

Article

Conceptualization and Mapping of Predictors of Technological Entrepreneurship Growth in a Changing Economic Environment (COVID-19) from the Polish Energy Sector

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Abstract: This study seeks to address the issue of the development factors influencing technological entrepreneurship capabilities of enterprises during the COVID-19 epidemic crisis. This research is particularly relevant in light of the leading role given to innovation and science-oriented technology companies in the economic and epidemiological crisis. This study aims to analyze the impact of the changing environment on the predictors of technological entrepreneurship, assess their impact by the management practice and establish a causal relationship between the used variables. The paper draws on foreign literature review, covering fundamental theoretical fields in international management literature, to develop an integrated research framework. Based on a differentiated approach, the collaborative framework emphasizes a range of network processes and attributes, their interactions and moderating managerial relationships related to their impact on companies' technological entrepreneurship capabilities and their contribution to business outcomes. The study was conducted by means of four-wave research. The factors of models included in the correlation analysis are management functions and demand for new technology. Results show that there is a weak positive relationship between management functions and manager's technological preferences. These findings show that during COVID-19, firms changed their management practices using digitalization to respond to the pandemic. Additionally, it shows that managers moved towards employing new technologies as a strategic response to the crisis. The results showed a mutual, two-way relationship between the demand for new technology and managers from the planning area, high level scientifically and managers with managerial functions, a quick diffusion of technological innovations and managers with the motivating function, a short lifecycle of products and processes and managers from the short lifecycle of products and processes. Taking into consideration that technology entrepreneurship and innovation are facets of the innovative entrepreneur sector, the need for a holistic approach is needed to support their development during the international economic crisis. The next practical implication derived from the crisis may hinder the ability of entrepreneurs to discover new opportunities for technology development. Moreover, an epidemic shock such as COVID-19 may have an impact on technology entrepreneurial opportunities. This article presents a new look at the theory of management by using the implementation role of predictors of the growth of technological entrepreneurship during the epidemic crisis. In addition, the article obviously contributes to the technology entrepreneurship literature by providing an empirical study that advances a new perspective on the process of developing new technologies in the period of crisis.



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1. Introduction

Studies maintain that common entrepreneurial responses during the COVID-19 pandemic were digitalization [1,2] and a focus on innovation to reply to the emerging needs of customers [3–5]. Despite its importance, there are few empirical data in the management

literature in terms of evidence of contributions of those traders that are taken into account to be innovative despite the development of the epidemic [6]. The outbreak of COVID-19 in 2020 shook international markets, and led many companies and countries into recession [7,8]. Due to uncertainty caused by the global pandemic, companies adopted various strategies to respond to the introduction of new technologies to withstand the negative impact COVID-19 and ensure their survival. The current crisis differs from the previous one, as companies faced a shortage of supply, uncertainty, and a lockdown of international markets as a response to increased cases of COVID-19 [9,10].

Businesses are aware that they are surrounded by conditions inherent in changing, turbulent environments with very intense competition. Factors that change with technological advances cause increasing speed and more rapid innovation [11]. In this vein, owners, CEOs and managers must understand that grown companies should respond to the crisis. Entrepreneurship plays a significant role in operating innovation, and especially growth-oriented firms should focus on predictors of growth entrepreneurship. Technological entrepreneurship is examined in terms of management trends conditioning its development—managerial and organizational skills, behavioral theory, knowledge theory or resource theory [12–14]. Technology entrepreneurship is often seen as more dependent upon technological paths compared to the general definition of entrepreneurship [15].

The role of technological entrepreneurship has become particularly important in the time of developing entities that are saturated with modern technology and have the ability to adapt the achievements of science quickly and flexibly. This is facilitated by the analysis of the determinants of enterprise development, enterprise competitiveness, stimulation of transformation processes and commercialization of knowledge, and increasing technological awareness.

A change in global market conditions, the effect of which is the global economic crisis caused by COVID-19, led to the identification of new limitations and barriers as well as the extension of the development process of enterprises, increasingly classified as technological entrepreneurship [16]. The paper presents how the role of the predictors of growth of technological entrepreneurship changes with the changing economic situation caused by the duration and effects of the COVID-19 epidemic. The entrepreneurship literature suggests that companies build emergency response strategies to limit the risk and look for possibilities of survival [17]. To sum up, this study aims to analyze the impact of the changing environment on the predictors of technological entrepreneurship and to assess their impact by the managerial staff. To show a causal relationship between different variables, the author employed an advanced statistical technique: the random-intercept cross-lagged panel model.

