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Impact of increased uncertainty on entrepreneurial behavior in Polish photonics sector enterprises under conditions of information asymmetry

Wpływ zwiększonej niepewności wynikającej z asymetrii informacji na zachowania polskich przedsiębiorstw z branży fotonicznej

In today's world, management of enterprises occurs under conditions of uncertainty. Paradoxically, despite so many sources of information, knowledge of a strategic nature remains difficult to access. Recently, increased uncertainty has been caused mainly by two factors. The first is the Covid-19 pandemic hit the world in March 2020 and which we are still dealing with to a greater or lesser extent. Even more recently, the world has become concerned about the open armed conflict in Ukraine, which may develop to a conflict of a global nature.

The purpose of the present paper is to assess the impact of increased uncertainty on the entrepreneurial behavior of employees (which translates into the development of technology entrepreneurship of the organization) under the conditions of information asymmetry in various relationship configurations. This was achieved by conducting qualitative research on selected photonics industry enterprises using the case study method.

This paper contains the characteristics of photonics industry, decision-making behind uncertainty, technology entrepreneurship the significance of information asymmetry and cese studies of three photonics firm in Poland.

Key words: uncertainty, photonics industry, technology entrepreneurship, information asymmetry.

Współcześnie zarządzanie przedsiębiorstwami odbywa się w warunkach niepewności. Paradoksalnie, mimo tak wielu źródeł informacji, wiedza o znaczeniu strategicznym – decydującym o przewadze konkurencyjnej przedsiębiorstw – jest trudno dostępna. W ostatnim czasie wzrost niepewności wynika głównie z dwóch czynników. Pierwszym z nich jest pandemia Covid-19, która pojawiła się w marcu 2020 roku i której skutki cały czas można zaobserwować. Drugim czynnikiem niepewności jest wybuch wojny w Ukrainie, która może przerodzić się w konflikt o charakterze globalnym.

Celem artykułu jest ocena wpływu zwiększonej niepewności na zachowania pracowników przedsiębiorstw (co ma przełożenie na rozwój przedsiębiorczości technologicznej organizacji) w warunkach asymetrii informacji. Cel osiągnięto poprzez przeprowadzenie badań jakościowych wybranych przedsiębiorstw branży fotonicznej metodą studium przypadku. W artykule scharakteryzowano branżę fotoniczną, proces decyzyjny w warunkach niepewności, przedsiębiorczość technologiczną, znaczenie asymetrii informacji oraz badanie metodą studium przypadku trzech firm fotonicznych prowadzących działalność w Polsce.

Słowa kluczowe: niepewność, przemysł fotoniczny, przedsiębiorczość technologiczna, asymetria informacji.

Introduction

In today's world, management of enterprises occurs under conditions of uncertainty. Paradoxically, despite so many sources of information, knowledge of a strategic nature – which determines the competitive position of enterprises – remains difficult to access. On the one hand, we are practically "bombarded" with more or less important information, which is often difficult to separate from the so-called information noise. On the other hand, though, information which is of key significance is often difficult to access or is subject to various restrictions. The very phenomenon of management under conditions of uncertainty presupposes information occurring in various dimensions and on various levels of relations.

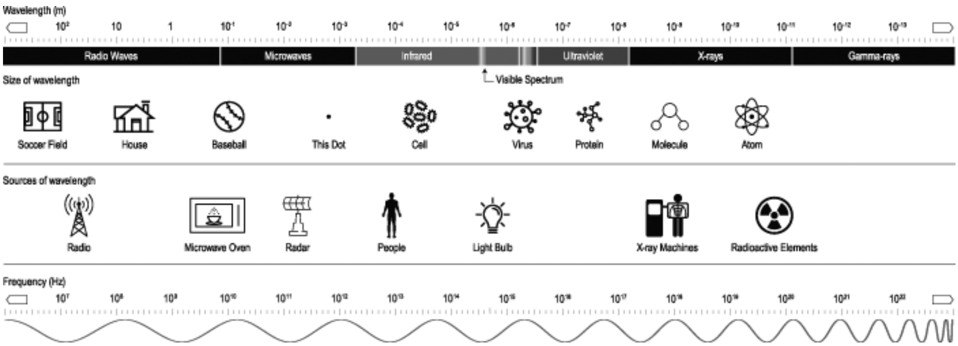
Recently, increased uncertainty has been caused mainly by two factors. The first is the Covid-19 pandemic hit the world in March 2020 and which we are still dealing with to a greater or lesser extent. The pandemic has caused disturbances in production and logistics processes, frequently manifesting in the disruption of global raw material and product supply chains. Even more recently, the world has become concerned about the open armed conflict in Ukraine, which may develop to a conflict of a global nature. In the economic and political sense, the conflict has existed for some time. All this gives a special context to the operation of enterprises. This is especially true for enterprises from the high-technology sector. One interesting segment of this sector is photonics enterprises, which, thanks to the technological entrepreneurship of their founders and employees, successfully operate on the global market. They take part in ”green energy” projects, including undertakings for the development of renewable energy sources. The photonics industry plays a significant role in the manufacturing of components of devices generating green energy as part of sustainable development. The factor that enables the effective performance of these actions is the entrepreneurial activity of the employees and the entire organizations.

