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THE IMPACT OF THE COVID-19 PANDEMIC ON DIGITAL TECHNOLOGY DIFFUSION

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ABSTRACT

The present paper looks at the COVID-19 external shock impacts on the diffusion of digital technologies for business continuity including videoconferencing, digital logistic services, telehealth services, e-commerce, online entertainment services and cybersecurity. The study reveals that COVID-driven digital trends differ in terms of character of technological diffusion and its dynamics. Some technological areas; i.e. e-commerce and online entertainment diffused only at the late stages of the pandemic while such specialized solution as telehealth have been more impacted by the short-run external shock. Telehealth-related technologies remain less adopted in practice despite significant growth in academic and professional media discussion.

Keywords: COVID-19, digital technologies, digital technology diffusion
JEL Classification: O30, O33, O39

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1. Introduction

The COVID-19 pandemic further triggered diffusion of digital technologies in the economy and the social sphere. Companies were forced to move towards a more active implementation of digital technologies in key business processes and adjust business models especially by means of switching to remote sales channels and remote work models due to regulatory restrictions resulting from the pandemic. In that digital technologies have ensured the resilience of many companies in a crisis and created their new competitive advantages [Papadopoulos et al., 2020]. The innovative businesses potential was partially redirected to the creation of effective solutions fighting COVID-19 social and economic consequences. Thus, COVID-19 pandemic is understood to act as an accelerator for digitalisation in many industries including online learning and teleworking, e-commerce or telehealth [Oldekop et al., 2020].

It's rather obvious that discussion in different communities – be it purely academic communities, industrial communities or also public debates even in the yellow press – show a clear focus on the pandemic and related consequences for business and daily life of people. Here digital technologies are a means of preserving the life of individuals in one way or another with a clear focus in interaction between individuals. Thus, communication-related technologies are viewed as especially important ones. At the same time all these technologies are nothing new but exist as technologies for many years. The question is now what had to happen that these technologies were applied hence diffusion speed accelerating. There is long discussion in the academic community that technologies which are ready in a technical sense and highly appreciated by developers and users do not make it into broad and widespread application by users. The reasons for that are manyfold, very likely this is referred to users would have to leave their private comfort zone if they were to adopt new technologies. But this is hardly a new phenomenon – it's the same for many technologies which are changing peoples' routines. That's not saying all technologies, the Apple example with the ipod two decades ago - followed by a whole family of devices based on the same principle - was well received by people although it changed their routines in one way and the other. But the changes imposed by these technologies were rather marginal compared to technologies changing work routines towards enabling remote work or influencing healthcare through telehealth and similar. Such changes have a direct impact on people and likely more important on the interaction between individuals. Having said that it's rather unlikely that technologies aiming at impacting the interaction between individuals and thus the social systems will be adopted at large scale without significant pressure on individuals. The pandemic appears to be such an unexpected event putting people under pressure to adopt the technologies as of a sudden. The paper therefore investigates the tendencies in digital technology diffusion which

emerged in light of the COVID-19. The COVID-19 pandemic is considered an external shock (or one might say event) which caused regulators imposing restrictions on people daily routines in many facets. In order to comply with these digital technologies suddenly were used (or had to be used). The paper covers the following areas:

- revealing technological areas which have been the most impacted by the pandemic;
- researching dynamical changes in the significance on the technological areas in pre-COVID and COVID periods;
- identifying specifics of the pandemic impact in some technological areas on the example of the telehealth case.

In this way, the first section of this paper (Literature review) contains an overview of the recent studies on the digital technologies implementation to combat COVID-19. The second section (Methodology) represents the approach to reveal main directions of the pandemic influence on the use of digital technologies big data semantic analysis. The third section (Findings) includes three analytical blocks: 1) the comparison of technological areas in terms of their significance during the COVID-19; 2) the study of the external shock impact on digital technologies diffusion in dynamics according to COVID-19 hype waves; 3) the observation of the specifics in diffusion of some technological areas on the case of telehealth. The Discussion section is dedicated to interpretation of some results, limitations of the study and potential further research in the field. The last section (Conclusion) presents the main analytical results of the research.