The aim of the study is to identify determinants shaping the business activity of technological entrepreneurship in the changing economic environment with the use of panel analyses. The article is structured as follows: first, the literature on technological entrepreneurship and its framework for the functioning of the crisis is reviewed. The research model, research gap and research question are presented on the basis of the literature review. Then, the theoretical part of the article, the research method and analysis are presented. The findings are then discussed. The final section outlines the conclusions, practical implications, limitations and areas of potential for future research.

2. Literature Review

Technological entrepreneurship is a multidimensional phenomenon. Based on a rich tradition of research, several authors indicate technology entrepreneurship as an interface of two well-established and related fields—entrepreneurship and technological innovation [18–20]. This in mind, for the purpose of the conducted research the definition of technological entrepreneurship was adopted as an element of a wider set of innovative entrepreneurship [21–23], being a bridge connecting such phenomena as technology transfer, intellectual and academic entrepreneurship [19,24]. It is also a continuous process based on creating, discovering and exploiting technological opportunities [25,26].

The selection of enterprises was limited to state-owned energy companies, in which the development of science and technology creates a key element of an entrepreneurial opportunity, enabling the generation of a given enterprise. They are characterized by technological entrepreneurship as anticipating technological changes, managing external and internal relations, or organizing resources allowing the use of technological opportunities. Beckam et al. [19] indicate that its use is based on network advantages, technical standards and cost reductions. Wściubak [27] states that a measure of the effectiveness of technological entrepreneurship is the ability to transform new technological solutions into a stream of economic benefits. When monitoring the progress of technological entrepreneurship, predictors of its growth should be systematically compared in different periods of time (OECD 1995): demand for new technology, high level scientifically, a quick diffusion of technological innovations, short lifecycle of products and processes, needs for pre-incubation and coaching, scientific and technology cooperation, increasing demand for highly qualified staff, creating new needs, a high level of capital expenditure and an investment risk [28]. The determinants of the growth of technological entrepreneurship take into account the rapidly changing conditions of the competitive environment. Research has been conducted on these growth factors for years [29–32]. Sushil [33], when examining the need for pre-incubation and coaching in technological enterprises, indicated that the essence of technological entrepreneurship comes down to a free choice in order to enable the most efficient implementation of a technological change, taking into account the pre-incubation period, with the optimal use of inputs and time in the enterprise.

Fritsch [34] analyzed the predictor—an increase in demand for highly qualified staff, where he diagnosed that technological enterprises, in search of technologically qualified employees, innovators and technology creators, enter the interregional and international market. Energy companies will have more innovation and a greater need for new business ventures and proactivity success than low-tech ones [18,35,36] analyzed the predictor—a rapid diffusion of technological innovations highlighting companies undertake activities in networks due to the possibility of quick learning or sharing knowledge. This is essential for technology transfer and diffusion in companies. Beckman et al. [19], in their predictor studies on the demand for new modern technologies, identified the demand for the effects of network advantages, higher technical standards and the reduction in company costs.

Guo et al. [2] claimed that the restrictions implemented to avoid increasing COVID-19 cases, namely social distancing, made firms employ digital technologies as an important source of their competitive advantage [11,37,38]. Innovation clearly depends on the openness to technologies that the company represents in relation to new business ventures—that is, creating new business in the organization by redefining the company's products or services and developing new products and markets. They also analyzed other factors in the growth of technological entrepreneurship: a high level of capital expenditure and an investment risk [39,40].

Despite high investment and high risk, a chance to transfer research results in the economic area in order to develop innovation and competitiveness of goods and services. The process involves steering scientific research towards greater practical utility and minimizing capital expenditure. In his research, Kordel [41] referred to the short lifecycle of products and processes, indicating recursive interactions, allowing for the development of entrepreneurial abilities as a result of external influences. He indicated that the category of time is important from the moment of identification of a technological opportunity to the creation of a product or service. Shane [42] analyzed the predictor—a high level of science intensity in the context of activating research and development activities, which means own research facilities and close cooperation with universities. The competency is understood as openness to knowledge and new skills in the context of technological entrepreneurship [30,43]. The competency covers all technological activities to which activity, exploration and social solidarity lead [34,44].

Another interesting research study conducted by Świadek and Wiśniewska [45] of the predictor—close scientific and technical cooperation—shows that the source of the advan-

tage of technological enterprises is multidimensional cooperation with the environment, including the scientific community, thus contributing to reducing costs, limiting uncertainty and increasing trust in the companies. In contrast, during pandemic, these short-term activities may focus on medium-term R&D and innovation [34]. The predictor—creating new needs—was analyzed by Rostek and Skala [46] towards searching, exploration technological opportunities. It is one of the key factors of production growth. Technology entrepreneurship also opens new opportunities for businesses [47]. Shareef et al. [48] presented that introducing new possibilities of doing business will be crucial to overcoming the pandemic crisis. The fact that firms focused on tailoring operations to customer needs, created by new circumstances, comes from the COVID-19 pandemic.