The purpose of the present paper is to assess the impact of increased uncertainty on the entrepreneurial behavior of employees (which translates into the development of technology entrepreneurship of the organization) under the conditions of information asymmetry in various relationship configurations. This 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.

Characteristics of photonic industry

Photonics is the science and application of light; it is the technology of generating, controlling, and detecting light. The characteristics of the waves of light or individual photons that make up light can be used to explore the universe, cure diseases, and even solve crimes. Photonics is so ubiquitous in our daily lives that the 21st century has been called the Age of the Photon [1].

Figure 1. The electromagnetic spectrum



Source: [1] (Optics & Photonics Industry Report 2019. SPIE)

Photonics covers the full electromagnetic spectrum, from gamma rays to radio, including X-rays, ultraviolet (UV), and infrared (IR) light as presented in Figure 1. The beginning of photonics as an area of research is considered to be the moment of the invention of the laser, i.e. the 1960s. It was only thirty years later that there was a marked increase in interest in this field, which was reflected in a sharp increase in the number of papers published in scientific journals. As the results show bibliometric analysis by Polish researchers [2], between 1990 and 2017, the number of articles published on the subject of photonics increased by approximately tenfold.

According to mensioned report [2] global annual revenues from production of optics and photonics core components amounted to more than $225 billion in 2016. The estimated photonics components industry revenues for 2018 were $255 billion, which represents a compound annual growth rate (CAGR) of 6.1% for the 2016-2018 period. According to the report of the 2014 European Technology Platform Photonics Report [3], the value of the global photonic market in 2015 amounted to EUR 447 billion. At the same time, the largest world producer in the field of photonics was China, which accounted for 26.6 percent of global production. Next in line were Europe (15.5%), Japan (15.4%), the United States and Canada (13.6% in total), South Korea (12.5%) and Taiwan (10.6%). The rest of the world accounted for only 5.8 percent of total production.

Production of optics and photonics core components is a global enterprise spanning more than 50 countries. More than 3,300 manufacturing companies produced core components in 2016: 75% of them are small to medium-sized enterprises (SMEs); 70% of all core optics and photonics components revenues are generated by only 2% of the companies. Companies in the photonic industry are located in the following positions in the supply value chain:

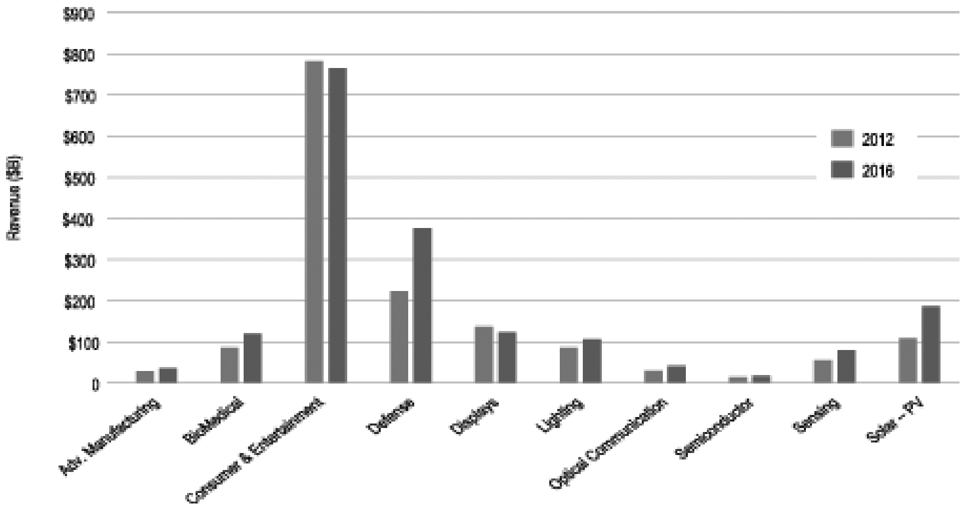
1. Integrator – Integration of services and products from various industries and industrial domains in order to obtain a final product or service. Comprehensive integration of photonic services and products with others in order to obtain energy, lighting, defense systems, etc.
2. Photonic-enabled services – Implementation of specialized services in the field of photonics to produce a semi final product. Examples of photonic-enabled services: Services related to the operation of production machines, design services, and services related to prototyping and testing.
3. Photonic-enabled products – Realization of specialized products in the field of photonics in order to produce a semi final product. Examples of photonics-enabled product: lighting systems, data centers, and smart phones.
4. Core components and materials – Production of elementary parts resulting from the knowledge and science of photonics. The photonics value chain starts with raw materials like glass, semiconductor substrates, diodes as UV light emitters, and progresses through optical components and subsystems.