2. Literature review

The COVID-19 pandemic dramatically increased the importance of digital technologies since many of them were used as a mitigating measure to overcome the crisis. Notably, Pandey and Pal (2020) argue that the pandemic and the resulting increase in digital technology diffusion speed forced companies and educational institutions to switch to remote work services. Likely, Nagel (2020) investigated that the COVID-19 has accelerated the shift to distant form of work which will be probably a more reliable source of income then before the pandemic. Furthermore, Soto-Acosta (2020) points out the vital role of digital transformation and innovative supply chains in avoiding long-term negative consequences of the pandemic such as unsatisfied demand for certain products.

Regarding different technological areas, some of them are actively analysed in academic studies as responses to the pandemic. Artificial intelligence (AI) is likely to be commonly used technology to combat the pandemic in various application areas. Dwivedi et al. (2020) claim the

essential role of AI-related solutions in providing more informed crisis management during the pandemic. Moreover, Jin et al. (2020) presented the research, illustrating use cases of AI deep machine learning in medical image testing and COVID-19 cases detection. However, other researchers pay attention to insufficient maturity of most AI-based systems to demonstrate visible effects to combat the COVID-19 [Naudé, 2020; Bullock et al., 2020]. Likewise, Adly et al. (2020) point out that AI-based solutions need massive investments to show more effectiveness in the fight against the pandemic.

Papadopoulos et al. (2020) found the use of digital technologies for guaranteeing business continuity as an important part of SME's managerial strategy during the pandemic. Mhlanga and Moloi (2020) examine how the lockdown measures have contributed to the shifts in educational sphere. Also, Budd et al. (2020) concluded that digital technologies support traditional public responses to the pandemic, being an important factor in comprehensive mitigating measures against the COVID-19. In the field of logistics and transportation Singh et al. (2021) present a model of the truck- and drone-based integrated delivery system to ensure food supply chain to infected zones. Researchers like Sigala (2020) and Gretzel et al. (2020) explore the issues related to COVID-19 and its effects on digital tourism, both agree about transformative character of the pandemic for the tourism industry.

Abdelhrim and Elsayed (2020) explored the pandemic effects on world leading e-commerce companies. Chand and Meyerhoefer (2020) found a correlation between increase in cases on COVID-19 and increase in e-commerce sales and in number of customers.

Aforementioned Pandey and Pal (2020) investigated an increasing need in cybersecurity and confidentiality solutions, provoked by a global shift to distance work services. Likewise, Andrare et al. (2020) presented an analysis of cybersecurity attacks illustrating that COVID-19 stimulated changes in the dynamics of cybersecurity services due to an increase in teleworking.

Other studies explore the impact of COVID-19 on the digital technology diffusion in healthcare as a most impacted industry, in particular telehealth solutions. The study by Wong et al. (2020) shows an increased demand for telehealth solutions as well as for scaling up their capabilities. Broad research by Koonin et al. (2020), also revealed an increase in demand on such services over the first 3 months of the outbreak. Wosik et al. (2020) focus on the role of the telehealth services in transformation of healthcare delivery and demonstrate that the pandemic has stimulated fast adoption of telehealth. Hirko and al. (2020) likewise found that the pandemic provoked changes in telehealth, which has increased acceptance among medical professionals and patients. Unlike, new research by Medigan et al. (2021) concludes that telehealth requires considering appropriateness based on confidentiality and patient need and can't be applied as panacea.