Most of the research to date on the possibilities of developing technological entrepreneurship in the changing economic environment, including COVID-19, concerned attitudes towards reducing demand in a situation of uncertainty [37,49], feeling threatened by infection that limits the supply possibilities of enterprises [50–52]. Hence, few companies were looking for technological opportunities. The science gap was formulated in the following science question: Which competitive advantages are the main predictors of the growth of technology enterprises in the changing economic environment?

3. Materials and Methods

A four-wave panel study was conducted between 5 June and 29 December 2020, which was 10 weeks after the beginning of the lockdown by the COVID-19 pandemic. The timespan between the data collection was 3 months. The frequency of data collection was caused by significant changes in the internal and external conditions of the energy company due to COVID-19. The Entre Intercept cross-lagged panel model is a panel model with a cross-delay random capture (EN-CLPM) for estimating the relationship between the predictors of technology entrepreneurship and managerial position (Pers) located within the four management functions (planning, organizing, motivating, controlling) for the data of the four-wave panel. Each observed result is split into two parts: the part capturing the increase in the predictor and the part not capturing the increase (decrease or constant) of the predictor. For years, researchers have employed the Cross-Lagged Panel Model (CLPM) to compare the dependencies and interactions of a wide variety of aspects of the cycle [53,54]. Cross-lagged panel models (CLPMs) are widely used to test mediation with longitudinal panel data [55,56].

First, the study used latent growth curve modelling to examine changes of demand of technologies during the pandemic. The univariate model enables examination of the initial level of a given variable, the rate of change and the relationship between the rate of change and the initial level [57]. The main aim of the research was to obtain a detailed insight into the relationship between the analyzed variables [58]. This model enables the decomposition of the analyzed variables into two units: (1) time-invariant, predictors of technology entrepreneurship growth (2) more state-like, constant predictors of technology entrepreneurship (Figure 1).

The main goal was to show detailed insight into the causal relationship between analyzed variables. The study applied the Entre intercept cross-lagged panel model (EN-CLPM). The Google form questionnaire was used to send an electronic questionnaire to managers. The studied sample included managers of four levels co-deciding on the directions of development of a technological enterprise [59,60], but taking into account age and gender [49,61]. They were involved in a study conducted in a turbulent economic environment during the COVID-19 epidemic. The explanatory variable was assigned to 4 management functions, appropriately explained in the questionnaire. The scope of managers' competences was assigned to the management function. For a company developing in an increasingly competitive environment and during the COVID-19 epidemic, it is important to perform the management function, most often assigned to the work of a manager-entrepreneur. Management functions are designed to achieve the company's goals, they are present in every area of its activity and at every level of the hierarchy,

but to a different extent. Entrepreneurship areas as part of the management functions performed: planning, organizing, motivating and controlling. A total of 979 managers took part in the first wave of research study, sent by mail. The random-quota sample was representative of the Polish adult. In order to ensure the quality of these data, 39 outliers were not matched: 14 participants using only the lowest or the highest scale levels in the survey, and 25 participants using the midpoint of the scale.

