broader sense, only R&D intensity can be a useful criterion for international comparisons. All this makes it difficult to clearly define industries that belong to the high-tech category.

According to Z. Wysokińska (2001, p. 84) high-technology includes primarily the following areas:

- Information technology related to the collection, storage, processing, transmission and presentation of information – mainly computer and communication technology (hardware and software),
- Advanced manufacturing technology, including computer-controlled or microelectronics-based equipment used to design, manufacture and move products and the use of these technologies e.g. in the form of flexible machining centres, robots, automatically controlled transport vehicles or computer-controlled equipment for automatic delivery or storage of materials, parts, subassemblies and finished products.

High-tech industries are the most dynamically developing components of global industry. In addition, these industries, whose material and energy intensity is several times lower than those of traditional industries, play a key role in creating new jobs requiring high qualifications (Grudzewski, Hejduk, 2008, pp. 31-33).

Table 3 presents the classification of high technology areas and products according to the European Classification of Activities and the Organization for Economic Cooperation and Development (OECD).

Table 3.
Classification of high technology areas and products according to the ECA and OECD

Classification of high-technology areas according to the ECA, developed by the OECD	Classification of high-technology products according to the OECD
Manufacture of air and spacecraft	Aircraft and related equipment, spacecraft (including satellites) and machinery, spacecraft launch vehicles and their parts, non-electric motors.

Cont. table 3.

Manufacture of office equipment and computers	Typewrites and automatic word word-processing machines, optical photocopiers, contact copiers or thermal copiers, automatic data processing machines (computers) and parts and accessories therefore.
Manufacture of radio, television and communication equipment and apparatus	Devices for recording and reproducing images and sounds, printed circuits, fibre optic cables, electron tubes, diodes, transistors and other semiconductor devices, electronic integrated circuits and micromodules, piezoelectric crystals, microwave tubes etc.
Manufacture of basic pharmaceutical products and pharmaceutical preparations and plant-based materials	Antibiotics, natural and synthetic hormones, glucosides, antisera and vaccines, drugs containing antibiotics, hormones, other drugs not included in this classification. Certain macromolecular chemical compounds with special physicochemical properties.

Source: own development based Wysokińska, 2001, pp. 88-97; Chyba, 2017, p. 90.

Research methodology

Academic enterprises at a time of new challenges. Case studies

The challenges of the modern world, both the Covid-19 pandemic in 2020-2022, as well as, and perhaps above all, the full-scale armed conflict in Ukraine, launched in February 2022 by the Russian Federation, caused significant re-evaluations in the functioning of enterprises. This applies in particular to academic enterprises operating in the high-tech sector. The effects of these challenges will be shown using the example of organizations from the photonics industry. The surveyed enterprises represent various types of spin-off enterprises due to the degree of connection with their home research centers. Companies X and Y represent the type of technological spin-off, in which these connections concern only the genesis and the transferred technology. These are university spin-off companies that live a life of their own in business terms. In the case of Company Z, we are dealing with an intermediate type between a hybrid and technological enterprise, because the founders and leading researchers of this company maintain contact with their original research centre and follow scientific achievements on an ongoing basis.

Company X was founded in 1987 by a group of scientists from the Military University of Technology. It is an innovation enterprise operating in the high technology sector. It makes use of its own research and development resources. The company's customers are industrial enterprises that manufacture their own products based on its output and the research sector, which constructs scientific equipment. This last group includes enterprises working for the military. Since the company follows a market niche strategy, its sales are conducted through an international distributors' network.