Despite a wide range of literature on the pandemic, a number of gaps related to the spread of digital technologies could be revealed:

- Firstly, there is a lack of studies focusing on medium range changes in digital technologies (as their majority were conducted in 2020), thus the period of 2021 remains under-explored (also due to time lag between research and publication).
- Secondly, although the aforementioned studies examine various dimensions of the topic, there is a lack of research papers, carrying out a comparative research of the COVID-19 external shock impact on digital technologies, being applied as the COVID response, so the research gap would be filled by examining comparative digital solutions development, showing differences in their dynamics over the period of the outbreak.
- Finally, in the context of digital technologies application in the studies lack empirical results, which can give important implications for the factors, contributing the technological areas dynamics and diffusion. Thus, the research gap can be filled by investigating the specifics of the digital technologies use by industry professionals, with the focus on obstacles to overcome.

In view of the above the following research questions are posed:

1. What technological areas are driven the most by the COVID-19 pandemic external shock?
2. How the dynamics of digital technology diffusion has been changing over the period of the pandemic?
3. What are the specifics in the character of diffusion of different digital technology and technological solutions?

3. Methodology

The methodological approach referring descriptive research consists of two major parts. The first part of the study is based on the semantic big data analysis, carried out in order to identify and compare significance and dynamics of the various technological areas, impacted by the COVID-19. The research is carried out by means of the intellectual big data analytical system developed in the Institute for Statistical Studies and Economics of Knowledge of the National Research University Higher School of Economics (ISSEK HSE) – iFORA (Intelligent Foresight Analytics) [Gokhberg et al., 2020]. The second part is dedicated to the findings of the expert survey, referring the COVID-19 impact on the use of telehealth solutions.

Semantic big data analysis

Semantic big data analysis includes following steps:

1) preparing keywords list including specific pandemic-related terms in different technological areas (Annex 1);

2) big data intellectual search, multiplication, clustering and quantitative assessment (significance and dynamics indexes calculation).

Initially, to prepare the keywords list the authors used the structural elements (framework) of the OECD OPSI COVID-19 Innovative Responses database [OECD OPSI, 2020]. The database structure is relevant to the present study as it aggregates digital solutions widely used after the pandemic broke out. Its categories were implemented as a basis for the keywords list development. Among others such issues as health and security solutions, real-time data collection, sharing tools, communication, connectivity solutions and others were included. On the next step, the sampling of keywords was corrected taking into consideration the academic papers analysed according to the scope of this research. Thus, the final sampling of terms includes specialised digital solutions, products and services relevant in the context of the COVID-19 pandemic. On the final step the keywords were checked out in the multiplier of scientific and technical terms of the iFORA system, which performs the function of validation of keywords [Nazarenko et al., 2021].

Finally, based on the results of compiling a database of keywords, more than 50 specialized terms were collected and uploaded to the iFORA system interface. The text-mining system has clustered keywords based on their semantic proximity and added semantically similar terms. In more details the process of clustering performed by iFORA is described in papers by Bakhtin et al. (2021) et al. and Saritas at al. (2020). As a result of iFORA calculations, a final list of technological areas was extended to more than 150 terms (presented in Annex 2) and classified into 7 clusters (distinguished automatically), which is a sufficient basis for further analysis.

Information sources used for the research include more than 170 thousand documents extracted from the target corpus referring to professional media, published from December 2019 - till 2021. The target corpus (including industry-related media, professional business media and companies official press releases related to digital technologies) is characterised by the following features [Saritas et al., 2021]:

- topics presented in publications from the iFORA database are related to digital technology;

- a wide readership, not limited by the professional interests of the audience;

- new publications are issued at least once a week (the parameter is set in accordance with the requirement for data relevance).

The final list of terms built the basis for the further semantic big data analysis, calculation of quantitative metrics and creation of visualisations, that allow identifying promising development trends and assessing the dynamics of their significance [Nazarenko et al., 2021].

1) **Significance** refers the intensity of mentioning a topic in documents in the analysed area. The higher the value, the more strongly the corresponding topic is presented in the analysed documents [Calof et al., 2020].

$$\mathrm{FREQ} = \sum_{i=1}^{T} f_i,$$

where

FREQ – an indicator of significance,

f_i – the frequency of occurrence of the term in the year i,

T – the period of years, i = 1,…, T.