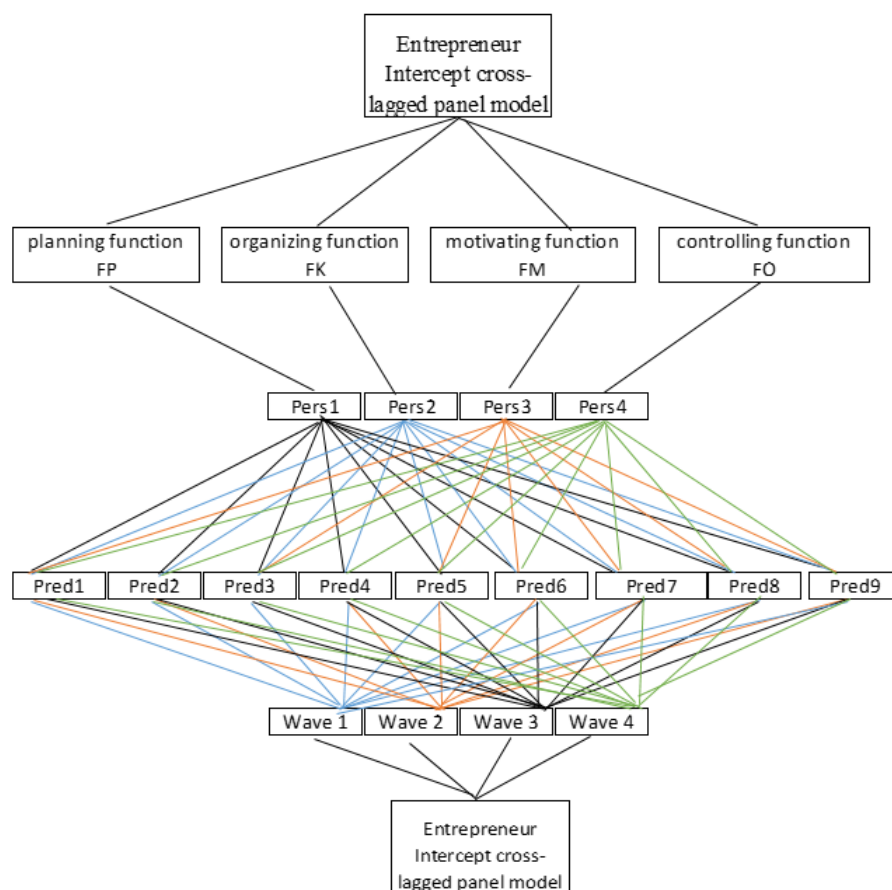


Figure 1. Model of scientific research.

Ultimately, data from 940 participants were analyzed. The majority (98%, $n = 920$) of participants declared that Poland was their country of origin. The sample included 464 females (49.4%) and 476 males (50.6%), age range from 18 to 85 ($M = 44.53$, $SD = 15.83$). Their ages ranged from 20 to 67 ($M = 45.41$, $SD = 14.72$). The next wave of study was conducted among 771 participants from the previous wave (377 women, 394 men; age ranged from 20 to 60 years, $M = 46.34$, $SD = 14.12$). The third data collection was carried out among 718 participants of the previous wave (387 women, 331 men; age range from 20 to 58 years, $M = 47.27$, $SD = 13.07$). The last data collection included 688 participants of the previous wave (315 women and 373 men, aged range from 20 to 55 years, $M = 48.45$, $SD = 12.88$).

The participants responded using a 9-point scale, where 1 meant “strongly agree” and 9—“strongly disagree”. The following indicators of the growth of technological entrepreneurship were taken by OECD (1995), where the study assigned them as the explained variable: demand for new technology (Pred1), high level scientifically (Pred2), quick diffusion of technological innovations (Pred3), short lifecycle of products and processes (Pred4), needs for pre-incubation and coaching (Pred5), scientific and technology cooperation (Pred6), increasing demand for highly qualified staff (Pred7), creating new needs (Pred8) and high level of capital expenditure and investment risk (Pred9). Survey responses were adopted as the explanatory variable: junior management (Per1), middle

management—coordinators (Per2), senior middle management—department management, main specialists (Per3) and senior management—department management (Per4). The participants were asked to indicate their judgment these technological solutions on a scale from 1 (identify improvement in the predictor) to 9 (not identify improvement in the predictor). The study showed mean value of all items in the analyses. The scale was correct in all four waves. “Do turbulent environmental conditions caused by COVID-19 favor the growth of predictors of technological entrepreneurship development?” The participants were asked to indicate their attitude towards these technological solutions on a scale from 1 (It should be growth) to 9 (it should not be growth). The mean value of all the items was used in the analyses. The scale had good reliability in all four waves: T1: $\alpha = 0.85$; T2: $\alpha = 0.87$; T3: $\alpha = 0.90$; and T4: $\alpha = 0.93$. The α -Cronbach’s satisfactory reliability of the scale of the studied correlation between the variables is 0.7.

The development of technology entrepreneurship was measured with nine items, based on [36,62]. Examples of items include the following: Does the level of predictor activity depend on the location of the regional enterprise? T1: $\alpha = 0.86$; T2: $\alpha = 0.90$; T3: $\alpha = 0.90$, and T4: $\alpha = 0.89$. The next item was measured: “Does the company decide to still a high level of capital expenditure and investment risk despite the epidemic? T1: $\alpha = 0.87$; T2: $\alpha = 0.86$; T3: $\alpha = 0.88$, and T4: $\alpha = 0.90$. Another important item is: Does the company look for technological competitive advantages more intensively during the COVID-19 epidemic? T1: $\alpha = 0.64$; T2: $\alpha = 0.71$; and T3: $\alpha = 0.71$. The final step involved reanalyzing the three waves with covariates and comparing answers for strength and number predictors (Tables 1 and 2).