The history of the company dates back to the 1970s, when a team of scientists from the Military University of Technology was the first in the world to show that photon far-infrared detectors can operate at ambient temperature. This contradicted the widely held view that such detectors could only work at the temperature of liquid nitrogen. The Polish scientists' successes were initially met with incredulity but repeated presentations of the correctly operating device properly functioning devices convinced the global research community of the team's potential. Due to the lack of a competitive industrial environment in Poland in the 1970s and 1980s, the invention could not be implemented domestically. Its enormous potential contribution to the development of modern optoelectronic equipment was appreciated by the Americans who expressed their willingness to utilize it. This allowed for a small level of export based on Military University of Technology production. The product was developed further and the offered selection was expanded to include electronic accompanying devices and accessories relating to infrared technology. In view of the growing international market and the continuing lack of interest in infrared technology in Poland in 1987 the company's founders established their own production company and in 1993 transformed it into a limited liability company. The company currently employs a highly-qualified staff including a professor and many PhDs and engineers.

Its main competitive advantage is its knowledge and technologies applied, since the product is characterized by a very high level of complexity. Knowledge management in the company is more intuitive than conscious in character. However, knowledge is being developed and managed effectively, since otherwise the company would immediately lose its competitive advantage and disappear from the market. The company's knowledge base is created by its owners, who have cooperated with each other for 30 years which is a clear advantage since it allows them to develop innovative solutions. The company holds many patents but no longer uses some of them.

The company is a world leader in the production of uncooled photon infrared detectors. Its mission is to replace cryogenically cooled mid- and far-infrared photon detectors with new generation detectors. The company provides:

- manufacture of infrared ration detectors,
- commissioned research and development work in the area of infrared technology,
- manufacture of optoelectronic equipment,
- construction and modernization of microprocessor-controlled measuring stations,
- technical consultancy,
- brokerage in the purchase of optoelectronic components, devices and systems.

The measure of the company's success is the constantly increasing demand for detectors from global and domestic equipment manufacturers. The company is constantly improving the detectors' parameters while decreasing their production costs. The company's multi-million investments are intended to ensure an ongoing improvement of its research and production potential and, consequently, the quality of the detectors produced.

Company Y was established in 1991 by employees of the University of Warsaw Faculty of Physics. It is a manufacturer of precision components, optical components and subcomponents for laser technology, medicine, lithography, telecommunications, metrology, aviation and the aviation and space industries. The company specializes in the production of prototypes and atypical precision elements. In addition to manufacturing, it provides services such as:

- repair, regeneration and modification of optical components,
- design and consultancy relating to individual optical components, subcomponents, assemblies and subassemblies, optoelectronic components and their application,
- optical measurements.

Initially (for the first two years) the company operated solely on the Polish market. However, during the economic transformation, the market of components and optical and optoelectronic components decreased significantly. The company's Polish customers were unable to withstand the competition of enterprises from the European Union, Japan and the USA. Faced with the virtual disappearance of the domestic market, the company expanded onto world markets (Weresa, 2007, pp. 161-165). It currently occupies a high market position, also internationally. It sells its products on practically every continent. It has no competitors in Poland and in Europe it is able to successfully compete with the best companies, manufacturing highly scientifically and technologically advanced products. Its customers are well-known European high-technology enterprises, including ASML. The company currently operates mainly on the foreign market.

The immediate reason for establishing the company was the lack of sufficient development prospects in the institute. The decision to establish an independent business was supported by the character traits of the founders, manifested in the tendency to take risks and take on new challenges. The initiative was not supported by Faculty, which, not seeing direct benefits for itself was also losing some of its research staff. The founders of the new enterprise had a good knowledge of the market, but the first period of the company's activity was not easy. Initially, the company, operating exclusively on the domestic market, was not profitable, and the profits in the first seven years were irregular. The company started operating solely on the basis of human capital. At the beginning, the funds for the equipment came from a private investor in the form of venture capital from abroad. Currently, the company's capital is entirely of Polish origin. The company faced many barriers to its development. The limited financing possibilities for new investment were a serious obstacle in its growth. The company's development depended on increasing sales.