Each level of the value chain has a higher value than the previous one, so the total revenues associated with the enabled services, for instance, are much larger than those derived from the core components. Along this value chain, other industry sectors may benefit and grow from related opportunities like software development. Figure 2 shows the market share of individual branches of the photonic industry. In terms of revenues, the top five growth segments based on compound annual growth rates between 2012 and 2016 were [3]:

- Solar PV (+15%): Significant increase in installations in China and a doubling of US installations in 2015 and 2016.
- Defense, Safety and Security (+15%): Resurgence in defense procurement and emerging imaging systems.
- Advanced Manufacturing (+8%): Implementation of robotics and vision technology, as well as 3D printing.
- Sensing, Monitoring, and Control (+7%): The Internet of Things is driving demand for a wide variety of photonic sensors.

- Biomedical (+7%): New diagnostic tools, point-of-care testing, and wearable devices all contribute to continued growth.

Figure 2. Enabled Market Segment Trends



Source: [1] (Optics & Photonics Industry Report 2019. SPIE)

When analyzing the photonic industry in Poland [4], it should be emphasized that the dominant number of research in the field of photonics takes place in the Masovian Voivodeship. When analyzing the scientific potential of Mazovia, attention should be paid to the drastic disproportion between the Warsaw Capital Region (Warsaw and – out of 32 identified centers dealing with photonics research, only one – the Siedlce University of Natural Sciences and Humanities, which carries out research on photonics – is located outside the Warsaw metropolitan area). The research conducted by the Masovian centers most often concerns lasers, spectroscopy, photonics and quantum optics, plasmonics, nanostructures and their optical and optoelectronic properties and their application in spectroscopy, photocatalysis and photovoltaics, as well as optical metamaterials, photovoltaics, fiber optics and optical sensors (including PIC/MOEMS/fiber optic sensors).

The study [4] identified 119 photonics sector organizations registered in Mazovia. Fewer than half of them specialize in a single type of activity (out of R&D, production – including one-off production – services and B2B distribution), with the majority trying to combine at least two types.

A substantial majority of organizations possess production capacities. The three most frequent combinations of activities pursued are the following: production and B2B distribution (19.3 percent), production and services (15.9 percent), and distribution and services (13.6 percent). The analysis of the identified companies in terms of their areas of activity shows that most Masovian representatives of the photonic industry operate in the area of production and distribution of laboratory and measuring devices and apparatus, lighting, as well as defense and military solutions.

In order to determine the photonics sector's significance to the Masovian Voivodship's economy, data from the financial statements submitted by companies to the National Court Register (KRS) in 2017 were analyzed. Total net sales revenue generated by the studied enterprises in 2016 amounted to 8,914.07 mln PLN (8 914 070 000/ 4,25 = 2 097 428 235 EUR); 2017 brought a slight decrease of sales to 8,407.76 mln PLN / 2 bln. Thus, the level of revenues generated by photonic enterprises in 2016 and 2017 was small. The lack of synthetic research on the financial condition of companies in the photonics sector in recent years does not for presenting the current picture, but the research conducted by the authors of this article shows that the industry is developing more and more dynamically and significantly exceeded the level of revenues in 2016 and 2017.

However, an assessment of the level of development of the photonic industry in Poland compared to similar companies in other countries in the EU indicates that it is characterized by only a limited number of dynamically developing companies and the lack of a significant ecosystem of cooperation with the industry, which hinders its development.