Table 1. EN-CLPM models chosen parameters.

Model	χ^2	Df	<i>p</i>	AIC	SRMR	RMSEA	CFI
FP ↔ Pred1	72.905	24	<0.001	21,465.231	0.04	0.05	0.98
FK ↔ Pred2	67.347	21	<0.001	28,942.849	0.03	0.04	0.99
FM ↔ Pred3	51.436	13	<0.001	31,375.562	0.02	0.03	0.99
FO ↔ Pred4	27.854	11	<0.001	24,349.436	0.03	0.02	0.99
FP ↔ Pred5	68.508	9	<0.001	18,232.142	0.04	0.05	0.99
FK ↔ Pred6	50.345	8	<0.001	19,365.945	0.03	0.05	0.99
FM ↔ Pred7	18.674	9	<0.001	17,856.564	0.02	0.02	0.98
FO ↔ Pred8	14.197	10	<0.001	16,834.859	0.03	0.03	0.98
FO ↔ Pred9	16.654	8	<0.001	14,306.166	0.04	0.03	0.98

Note: FP—planning function, FK—manage function, FM—motivating function, FO—control function, Pred1—demand for new technology, Pred2—high level scientifically, Pred3—quick diffusion of technological innovations, Pred4—short life cycle of products and processes, Pred5—needs for pre-incubation and coaching, Pred6—scientific and technology cooperation, Pred7—increasing demand for highly qualified staff, Pred8—creating the new needs, Pred9—high level of capital expenditure and investment risk.

Table 2. EN-CLPM models chosen parameters with covariates (age, sex).

Model	χ^2	Df	<i>p</i>	AIC	SRMR	RMSEA	CFI
FP ↔ Pred1	223.874	77	<0.001	38,938.439	0.04	0.05	0.98
FK ↔ Pred2	201.843	77	<0.001	44,024.066	0.02	0.04	0.99
FM ↔ Pred3	174.372	45	<0.001	39,495.943	0.05	0.04	0.99
FO ↔ Pred4	149.323	38	<0.001	43,853.177	0.05	0.05	0.99
FP ↔ Pred5	176.806	44	<0.001	37,473.639	0.04	0.03	0.99
FK ↔ Pred6	148.345	36	<0.001	40,249.548	0.04	0.04	0.99
FM ↔ Pred7	97.644	23	<0.001	33,040.542	0.03	0.03	0.98
FO ↔ Pred8	98.875	24	<0.001	27,406.154	0.04	0.03	0.99
FP ↔ Pred9	96.562	22	<0.001	28,549.547	0.04	0.02	0.98

Note: FP—planning function, FK—manage function, FM—motivating function, FO—control function, Pred1—demand for new technology, Pred2—high level scientifically, Pred3—quick diffusion of technological innovations, Pred4—short life cycle of products and processes, Pred5—needs for pre-incubation and coaching, Pred6—scientific and technology cooperation, Pred7—increasing demand for highly qualified staff, Pred8—creating the new needs, Pred9—high level of capital expenditure and investment risk.

4. Results

4.1. Theoretical Results

At the level of managerial positions, a significant correlation was found between random factors of intersection of the demand for new technology and the planning area, which means that managers from the planning area reported a higher level of readiness for new technologies than managers from the area of organizing, motivating or controlling in four measurement waves. The study examined systematic patterns of attrition by comparing incomplete responders ($n = 970$) with complete responders ($n = 687$) on key demographic variables and the most important variables used in the models. The incomplete sheets were considered irrelevant. Complete responders were men rather than women, $\chi^2(1) = 10.97, p = 0.001$. These were older than incomplete responders, $t(970) = -6.04, p < 0.001$. No significant differences were observed according to the rest of variables used (Wave1): $t(970) = -0.09, p = 0.93$, demand for new technology: $t(970) = 1.31, p = 0.19$, high level scientifically: $t(970) = 0.05, p = 0.96$, perceived efficacy of technology: $t(970) = 1.68, p = 0.09$; quick diffusion of technological innovations: $t(970) = -0.557, p = 0.59$; high level of capital expenditure and investment risk: $t(970) = 0.013, p = 0.98$. Hence, the assumed missing data in analyzed variables can be showed as missing at Intercept only if demographic variables are included in the model. A confirmatory factor analysis (CFA) was conducted based on the results presented in the first wave. The analyses were compatible with the prepared structure of measures, the model fit was accepted: $\chi^2(125) = 694.168, RMSEA = 0.05, CFI = 0.91, SRMR = 0.06$. Based on the modification indices correlations were added between two error terms in nine scales: demand for new technology (Pred1), high level scientifically (Pred2), quick diffusion of technological innovations (Pred3), short lifecycle of products and processes (Pred4), needs for pre-incubation and coaching (Pred5), scientific and technology cooperation (Pred6), increasing demand for highly qualified staff (Pred7), creating the new needs (Pred8) and high level of capital expenditure and investment risk (Pred9).