2) **Dynamics** relates to the average annual growth rate of significance [Nazarenko et al., 2021]. Dynamics as a relative increase in the total occurrence is determined by the formula:

$$\mathrm{AAGR} = \frac{1}{T}\left(\frac{\sum_{i \geq T/2} f_i}{\sum_{i \leq T/2} f_i} - 1\right),$$

where

AAGR – an indicator of dynamics,

f_i – the frequency of occurrence of the term in the year i,

T – the period of years, i = 1,…, T.

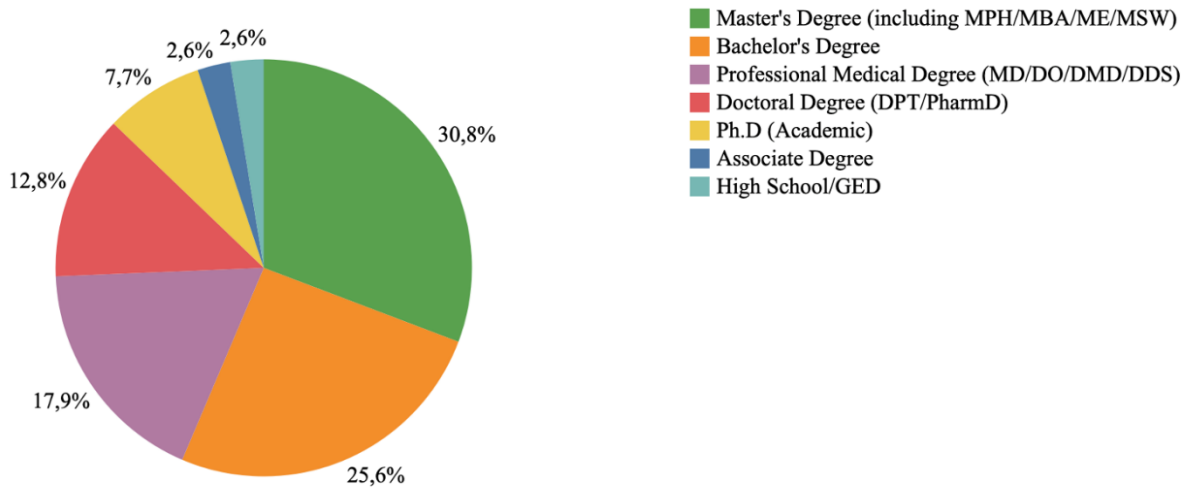
Based on the results of big text data analysis, the most dynamic and significant technological areas were selected. In order to rank and categorise the services technological areas, the results of big text data analysis were normalised from 0 to 1 (both dynamics and significance indexes). The overall score is the sum of dynamics and significance normalised scores in each service. The obtained results allow to identify and compare the most affected by the pandemic digital applications and thus investigate technological changes during the COVID-19. In addition, big text data from iFORA documents database over the period from January 2020 to August 2021 were also studied in dynamics.

The approach based on iFORA intellectual big text data analysis of professional media document corpus is applicable for studying market forecasts and analytics to describe technological diffusion [Calof et al., 2020]. Findings obtained with iFORA system can approximate the market shifts in given area and used for technological trends implications. Particularly, iFORA system was used as a research tool in papers aimed to study business trends in various sector of the economy (agriculture and food sector by Gokhberg et al. (2019); mobile commerce by Saritas at al. (2021); and extractive industries by Gokhberg et al. (2020).