Decision-making Under Uncertainty

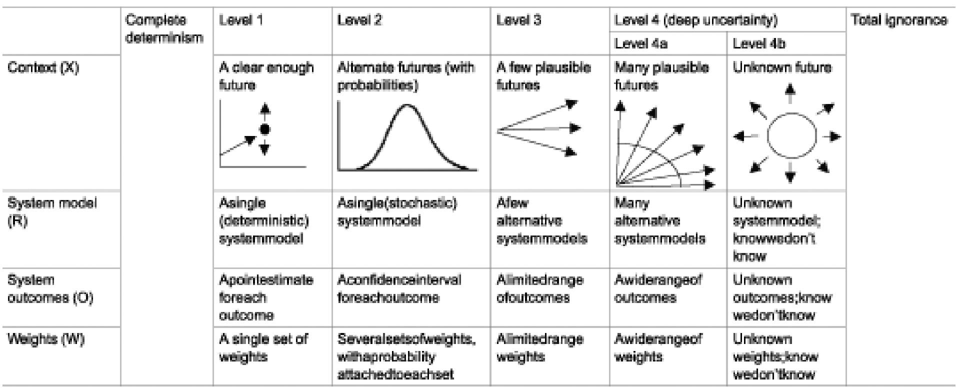
Research and analysis of uncertainty has a long history taking into account epistemological issues debated among the ancient Greeks. However, the modern perception of uncertainty begins around 1921, when Knight [5] distinguished between risk and uncertainty. According to Knight, risk is identifiable, quantifiable, so we can characterize the probability. According to Knight, uncertainty cannot be determined and characterized by probability. Over the years, this definition has been adopted by various authors to distinguish between decision-making under risk and decision-making under uncertainty. It should be noted that decision-making concerns the uncertainty resulting from future turbulences of the environment and the internal behavior of the entities involved in making decisions. Therefore, at present, risk is treated as a low level of uncertainty which can be determined by probability and as a consequence of losses. Thus, the probability may characterize the first level of uncertainty, but it cannot characterize the other levels shown in Figure 3 [6]. With regard to decision-making, a distinction can be made between two extreme levels of uncertainty (determinism and total ignorance) and four intermediate levels [7] [8]. The uncertainty levels will be presented below and in Figure 3.

Level 1 *uncertainty* represents situations in which one admits that one is not absolutely certain, but one does not see the need for, or is not able, to measure the degree of uncertainty in any explicit way [9]. These are generally situations involving short-term decisions, in which the system of interest is well defined and it is reasonable to assume that historical data can be used as predictors of the future. Level 1 uncertainty, if acknowledged at all, is generally treated through a simple sensitivity analysis of model parameters, where the impacts of small perturbations of model input parameters on the outcomes of a model are assessed. Several services in our life are predictable, based on the past such as mail delivery and garbage collection. These are examples of this level of uncertainty.

In the case of **Level 2**, it is assumed that the system model or its inputs can be described probabilistically, or that there are a few alternative futures that can be predicted well enough (and to which probabilities can be assigned). The system model includes parameters describing the stochastic – or probabilistic – properties of the underlying system. In this case, the model can be used to estimate the probability distributions of the outcomes of interest for these futures. A preferred policy can be chosen based on the outcomes and the associated probabilities of the futures (i.e., based on "expected outcomes" and levels of acceptable risk). The tools of probability and statistics can be used to solve problems involving Level 2 uncertainties.

Level 3 *uncertainties* involve situations in which there are a limited set of plausible futures, system models, outcomes, or weights, and probabilities cannot be assigned to them – so the tools of neither Level 1 nor Level 2 are appropriate. In these cases, traditional scenario analysis is usually used. The core of this approach is that the future can be predicted well enough to identify policies that will produce favorable outcomes in a few specific, plausible future worlds [10]. The future worlds are called scenarios. Analysts use best-estimate models (based on the most up-to-date scientific knowledge) to examine the consequences that would follow from the implementation of each of several possible policies in each scenario. The "best" policy is the one that produces the most favorable outcomes across the scenarios. A scenario does not predict what will happen in the future; rather it is a plausible description of what can happen. The scenario approach assumes that, although the likelihood of the future worlds is unknown, the range of plausible futures can be specified well enough to identify a (static) policy that will produce acceptable outcomes in most of them.

Figure 3. Progressive transition of levels of uncertainty



	Complete determinism	Level 1	Level 2	Level 3	Level 4 (deep uncertainty)		Total ignorance
					Level 4a	Level 4b	
Context (X)		A clear enough future	Alternate futures (with probabilities)	A few plausible futures	Many plausible futures	Unknown future	
System model (R)		Asingle (deterministic) systemmodel	Asingle(stochastic) systemmodel	Afew alternative systemmodels	Many alternative systemmodels	Unknown systemmodel; knowwedon't know	
System outcomes (O)		Apointestimate foreach outcome	Aconfidenceinterval foreachoutcome	Alimitedrange ofoutcomes	Awiderangeof outcomes	Unknown outcomes;know wedon'tknow	
Weights (W)		A single set of weights	Severalsetsofweights, withaprobability attachedtoeachset	Alimitedrange weights	Awiderangeof weights	Unknown weights;know wedon'tknow	

Source: [6] (Marchau V., Walker W.E., Bloemen P.J., Popper S.W. (2019), Decision making under deep uncertainty from theory to practice, Springer)

Level 4 *uncertainty* represents the deepest level of recognized uncertainty. A distinction can be made between situations in which we are still able (or assume) to bound the future around many plausible futures (4a) and situations in which we only know that we do not know (4b). This vacuum can be due to a lack of knowledge or data about the mechanism or functional relationships being studied (4a), but this can also stem from the potential for unpredictable, surprising, events (4b) calls these events "black swans". He defines a black swan event as one that lies outside the realm of regular expectations (i.e., "nothing in the past can convincingly point to its possibility"), carries an extreme impact, and is explainable only after the fact (i.e., through retrospective, not prospective, predictability).