Invariance tests were carried out to confirm the structure of measures in all four waves. For evaluating model-fit across models, it also used such criteria as: RMSEA, SRMR, CFI and TLI. Each model met the required criteria. In support of measurement invariance, $\Delta CFI, \Delta RMSEA$ and $\Delta SRMR$, analyzed across all models, were no greater than 0.014. The study analyzed the robust maximum likelihood estimation (MLR) to account for non-normally distributed data. The results of the model (see Table 3) have improved when the next predictors were added ($\chi^2(8) = 10.32, p = 0.24, CFI = 1.00, RMSEA = 0.02$). This was due to a mistake. In order to understand the causes and strength of the relationship between the variables, three EN-CLPMs were modeled in order to examine the management function: planning function (FP), manage function (FK), motivating function (MF), control function. Nine predictors of these functions were analyzed. Table 1 presents model EN-CLPM for the predictors: demand for new technology, high level scientifically, quick diffusion of technological innovations, short lifecycle of products and processes.

Table 3. Results—comparison of RI-CLPMs with and without moderation effects.

Model	χ^2	Df	$\Delta\chi^2p$
FP ↔ Pred1			
1. Perceived efficacy—no mod.	83.278	38	-
2. Perceived efficacy—mod.	76.154	34	x
1. Not relevant—no mod.	73.281	46	-
2. Not relevant—mod.	69.568	32	x

Table 3. Cont.

Model	χ^2	Df	$\Delta\chi^2_p$
FK ↔ Pred2			
1. Perceived efficacy—no mod.	62.672	38	-
2. Perceived efficacy—mod.	54.075	35	x
1. Not relevant—no mod.	60.786	32	-
2. Not relevant—mod.	57.879	28	x
FM ↔ Pred3			
1. Perceived efficacy—no mod.	12.085	13	-
2. Perceived efficacy—mod.	14.765	12	x
1. Not relevant—no mod.	39.875	14	-
2. Not relevant—mod.	32.987	10	x
FO ↔ Pred4			
1. Perceived efficacy—no mod.	17.097	16	-
2. Perceived efficacy—mod.	15.983	14	x
1. Not relevant—no mod.	18.983	17	-
2. Not relevant—mod.	32.987	15	x

Note: FP—planning function, FK—manage function, FM—motivating function, FO—control function, Pred1—demand for new technology, Pred2—high level scientifically, Pred3—quick diffusion of technological innovations, Pred4—short life cycle of products and processes; no mod.—no moderation effects, i.e., cross-lagged effects constrained across groups, mod.—moderation effects.

Models with nine predictors were analyzed in four waves. Maximum likelihood estimation (MLR) was used to account for non-normally distributed data. The robust maximum likelihood procedure (FIML) was used to deal with missing values. All models indicated good fit to the data (see Table 1). The added covariates did not change the models' parameters (see Table 2).

The factors of models included in the correlation analysis are management functions and demand for new technology. Results present that there is a weak positive relation between management functions and manager's technological preferences [63]. These findings show that during COVID-19, firms changed their management habits using digitalization to respond to the pandemic [64]. This result shows that managers turned to the use of new technologies as a means of surviving the crisis. At the level of managerial positions, a significant correlation was found between random factors of intersection of the demand for new technology (Pred1) and the planning area, which means that managers from the planning area reported a higher level of readiness for new technologies than managers from the area of organizing, motivating or controlling in four measurement waves. The results showed a mutual, two-way relationship between demand for new technology (Pred1) and managers from the planning area (FP), high level scientifically (Pred2) and managers from manage function, quick diffusion of technological innovations

(Pred3) and managers from motivating function—short lifecycle of products and processes (Pred4) and managers from control function—short lifecycle of products and processes.

4.2. Practical Results

The companies changed their plans in terms of diversifying their product portfolio, suspending existing research and R&D implementation. The time of the epidemiological crisis ranked predictors different from the rules adopted over the years. New technologies were always preferred, being created in a long process of cooperation with scientists from universities, where having looked for their need, an investment expenditure was estimated and a risk was minimized.