Expert survey

The second part of the research focuses on telehealth case study. It comprises the results of the healthcare experts' survey about the impact of the COVID-19 on performing their duties and the role of digital technologies in it. The telehealth was chosen as a field to study taking into account findings of big text data analysis. In this context, the survey broadens the understanding of conditions under which telehealth diffuses during the pandemic. The sample includes experts from about 40 organisations, mostly from the USA (69%), Switzerland (13%), the EU countries (10%) and the UK (8%). Respondent's list includes healthcare workers, engaged in clinical work, managerial, research activities as well as medical trainees. In more details, the sample includes the following categories of respondents by the field of occupation: 20 clinicians (51%), 7 management workers (18%), 6 medical trainees (16%), 5 researchers (13%) and 1 social worker (3%). Another selection criterion refers to the obtained degree of respondents which should be associate degree, bachelor's degree, master's degree (including MPH/MBA/ME/MSW), PhD, Professional Medical Degree (MD/DO/DMD/DDS) or Doctoral Degree (DPT/PharmD) (Figure 1). Highly qualified medical professionals from both public and private healthcare organizations took part in the survey.

Figure 1. The distribution of surveyed experts by obtained degree



Source: authors' elaborations based on expert survey results.

The survey was conducted in April-June 2021 in an online-format. A questionnaire contains 3 sections (Annex 3): general personal information, opinion on the impact of the pandemic on the day-to-day job and experience of the use of telehealth solutions during the COVID-19 outbreak. Respondents were asked about the changes in frequency of the use of telehealth after the pandemic and in the quality of patient care.

4. Findings

Evidently, in the face of the pandemic, business and individuals were forced to implement digital technologies more widely. On closer look the effects of the pandemic external shock were unevenly distributed (both in short and in a longer run) across technological areas. In order to evaluate impacts and reveal some patterns, 7 technological clusters were identified and investigated. Some of them were quite widespread even before the pandemic, among them E-commerce, digital logistics, online entertainment, cybersecurity. Others presented rather narrowly focused or niche areas such as videoconferencing, business continuity services or telehealth. Despite all these technological areas are not new and were not created by the pandemic, the COVID-related conditions have a strong impact on the nature of their dynamic diffusion. Moreover, the post-COVID character of the technology diffusion is highly dependent on their adoption before the pandemic. So far, the research task was to reveal most impacted areas in terms of shifts in their significance according to semantic big data analysis.

To further investigate divergences in post-pandemic diffusion of this technological areas authors examined their development in dynamics. Short-run trends are already observable and can be evaluated. Over the first months of the pandemic, the interest towards digital technologies jumped up as they are considered a part of a COVID-19 response, keeping social economic process continued. However, long-term trends are still debatable as COVID-related environment is constantly changing; new variants of the virus, vaccines promotion and regulatory changes may influence the diffusion of certain digital technologies over a long run. Thus, investigation of medium-term trends might give insights and suggestions for understanding long-term shifts.

Considering the character of technology diffusion, besides direct COVID-19 effects, internal sector-specific conditions should be taken into consideration. Some factors determining the patterns of technological diffusion are dependent on how the field reacts and adopts to the pandemic conditions. In this context, the analysis of the adoption specifics of narrowly focused areas like telehealth might give the insights for the whole landscape of technological diffusion during the pandemic

4.1 Increased significance of digital technologies due to the pandemic

All services which were studied can be classified into three large groups, according to their significance and dynamics in the context of the COVID-19 shifts caused by the pandemic (Figure 2 and Table 1). The categorization is based on the overall score of significance and dynamics

which refers to the impact the pandemic external shock has been having on group of technological areas from the beginning of the outbreak till present time.