Company Y is constantly working on innovation and improvement of its products. These are technologies of producing laser modulators and thin optical coatings and processing of optical elements. In addition to technological innovations, organizational and marketing innovations are also introduced. The company's employees implemented their knowledge gained during their scientific activities at the Institute of Physics in their business activities. This applies to both theoretical (scientific) knowledge and applied knowledge and knowledge

about the functioning of the market in which the company operates. The company implements its knowledge commercially through the sale of technologically-advanced products and services. It has a group of regular customers. They are industry-leading companies located virtually all over the world. However, the largest group is from Germany. These customers support the research conducted in the company. Company Y is based on internally-developed technologies. It does not propagate its knowledge through licensing. It follows the principle of protection of intellectual property developed within the enterprise. A similar principle is followed by the majority of companies from the advanced technology sector, as selling products based on proprietary technology brings greater profits and competitive benefits than the sale of the technology itself.

Company Z was founded in 2002 by employees of the Institute of High Pressure Physics of the Polish Academy of Sciences. He specializes in advanced laser manufacturing technologies. Like companies X and Y, it is an example of an entity with roots as an academic spin-off. The enterprise has used and continues to benefit from the help and support of so-called "Business Angels". Due to the niche nature of the business, it has difficulties in obtaining venture capital. The company has very limited possibilities of increasing the scale of production and therefore remains an entity operating in a narrowly specialized global niche.

One of the contemporary challenges for Company Z is operating in the field of quantum technologies with a very high level of technology development, which in the future may contribute to the development of so-called quantum computers. The company has a stable team of top-class specialists. Currently, it employs 25 persons, including 11 PhDs and 3 professors of physics. It is in the process of acquiring new specialists with appropriate experience in research work, preferably with at least a doctoral degree. This is due to the advancement level of the high-tech products it manufactures. The company maintains contacts with the parent Institute of High Pressure Physics of the Polish Academy of Sciences, mainly due to the need to exchange scientific experiences and recruit specialists with scientific degrees. Currently, it is an example of a technological spin-off, which runs a completely independent business, related to the mentioned research centre mainly through the history/genesis of the activity and recruiting new employees. R&D intensity in Company Z remains at a consistently high level.

Summing up, it can be said that the surveyed enterprises differ in the time they have operated on the market, which is also reflected in the style of management and the nature of links with the scientific community. There was a generational change in the management of Companies X and Y, which slightly changed the way of thinking, unlike in Company Z, which has been operating for the shortest time (since 2002) and under the same management.

The present paper was prepared based on results of qualitative research using the case study method. The author posed the following research question: Do current conditions and changes in the rules of the market game impact the entrepreneurial behavior of high-tech enterprises and if so, in what way? The research of three purposefully selected academic enterprises of the high-

tech sector, representing the photonic industry, was conducted in the spring and summer of 2022, after the Russian Federation's aggression against Ukraine.

The research concerns the impact of technology entrepreneurship and specific contemporary conditions on the entrepreneurial behavior of academic enterprises from the high-tech sector. In the present study the following definition of technology entrepreneurship was formulated: "Technology entrepreneurship occurs when scientific and technical development create a key opportunity which stimulates entrepreneurial behavior of the employees of the surveyed enterprises". The key issues in the area of technology entrepreneurship are:

- Technology entrepreneurship of the studied enterprises at the level of individuals and the organization.
- Key determinants of technology entrepreneurship in a given enterprise.
- Determinants of entrepreneurship in the two perspectives mentioned above – the economic cycle and the so-called "black swans".

The photonics sector enterprises selected for the study met the following criteria:

- At least 5 years on the market.
- 100% or majority Polish-owned.
- Development of own unique and world-class photonics solutions.
- Significant R&D expenditures as part of regular operations.
- Exports accounting for a significant portion of sales.

A comparative analysis of the selected enterprises was performed based on the survey results. The case study method allowed for comparing the analyzed enterprises in pairs, which is presented in greater detail in further portions of the present paper. The research will result in the formulation of conclusions and recommendations for photonics sector enterprises in Poland, aimed at enabling them to operate more effectively in conditions of global market competition. The procedure in relation to the case study is defined in the procedure presented in Table 4.