In these situations, analysts either struggle to (Level 4a) or cannot (Level 4b) specify the appropriate models to describe interactions among the system's variables, select the probability distributions to represent uncertainty about key parameters in the models, and/or value the desirability of alternative outcomes.

Currently, the surrounding world is characterized by a strong level of turbulence and variability of structures and hierarchies, which, together with the increased number of variables and actors, does not provide the right tools for making decisions under deep uncertainty. Until now, the deep uncertainty decision support tool (level 4a, 4b) used tool concepts for level 1, 2, 3, which were insufficient because they had an inability to deal with the multiplicity of long-term probabilities. Therefore, the effort of practitioners and researchers is needed to try to develop innovative tools to support decision-making in conditions of deep uncertainty in enterprises dealing with modern technologies, i.e. photonics.

Technology entrepreneurship and entrepreneurial behavior of companies in the photonics industry

Development of photonics sector enterprises in Poland is possible thanks to the entrepreneurial behaviors of many managers who are able to see opportunities for technological changes in the environment, and then translate them into market success. In conditions of a technology race and a shortening of product and technology lifecycles, a special role is taken on by technology entrepreneurship 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 at the level of the whole organization. This entrepreneurship combines the issues of academic entrepreneurship, technology management (including technology transfer) and intellectual entrepreneurship [11].

Technology entrepreneurship has been attracting significant interest in recent years, both from management theoreticians and practitioners. Even though the term has been known in the world literature for several decades, the number of publications on it did not increase markedly until the 2010s. The theoretical foundations of the concept in its modern understanding appeared in a special edition of the "Strategic Management Journal" from 2012, scientific editor Ch. Beckman, editors K. Eisenhardt, S. Kotha, A. Meyer and N. Rajagopolan, entitled "Technology Entrepreneurship" [12]. Other papers presenting an attempt to explain the concept include T. Bailetti [13], 2012. The topic of technology entrepreneurship was undertaken by numerous authors, including S. Muegge [14], T. Bailetti et al [15].

The concept of technology entrepreneurship should be placed in the area of strategic management, including innovation theory and entrepreneurship theory. Technology entrepreneurship primarily concerns advanced technology sectors, although it can also be applied with respect to traditional industries. It is a process consisting of the entrepreneurial activities of an innovation leader, the team members and the members of the entire organization. It is a special process that is primarily characterized by creative, collaborative activities or processes, innovation, a propensity toward risk and a positive focus on actions, their results, primarily serving the benefit of society.

Technology entrepreneurship is an innovative process that can be considered on two levels. The first of these is the stage of creating the idea for an innovation and the probability of its practical use. The second is the actual implementation and commercialization of the innovation idea. This means that technological entrepreneurship is also a special, complex, multi-stage undertaking, requiring non-routine actions, often unique decisions, as well as specific project management competences. It must be emphasized that technological entrepreneurship should be considered in a broader context of corporate strategy and be the determinant of its formulation.

The significance of information asymmetry

Information asymmetry is defined as a situation in which one of the parties to a transaction possesses more information than the other party on the market exchange in which they are participating, which many economists perceive as a negative phenomenon [16]. According to J. Oleński [17] there are two types of asymmetry. The first is full asymmetry, when the recipient of information buys something on which they have no knowledge and has no means of confirming the information prior to the transaction – an example is a custom-made IT system or the production of a unique device in batch or very short batch production. The second type is incomplete asymmetry, which occurs when somebody buying a product or service doesn't possess full information on them but can request such information before the transaction. The existence of full and incomplete asymmetry is indispensable in some industries that offer services or products. According to J. Kubiak [18] the existence of information asymmetry increases uncertainty for both parties to the transaction. Information asymmetry may be caused by problems with accessing information, as well as with its reception and interpretation. The phenomenon of information asymmetry may thus involve not only differences in two organizations' access to data but also limitations related to processing and understanding information, as well as identifying and eliminating disinformation. When considering information asymmetry problems, one should bear in mind both the consequences of a different level of access to information (lack of access to data, concealment of data by one of the parties) and the need to have the knowledge required to interpret the data provided. Both causes of asymmetry may have negative consequences for the parties transmitting and receiving information, as well as for their surroundings.

The development of research on information asymmetry can be analyzed from two points of view or from the perspectives of two disciplines of science – economy and management science [19]. A presentation of the concept's development in the area of economics should emphasize that the asymmetry of information was interwoven with research looking for ways to explain the behavior of market participants [20].