In the four-wave panel study, managers indicated the implementation of new technologies (Pred1) as the most important predictor of the development of technological entrepreneurship during the epidemic (see Table 1). At the same time, the model showed that it is decreasing or still constants interest in the predictors of entrepreneurship growth from Pred1 to Pred2 from control area managers (FO). The relationship between the predictors and the degree of development differs in managerial positions. The lower the managerial rank, the less interest in growth predictors with each wave of the survey (from Wa1 to Wa4). It is important that predictors were dropped in the first wave (Wa1): scientific and technology cooperation (Pred6), increasing demand for highly qualified staff (Pred7). The next wave (Wa2) did not include: short lifecycle of products and processes (Pred4), needs for pre-incubation and coaching (Pred5). In the third wave (Wa3), the following predictors were often not included: high level scientifically (Pred2), quick diffusion of technological innovations (Pred3). Predictors that in the fourth wave (Wa4) were important by managers: demand for new technology (Pred1), creating the new needs (Pred8), high level of capital expenditure and investment risk (Pred9). The indications of the managers at the organizing level indicate a significant dependence. They considered the predictors related to science circles and universities to be the most important for each of the research waves (from Wa1 to Wa4), i.e., high level scientifically (Pred2), high level scientifically (Pred2), scientific and technology cooperation (Pred6), increasing demand for highly qualified staff (Pred7). The non-scientific predictors of technology entrepreneurship were given little weight. Managers of the motivating level indicated that the following predictors have a strong influence on the development of technological entrepreneurship: quick diffusion of technological innovations (Pre3), short lifecycle of products and processes (Pre4), needs for pre-incubation and coaching (Pre5). They pointed to the insignificant ones: increasing demand for highly qualified staff (Pred7), scientific and technology cooperation (Pred6), or high level scientifically (Pred2), demand for new technology (Pred1), creating the new needs (Pred8), high level of capital expenditure and investment risk (Pred9). To show in which trend the effect was stronger, the unconstrained model fit was compared with the model constrained on the directional cross-lagged parameters.

The constrained model had reduced model fit, $\Delta\chi^2(1) = 8.91, p < 0.001$, suggesting no equality between the two waves (see Table 3). Managers in Wa1 i Wa2 indicated the same predictors and their strength. There were no significant differences in the model.

5. Discussion

Since the start of the pandemic, many authors have debated how technology, artificial intelligence, machine science and science contributed to the fight against COVID-19 [38,49]. Remembering previous correlational studies, there was an important correlation between technology and many levels of analysis. At the personal level, Shane [42] addresses the importance of prior research. Colombo and Grilli [65] show the significance of human capital of the predictor growth of new technology-based firms. Such antecedents as Marino [66,67] found that personal characteristics, human capital and technological competences and managerial skills are required by technology entrepreneurs. The previous studies also showed that, for example, specific opportunities and packages of opportunities are required for managers by various team technology categories, other strategic intentions focus on

the industrial sector [68–70]. However, none of the researchers took into account the development of technology entrepreneurship in the extraordinary conditions of the epidemic. This study extends the existing international research in the field of development factors of technological entrepreneurship with the aspect of managerial decision making in the time of COVID-19 [71].

The latest technology entrepreneurship phenomenon during COVID-19 was driven by technological assets to information and communication technologies by Internet [1,46,72,73]. An important result of the four-wave test is the answer to the research question indicated in the introduction. The indication of managers of various business activity affected by the economic crisis brought about by the COVID-19 epidemic does not reduce the role of growth predictors in the process of running a business. In epidemic times, technology companies are looking for competitive advantages based on new technologies (Pred1), which in a short time will allow them to maintain an economic balance (Pred3, Pred4) and survive the crisis caused by COVID-19. This outcome is also in line with that of Shane [42], who found that the spread of this new technology creates a competitive advantage. Development opportunities, such as the transfer of assets, services or the improvement of organizational processes, offer a field for technological entrepreneurship [50,67]. One important result of the research is the different prioritization of growth as the epidemic develops. Gartner, Maresch and Fink [62] developed integrated prioritization of predictors of technological entrepreneurship recovery and used it for evaluating the results of additive manufacturing. In COVID-19 days, numerous restrictions caused economic downturns in most of the world in the years 2020–2022, while digital entrepreneurship saw rapid growth [73–76].