Table 4.
Stages of the case study process

Stage 1	Formulation of research question
Stage 2	Case selection
Stage 3	Development of data-collection tools
Stage 4	Field research
Stage 5	Analysis of collected data
Stage 6	Formulation of general conclusions
Stage 7	Confrontation with the literature
Stage 8	Study conclusion – generalization

Source: Czakon, 2006, p. 10; Czakon, 2020, p. 199; Chyba, 2021, p. 140.

The selection of cases is deliberate and is made on the basis of five basic criteria: data availability, the clarity of the case, diversity in multiple case studies, a critical phenomenon and a metaphor that directs the researcher to a specific course of the phenomenon under study (Czakon, 2020, pp. 200-201; Flyvbjerg, 2004). The first of these is the pragmatic criterion of data availability. It has allowed us to prepare the most thorough descriptions of enterprises that are particularly important from the point of view of answering the research question posed. The second criterion is the clarity of the case, an extreme illustration of the principles being studied, thus ensuring unambiguous interpretation. The third criterion is diversity. This requires that many cases be examined in such a way that they represent at least different circumstances or contradictory situations.

Repeated case studies should cover four to ten cases, which are most often compared in pairs. This gives from two to five pairs of comparisons of phenomena with a different progress or taking place in different industries, allowing for the formulation of generalizations largely free from the factors of circumstances or industry. The selection then consists of setting up pairs of cases, e.g. low technology – high technology; mature market – growing market; simple product – complex product; local enterprise – global enterprise.

The fourth selection criterion is a critical phenomenon, whose progress, which is extreme or different from commonly accepted views, allows for the formulation of generalizations. The fifth criterion concerns a metaphor that directs the researcher's attention to a specific progress of the phenomenon under study or makes it possible to assume a specific research position. For example, the metaphor of the life cycle requires a selection of cases in which it will be possible to observe the moment of emergence, and the development, maturity, decline and disappearance phases of a given phenomenon (Chyba, 2021, pp. 139-141).

Results and discussion

Table 5 presents the characteristics of the surveyed organizations and the determinants of uncertainty in the short and long term, as well as technology entrepreneurship in the macro- and microeconomic environment.

Table 5.
Characteristics of enterprises and determinants of uncertainty and technological entrepreneurship

	Company X	**Company Y**	**Company Z**
Established	1987	1991	2002
Number of employees	ca. 120	ca. 70	ca. 25
Company profile	The enterprise produces primarily MOCVD (Metal Organic Chemical Vapour Deposition) technology uncooled photon infrared detectors for industry, medicine and in the area of military technology; it conducts R&D work in the area of infrared technology.	The enterprise produces general-purpose precision optical elements. The technologies used cover the full production cycle of optical elements from almost all types of optical glasses, quartz glasses, optical ceramics and crystals, starting from cutting raw material in blocks or bars, through all standard technological processes such as: milling, grinding, polishing, MRF correction polishing up to comprehensive measurements, thin layers, framing and precise assembly of optical systems.	The company produces semiconductor laser diodes that emit light with a wavelength of 400-420 nm. This technology is based on the GaN crystal growth method under high pressure developed at the Institute of High Pressure Physics of the Polish Academy of Sciences and on many epitaxial crystal growth technologies such as MOVPE, MBE and HVPE
Impact of uncertainty factors in a short-term perspective (1 year)	**Positive** • Reorganization of the enterprise's work terms of procedures and interpersonal relations due to Covid. **Negative:** • Supply chain disruptions due to Covi	**Positive** • Reorganization of the enterprise's work terms of procedures and interpersonal relations due to Covid. • Mobilization of Employee mobilization resulting from the employer-employee relations during the pandemic **Negative:** • Significant decrease in sales due to Covid • Disruption of supply chains due to Covid • Abrupt change of the head managers of the enterprise and the resulting turbulence	**Positive** • Reorganization of the enterprise's work terms of procedures and interpersonal relations due to Covid. **Negative:** • Decrease in sales due to Covid • Stable access to production tools

Cont. table 5.