These behaviors were considered with the assumption that the market is not perfectly competitive and has certain limitations. G. Akerlof [21], M. Spence [22] and J. Stiglitz [23] developed the theoretical foundations of markets characterized by information asymmetry. They pointed out that a slight deviation from rationality in the parties' micro-behaviors causes significant macroeconomic deviations. In such a situation, the economy achieves equilibrium at a level below the optimal use of resources. A condition necessary for the appearance of information asymmetry in an economy is the existence of two organizations remaining in a specific relationship as a result of concluded contracts or intention to enter into a transaction. Information asymmetry between them will arise if they do not possess equal levels of knowledge and skills and consequently, are unable to correctly interpret the available data [18].

The literature distinguishes the following reasons for information asymmetry [18]:
1. different extent of information provided to parties – scope of information differing with respect to its quantity and access rights;
2. psychological aspects related to the reception of incoming information – incorrect interpretation of information due to the irrationality of the client's actions.

The psychological aspects related to the reception of incoming information are worthy of note. A cause of information asymmetry related to this area may be the client's non-rational approach to receiving and processing the message. This points to the existence of certain psychological phenomena determined by the human subconscious, including anchoring error, confirmation effect, illusion of truth, overconfidence and cognitive conservatism.

The literature [24] points to three main consequences of information asymmetry – increasing the transaction costs of the contract implementation (studied within the theory of transaction costs), the occurrence of the phenomenon of moral hazard and negative selection (studied within the framework of the agency theory). A significant characteristic of information asymmetry is that it makes it impossible to define the asymmetry level directly. A direct measurement of the level of asymmetry would need to identify the actual differences in the information possessed by the supplier and the customer for every single sale and purchase transaction. The researcher would thus need to have access to all the possessed by the supplier and then compare it with the scope of information available to the customer. A barrier to conducting such research – in addition to its great labor-intensiveness – is the difficulty of obtaining complete information. Researchers are forced to measure the asymmetry of information indirectly by approximating the level of asymmetry based on indications of its differentiation. The difficulty of making such a measurement is certainly one of the reasons for the existence of a gap in the literature on the subject of the analysis of the impact of information asymmetry on the implementation of high-tech projects.

Research concept and methodology

The present paper was prepared based on results of qualitative research using the case study method. The authors posed the following research question: Do conditions of uncertainty impact the entrepreneurial behavior of high-tech enterprises under conditions of information asymmetry?

The research covered two main thematic areas: the issue of information asymmetry and entrepreneurial behavior as a condition for technology entrepreneurship. The key issues in the area of information asymmetry are:

- Information asymmetry and its individual types: between a customer and a supplier, between an enterprise and a global component manufacturer, between an employee and an employer, between research organizations and an enterprise, between investors and an enterprise. (We are interested in indicating the axes of information asymmetry that the surveyed enterprises believed to be the main ones).
- Determinants of uncertainty divided into two perspectives: an economic cycle 4-6 years, as well as the so-called "black swans", i.e. events that happen unexpectedly, e.g. the COVID-19 pandemic, armed conflict and the prospect of its possible extension. (Indication of events creating uncertainty in the horizon of the economic cycle and ad hoc, e.g. "black swans").

The second research area concerns the impact of increased uncertainty on technology entrepreneurship in the studied enterprises. 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 ate 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 of operation.
- 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 1.

Table 1. Stages of 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: [25], [11] (W. Czakon, *Zastosowania studiów przypadku w badaniach nauk o zarządzaniu*, [w:] W. Czakon (red.), *Podstawy metodologii badań w naukach o zarządzaniu*, Oficyna a Wolters Kluwer Business, Warszawa 2011, pg. 102; see: Z. Chyba, *Przedsiębiorczość technologiczna w procesie kreowania przewagi konkurencyjnej przedsiębiorstwo wysokich technologii*, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2021, pg. 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 [25]. 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 [25].

Multiple 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 [26].

Case studies of selected enterprises

Company X was founded in 1987 by a group of scientists from the Military University of Technology [27]. It is a medium-sized enterprise operating in the high technology sector. It has a 100% share of the Polish infrared detector market and an approx. 50% share in the world market (the United States, Japan and the European Union). It makes use of its own research and development resources. It develops new technologies but does not make them available to other organizations. Its case is an example of internal technology transfer. 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. In Poland it sells its products to a few customers with which it maintains direct business contacts. This means that customer contacts are very close. The company develops most of its innovations, technical improvements and new products in direct response to customer needs [28].

The history of the company dates back to the 1970s, when a team of scientists from the Military University of Technology was the fist 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 to 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. Currently, it does not make financial sense for the company to patent new solutions, because obtaining a patent takes about 3 years, which means that when awarded, a patent is already obsolete [26].