The lack of a transparent future and a clearly defined end date for COVID-19 caused managers to deviate from the choice of technologies that could be developed with universities in the long run (Pred 5, Pred6). They also protected budgets of companies against a high level of capital expenditure and investment risk (Pred9). The literature shows that entrepreneurial technology thrives in uncertain times and increases the risk appetite [58,77]. This research is in agreement with Modgil et al. [78]. Their research observed various factors that opening to innovation and show how the innovation is perceived better than the current programs or products. In accordance with predictions, the demand for technology and new innovative products grew with each wave of research and this was known as the basic predictor of development during COVID-19. The article by Colovic and LaMotte [79] explores predictors of entrepreneurship development at the national level of such technological environment as R&D investments, ICT access and infrastructure. By using EN-CLPM, the research extended the previous correlational results by showing that the relation between predictors of development and the managers' decisions is not only present at the between-subject level, but also at the within-subject level, thus giving preliminary evidence for the reasons of this relationship [77].

As a result of limited opportunities for running a business, a decline in revenues and isolating employees, creating the new needs (Pred8) was observed during four waves of the conducted research. Technological solutions were given to still running business activity [48]. It is also important that during the research, technology companies developed innovative solutions and products for their needs, resulting from COVID-19 [44]. Then they sold these solutions to the market as innovative products and services. The international economic crisis triggered by COVID-19 has created an increased demand for innovative products and services to advance business and the diffusion of innovation on a large scale. Managers repeatedly indicated in the surveys that their companies report the need for innovations from the market, but at the same time act as creators of new technological solutions [22,69,70]. The research incorporated an advanced longitudinal analysis to investigate inter-municipal causality and individual aspects and attitudes towards technology. It was particularly interested in relationships between managers of chosen management function in identifying significant predictors of technology entrepreneurship growth over time.

All these factors could impact the manager's perception of the COVID-19 threat and may be associated with a different business response, such as a greater or lesser tendency to involve in business needs for technological innovation [71,80].

6. Conclusions

This paper presents both theoretical and practical implications for research concerns with regard to the predictors of the development of technological entrepreneurship. The conducted research aimed to estimate the significance of their impact on increasing the development opportunities of enterprises that have been using technology for many years. The time of the epidemiological crisis ranked predictors differently from the rules adopted over the years. Invariable preference was given to new technologies which were created in a long process of cooperation with scientists from universities, where insights were made into the needs, then investment expenditure was estimated and the risk was minimized. The conducted research showed that, companies need fast, effective and cheap technological solutions in the period of crisis, although these solutions are often burdened with a lower success rate. In recent years, the phenomenon of technology entrepreneurship has become an unfathomable topic of interest of researchers that recognized its positive effects even during a crisis. One practical implication, taking into consideration that technology entrepreneurship and innovation are facets of innovative entrepreneurs sector, is the need for a holistic approach to support development during the international economic crisis. The next practical implication resulting from the crisis may not make it easier for entrepreneurs to explore new opportunities for technology development. Moreover, such an epidemic shock as COVID-19 may have an impact on technology entrepreneurial opportunities. The companies changed their plans to maximize the crisis by implementation new products. Thus, the expectations of managers in terms of improving the situation in the company during the epidemic relate to innovative solutions that will contribute to cost reduction, where the reduction in labor costs seems realistic and appropriate. This study shows that still openness to change and looking for technology chances, creativity, the ability of these firms to take risks, focus on the future have a positive impact on the company's results.

In addition, this paper obviously contributes to the technology entrepreneurship literature by giving an empirical results for study that advances a new perspective on the process of developing new technologies in the period of crisis. Technology entrepreneurship can be show as looking for technology chances, but also going away from technological managers' decisions. Such paths have primarily been showed as different events, where individuals with prior research discover a new chances within the crisis economy. This paper shows a new insight into the behavioral theory through its application in describing the cognitive role of technological entrepreneurship growth predictors during the epidemic crisis. With the far-reaching relevance of this study to the entrepreneurial literature, there are some gaps that arise from it. Thus, research is not free from limitations. One of them is the limitation of this research to one country—Poland only—and solely to managers from the energy industry. The next gap is situation, that polish energy sector considered strategic, when owner is in around 98% of the state treasury company. It can also be argued that conclusions drawn from the Polish experience are largely generalizable for many other industries and countries with comparable stages of pandemic development. However, this choice was guided by theoretical and practical considerations discussed in the article. Therefore, future studies could undertake a comparison between making an in-depth analysis of new technological solutions applied by companies in correlation to the functions of science management in the period of epidemic crisis.

In conclusion, the empirical results of this research contribute to the growing amount of literature that aims to provide the basis for the popularization of current, concentrated technological entrepreneurship growth predictors, even in the period of such an emergency as the COVID-19 epidemic.

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