Impact of uncertainty factors in a long-term perspective (5-6 years)	**Positive** • Increased orders due to the armed conflict • Brexit has given employment opportunities to émigrés returning from the UK. **Negative** • • The rapid development of science and technology creates difficulties in making business decisions on investments and development. • Intensive increase in international competition leading to difficulties in hiring and retaining specialists. • Uncertainty in the stable functioning of the supply chain resulting from the characteristics of the global market and the occurring turbulence	**Positive** • Increased orders due to the armed conflict • Capital changes in the company • Enterprise reorganization due to the change of head manager. **Negative** • Intensive increase in Polish competition stimulated by public institutions and leading to difficulties in hiring and retaining specialists.	**Positive** • Increased orders due to the armed conflict • Rapid development of laser utilization possibilities **Negative** • Stable access to production tools
Catalogue of determinants of technological entrepreneurship at the micro- and macroeconomic level	Impact of technological progress Limitations in availability of development funding for the enterprise. Verification of the semiconductor production policy in the EU (EU Chip-act) The enterprise's place in the supply chain	Limitations in availability of development funding for the enterprise. Pressure of low margins Succession related to change in company management The enterprise's place in the supply chain.	Poland lacks a laser production ecosystem; this is due to a lack or traditions in this area. Lack of funding sources to enable an enterprise to get across "Valley of Death," i.e. the gap when it no longer receives public assistance but is not yet able to attract private investment Globalization of the labor market for workers with special skills.
Catalogue of management's and staff's entrepreneurial behaviours	Employees' better understanding for intensification and consolidation of activity in the face of unexpected threats Employees' increased involvement due to management's care for the staff	Large consolidation, integration of activities and mobilization of the team Employees' greater understanding of the need for personnel changes implemented by the management	Increase in employee involvement in entrepreneurial activities under the influence of the situation Employees' understanding for greater activity, while appreciating the management's efforts to maintain staff consistency

Source: own elaboration based on interviews with representatives of the enterprises studied.

Table 5, beneath the description of the enterprises, presents a catalogue of short-term uncertainty factors, due mainly to "black swan" events treated as presenting a high degree of uncertainty, i.e. Covid and the outbreak of war in Ukraine. The synthesizing research indicates

that in the short term, the occurrence of external uncertainties from Covid forced organizational changes in the field of business processes, procedures, in ways of performing tasks and in interpersonal relations. These were enforced changes aimed at adapting to new conditions, mainly in the area of supply chain management which collapsed temporarily, and the sales process. The pandemic in some ways limited the possibilities of information exchange in the development of cooperation due to the impossibility of maintain personal scientific and business contacts during conferences, fairs, scientific and industry seminars, trade meetings, etc. The period of the pandemic stimulated the enterprises to alter their management of highly unique and specialized human resources. Already before the pandemic, the labor market of Companies X, Y, Z was changing towards an employee's labor market, which was associated with increased investments in this part of Europe, both on the part of technological leaders and state-owned enterprises specializing in the military industry. However, it was only the pandemic period that forced employers to take active measures to retain employees as well as acquire new ones.

It should be noted that short-term uncertainties did not significantly weaken the enterprises' market position. On the contrary, they were largely seen as an opportunity. Technology entrepreneurship, also in conditions of increased uncertainty, creates new opportunities for cooperation in the supply chain, and also opens up completely new fields for cooperation that had not been developed before. As a of short-term uncertainty factor, the conditions of the pandemic period forced the management to reorganize and change in order to adapt to new conditions. The outbreak of war in Ukraine, as a deep uncertainty, is treated as a development opportunity which results from the acceleration of the militarization process in the region of Central Europe. In addition, the opportunity for the surveyed companies is to take over the existing orders placed by EU companies in Russia and to develop on the Ukrainian market.