Company X is a world leader in the production of uncooled photon infrared detectors. The company's 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 the former employees of the Military University of Technology. 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 specializes in the production of prototypes and atypical precision elements. In addition to manufacturing, it provides services such as:

- optical coatings,
- 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 [29]. 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 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 the Military University of Technology, 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 – family owned. The company faced many barriers to its development. The limited financing possibilities for new investment were a serious obstacle in its development. The company's development was dependent 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. These technologies were developed by the company's employees. 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 commercializes knowledge by selling 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 center mainly through the history / genesis of the activity and recruiting new employees. R&D intensity in Company Z remains at a consistently high level.

Research results and discussion

Table 2 presents the characteristics of the surveyed organizations and the determinants of uncertainty in the short and long term, as well as a catalog of information asymmetry and determinants of technological entrepreneurship in the macro- and microeconomic environment, the internal environment of the organization and the position of the surveyed entities in the value chain.

Table 2. Characteristics of enterprises and determinants of uncertainty, technological entrepreneurship and a catalog of information asymmetry

	Company X	Company Y	Company Z
Established	2002	1991	2001
Number of employees	ca. 120	ca. 70	ca. 25
Company profile	The enterprise produces primarily MOCVD (*Metal Organic Chemical Vapor 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 enterprises 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

	Company X	Company Y	Company Z
Established	2002	1991	2001
Number of employees	ca. 120	ca. 70	ca. 25
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 Covid	**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
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

	Company X	Company Y	Company Z
Established	2002	1991	2001
Number of employees	ca. 120	ca. 70	ca. 25
Catalog of information asymmetries in the studied enterprises and their description	**AX1** – Asymmetry regarding knowledge and information possessed by company X regarding new solutions and available in the scientific and business space resulting from technological progress **AX2** – Asymmetry regarding technology information between company X and its customers	**AY1** – Asymmetry regarding general conditions, existing between the management and the employees **AY2** – Asymmetry regarding organizational and commercial conditions, existing between suppliers in a supply chain	**AZ1** – Asymmetry regarding laser development tools, existing between Company Z and a supplier of e.g. reactors **AZ2** – Asymmetry regarding laser application areas and methods, existing between Company Z and its customers
Catalog of determinants of technological entrepreneurship at the micro- and macroeconomic level	**CX1** – Impact of technological progress **CX2** – Limitations in availability of development funding for wthe enterprise. **CX3** – Verification of the semiconductor production policy in the EU (EU Chip-act) **CX4** – The enterprise's place in the supply chain	**CY1** – Limitations in availability of development funding for the enterprise. **CY2** – Pressure of low margins **CY3** – Succession related to change in company management **CY4** – The enterprise's place in the supply chain	**CZ1** – Poland lacks a laser production ecosystem; this is due to a lack or traditions in this area **CZ2** – 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 **CZ3** – Globalization of the labor market for workers with special skills
Catalog of management's and staff's entrepreneurial behaviors	**ZX1** – employees' better understanding for intensification and consolidation of activity in the face of unexpected threats **ZX2** – employees' increased involvement due to management's care for the staff	**ZY1** – large consolidation, integration of activities and mobilization of the team **ZY2** – employees' greater understanding of the need for personnel changes implemented by the management	**ZZ1** – increase in employee involvement in entrepreneurial activities under the influence of the situation **ZZ2** – employees' understanding for greater activity, while appreciating the management's efforts to maintain staff consistency
Product's place in the value chain	Core components and materials	Core components and materials	Core components and materials

Source: own elaboration based on interviews with enterprise managers

Table 2, beneath the description of the enterprises, presents a catalog 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. Already before the pandemic, the labor market of Enterprises 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 2 also presents a catalog 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.

Noteworthy is the indication of the uncertainty factor regarding supply chain functioning resulting from the characteristics of the global market and the occurring turbulence. The highly dispersed structure of the logistics supply chain in the conditions of globalization is extremely sensitive to dynamic changes, such as the war in Ukraine, Covid-19, or political changes, e.g. the UK's exit from the EU. Respondents from the surveyed companies indicate that mitigating this type of uncertainty will be a source of macroeconomic changes consisting in changing the location of production of important components in the photonic industry, but not only.

An important phenomenon influencing the short- and / or long-term uncertainty is the asymmetry of information between different market players. Table 1 presents the catalog of the occurrence of the asymmetry phenomenon in the relations within the studied enterprises as well as in the relations between enterprises and the surroundings. When synthesizing the results of the authors' research, the first asymmetry of information is the difference in knowledge and information between an enterprise and the broadly understood research and industrial environment. Enterprises may not have sufficient knowledge about the use and application of new scientific achievements in the field of photonics compared to members of the research and development community. A challenge is posed by the high dispersion of scientists specializing in the field of photonics in the world and their potential willingness and ability to cooperate with business. The second important information asymmetry is the difference in knowledge and information regarding products and the purchasing process between the supplier and the customer or sales agent. Customers have application knowledge about the product or service ordered, and often do not disclose to the end supplier how to use the device for which they order the product. The result is a lack of suppliers' knowledge that could stimulate the further development of their services or products. Additionally, the supplier using sales agents may not have sufficient and up-to-date knowledge of the sales processes and their conditions on specific sales markets. The third important information asymmetry is the difference in knowledge and information between the employer and employee in terms of employee competences in local as well as global conditions. It is difficult for the employer to verify the unique competences of employees in the photonic industry that the employee may have. The employee does not have knowledge about the condition of the employer's enterprise, development directions and work culture, in particular at the moment of the appearance of deep uncertainty, a "black swan", e.g. the Covid pandemic.

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 catalog 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 that connects the analyzed enterprises is their location in the supply chain and thus in the value chain, which represents the level of added value generated by the enterprise. The initial stages of this chain are dominant among the studied enterprises, which has significant economic and business consequences.

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 ecosystem financial. The possibility of an armed conflict on an international scale is perceived rather as an opportunity due to the specificity 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 the president of Company Y, “the pandemic has overwhelmed us”. Some supply chains, mainly from Germany, have been disrupted.

The potential armed conflict is perceived as more of an opportunity due to the company’s cooperation with the armaments 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 favorable 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. Depending on the nature of the application of the manufactured products, different levels of uncertainty arise, which is associated with other aspects of information asymmetry.

Summary

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 deep uncertainty group 4a and 4b. 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 presented in Figure 3 influence the entrepreneurial behavior of high-tech companies. In addition, research has shown that the phenomenon of information asymmetry between market players may increase uncertainty. The entrepreneurial behavior of employees and entire organizations is the basis for the success or failure of the studied companies in the photonic industry.

The results of the research show that the impact of uncertainty of levels 1-3 and 4a and 4b on entrepreneurial behavior was mixed, i.e. strengthening as well as weakening the economic condition of the company. Events such as "black swans" characteristic of uncertainty 4a, 4b forced the organizations to dynamic adaptation actions, which in turn intensified entrepreneurial activities both at the level of ownership and employees. The senior management together with the owners of the companies was determined to undertake entrepreneurial activities in the area of reorganization of employee 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 level 4a, 4b uncertainty affecting the entrepreneurial behavior of a high-tech company. In the initial phase of uncertainty 4a, 4b, e.g. a "black swan", entrepreneurial behavior 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, i.e.:
   a. 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.
   b. The products of the studied companies, to a large extent products of a niche character, are currently attracting increased market demand. The development of the defense industry and increasing expenditure on modernizing and rearming the army is creating additional sales opportunities for products manufactured by companies in the Polish photonics industry.

c. 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.

2. The phenomenon of information asymmetry between market players affects the level of uncertainty in decision-making. The work culture and the vision of the management and/or owners can stimulate entrepreneurial activities aimed at reducing the level of information asymmetry; in the event of deep uncertainty, this helps the enterprise to survive on the market and then increase the competitive advantage. The role of the company's management is to build an "early warning" system in order to analyze and reduce the phenomenon of information asymmetry at many decision-making levels and to identify potential uncertainty conditions at each level.
3. The high-tech photonic industry enterprises studied use the results of the latest Polish and international research. A very rapid scientific progress in the field of the technology used may be accompanied by an information gap in the surveyed companies regarding the choice of implementing a scientific invention in a specific product. In the studied enterprises, entrepreneurial behaviors aimed at reducing the asymmetry of information in the area of using scientific discoveries and inventions, which may reduce the determinants of uncertainty.
4. The conditions related to the uncertainty resulting from funding investments in the development of high-tech enterprises in the photonic industry deserve attention. Information asymmetry between high-tech enterprises and financial institutions in terms of knowledge and information regarding activities in the photonic industry was identified. Additionally, the lack of tradition in this industry in Poland and the lack of a photonic industry ecosystem mean that the number of financial institutions willing to invest in this industry is limited. It should be emphasized that the proposed terms of financing investments may differ significantly from the expectations of business owners, which is due to the above-mentioned information asymmetry and the financial institutions' perception of risk factors and uncertainty.

To summarize, it should be emphasized that in the studied organizations, uncertainty had a significant impact on entrepreneurial activity at every organizational level. An important source of uncertainty is the asymmetry of information between the main players inside and outside the organization. Therefore, activities related to the reduction of the phenomenon of asymmetry on many levels and an attempt to identify uncertainty may be an important entrepreneurial activity.

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