Table 5 also presents a catalogue of long-term uncertainty factors. By synthesizing the research, they indicate that the first important factor of long-term uncertainty is the rapid development of science and technology, which forces companies to conduct constant and dynamic activities aimed, on the one hand, at determining which scientific and technological solutions are appropriate for the implementation of orders, and on the other hand, in what areas to do investments. It is worth noting that the EU policy regarding the production of semiconductor components has changed by introducing the EU Chip Act. The European Chip Act will increase Europe's competitiveness and resilience in semiconductor technologies and applications, and help achieve both the digital and green transformation. The second important factor of long-term uncertainty is the limited access to investment capital among companies in the photonics industry. The lack of a long tradition and culture of the photonics industry in Poland causes limitations in the creation of the ecosphere in the photonics industry, which would stimulate, on the one hand, the development of the local photonic industry, and on the other hand, create circumstances and good models for financing new investments. Additionally, the low-level location of the surveyed enterprises in the value chain may not be conducive to

increasing the chances of finding financing. There are limited possibilities of financing investments in the photonic industry, including allowing you to jump over the "valley of death" or the financial gap when the project no longer has public funds and the private sector is not ready to get involved financially. The third important factor of long-term uncertainty is the smooth succession between successive generations of business owners who have knowledge and experience in running a business in such unique areas.

The entrepreneurial behavior (or lack thereof) of employees and entire organizations is largely the basis for the success or failure of enterprises. Table 1 presents the key determinants of entrepreneurship and a catalogue of entrepreneurial behaviors. The studied Enterprises X, Y and Z pointed to various determinants; nevertheless, some shared opinions can be identified. The factor raised by all entities was the issue of limiting (or even lack of) the availability of financing for the development of the enterprise. This would allow for overcoming a difficult moment for companies, known as the "valley of death".

Another issue is the entrepreneurial behavior of employees under the impact of unexpected events, known as "black swans". Here we can observe a high level of agreement in the opinions of the employees of all the enterprises. All the organizations experienced an increase in the commitment and creativity of employees, which proves they understood the seriousness of the situation. Representatives of companies X and Z took steps to protect and maintain the numbers of their employees, which the latter appreciated. In the case of company Y, in the period preceding the analyzed events, there were significant personnel changes, which contributed to the increase in technology entrepreneurship of the employees, who undertook numerous creative and innovative activities.

The difficulties from the company's point of view are seen rather in terms of uncertainty about market needs and a reduction in the level of investment. The pandemic conditions have in some way limited the possibilities of information exchange in the development of cooperation due to the impossibility of direct scientific and business contacts as part of conferences, fairs, scientific and industry seminars, etc. The problem is still difficult access to loans, limited dialogue with the business environment and the lack of an appropriate financial ecosystem. The possibility of an armed conflict on an international scale is perceived rather as an opportunity due to the specific characteristics of the products offered and cooperation with the defense industry.

In the case of Company Y, the pandemic and the military threat are perceived less optimistically. Protecting workers in pandemic involved additional costs for the company. According to Company Y’s president, “the pandemic hit the company hard”. The potential armed conflict is perceived as more of an opportunity due to the company’s cooperation with the arms sector. The opportunity for the company is the withdrawal of its competitors from Russia and the possibility to expand operations in Ukraine. The aforementioned short-term conditions (Covid, armed conflict) prompted the company's employees to greater integration, consolidation of activities and stronger mobilization and motivation of the team. The processes

of integrating employees with the organization have intensified and the understanding of the company's mission and strategic goals has deepened. The company's problem at the moment is the need for greater automation of production processes, which would enable an increase in the scale of production due to the growing demand and favourable economic conditions for the company's products.

In the case of Company Z, the impact of uncertainty in relation to the so-called "Black swans" manifested itself mainly in impeding direct physical contact with potential users of its products, which, by affecting the effectiveness of research and development activities, translated into the functioning of the supply chain and, as a result, diminished the effectiveness and efficiency of market activities. With regard to the armed conflict, in the long term Company Z sees its effects as a development opportunity. This makes Z's way of thinking similar to the previously analyzed companies X and Y. In this case, adopting the strategic perspective may increase the company's sense of uncertainty by limiting access to modern devices that use new methodologies for the use of modern technologies. This concerns primarily the uncertainty resulting from the lack of sufficient information about new devices, as well as the lack of fuller communication between the leading scientific and research centers.

Conclusions

Modern management, conducted in conditions of increased uncertainty, has recently become even more difficult, mainly due to unexpected events, sometimes referred to as "black swans," which belong to the category of deep uncertainty. The most significant factors are the COVID-19 pandemic, which swept the world in spring 2020, and the armed conflict in Ukraine, caused by the aggression of the Russian Federation and the related threat of an international armed conflict. The research conducted shows that the uncertainties of various levels influence the entrepreneurial behaviour of high-tech companies. The entrepreneurial behavior of employees and entire organizations is the basis for the success or failure of the studied companies in the photonic industry. "Black swan"-type events forced the organizations to dynamic adaptation actions, which in turn intensified entrepreneurial activities both at the level of owners and employees. The senior management together with the owners of the companies was determined to undertake entrepreneurial activities in the area of reorganization of relations with employees, sales activities aimed at winning new contracts, reorganization, including the reduction of operating costs, and ensuring financial liquidity. Additionally, the increased uncertainty resulted in a greater consolidation of employee teams, and also generated additional resources of entrepreneurial opportunities and behaviors, in addition, employees were inclined to build more flexible relations with employers.

The research points to the following conclusions:

1. Short-term as well as long-term uncertainty factors are significant determinants of uncertainty affecting the entrepreneurial behaviour of a high-tech company. In the initial phase of uncertainty a "black swan", entrepreneurial behaviour is meant to ensure the company's survival and protect its resources. As the uncertainty level rises, entrepreneurial activities may move towards taking advantage of the emerging opportunities for the development of the enterprise, which results mainly from changes in the enterprises' surroundings.
2. The Covid pandemic has had a certain impact on disrupting the operation of high-tech companies' supply chains. On the other hand, however, the threat of an international armed conflict caused by the aggression of the Russian Federation against Ukraine, resulted in many competitors leaving Russia and Ukraine, which creates an opportunity for the studied companies to develop the "liberated market area" and, consequently, to expand into new markets.
3. The products of the studied companies, to large extent products of a niche character, are currently attracting increased market demand. The development of the defence industry and increasing expenditure on modernizing and rearming the armed forces is creating additional sales opportunities for products manufactured by companies in the Polish photonics industry.
4. The Russian Federation's current policy on the conflict in Ukraine, its attempts to make certain countries dependent on gas and oil supplies from the Russian Federation, and turbulence related to the supply of gas and oil to EU countries are increasing many countries' determination to become independent from gas and oil supplies from Russia. Thus, the companies studied are faced with an opportunity to enter the green energy market.
5. The studied photonics sector high-tech enterprises make use of the results of the latest research conducted in Poland and abroad. The strongest ties with their research centre of origin existed in the case of Company Z (hybrid-technology type) and to a lesser extent in Company X and Company Y (technology spin-offs).
6. Noteworthy are the conditions related to the uncertainty resulting from the financing of investments in the development of high-tech enterprises in the photonic industry. In addition, the lack of tradition in this industry in Poland and the lack of a photonics industry ecosystem mean that the number of financial institutions willing to invest in this industry is limited. It should be emphasized that the proposed investment financing conditions may differ significantly from the expectations of business owners, which results from the perception of risk factors and uncertainty of financial institutions.

Summing up, it should be emphasized that in the analyzed entities uncertainty had a significant impact on entrepreneurial activity at every organizational level. Paradoxically, due to the nature of the business and the products offered, the impact of unusual occurrences,

sometimes referred to as "black swans," had a positive effect on the analyzed entities and can be seen as an opportunity for development and building further technological and competitive advantages on the global market.

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