Table 1. Big data semantic analysis metrics for groups and technological areas

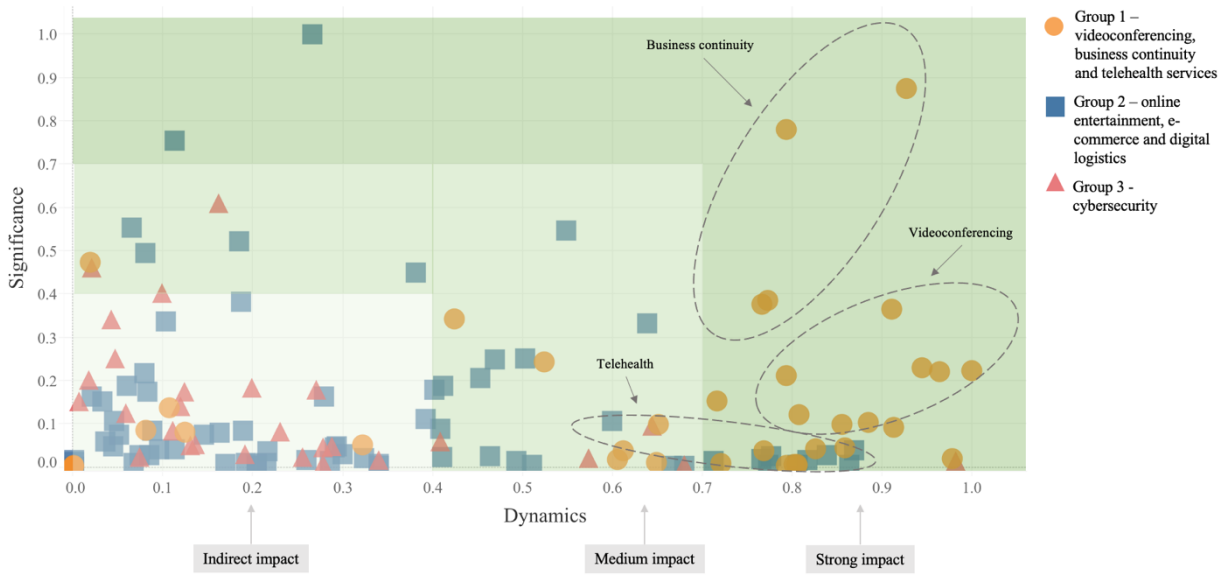
Impact Group	Technological areas clusters	Overall index	Dynamics index	Significance index
1. Strong impact	**Videoconferencing**	0,80	0,68	0,12
	Business continuity services	0,78	0,52	0,26
	Telehealth	0,73	0,70	0,03
2. Medium impact	**E-commerce**	0,53	0,34	0,19
	Digital logistics	0,51	0,42	0,09
	Online entertainment	0,41	0,31	0,10
3. Indirect impact	**Cybersecurity**	0,37	0,23	0,14

Notes: The scores for each service are average normalised values from 0 to 1, thus maximum for dynamics and significance indexes is 1. Overall score is a sum of dynamics and significance normalised indexes. Significance approximates the digital products and services demand, dynamics reflects a relative increase in significance.

Source: authors' calculations based on the intellectual big data analytical system iFORA evaluation.

The first group consists of highly critical services which were suddenly demanded and were extremely dynamic after the pandemic. The second one refers to the services which were mature trends before the outbreak but moderately stimulated by the COVID-19. The third group includes solutions impacted by the COVID-19 indirectly.

Figure 2. Technological areas trend map



Source: *authors' calculations based on the intellectual big data analytical system iFORA evaluation.*

Strong impact

As the COVID-19 have been spreading over the globe, Zoom, MS Teams, Skype, and other similar videoconferencing solutions have become one of the main discussion topics in the mass media and social networks. The findings of the semantic analysis confirm the trend and demonstrate relatively high significance and dynamic speed. In particular, the dynamics score of the videoconferencing tools equals 0,7, which means that the significance parameter has been gone up dramatically since the beginning of the pandemic. For example, Zoom daily meeting participants went up 100 times from 31 December 2019 to 21 April 2020 [Backlinko, 2021]. Monthly downloads of the Skype in France skyrocketed approximately tenfold in March and November 2020, suddenly after the government announced a lockdown [Airnowdata, 2021]. Other popular videoconferencing tool, MS Teams, show explosive growth in downloads in Poland in October 2020, after the second wave of COVID-19 outbreak [AppMagic, 2021].

Another technological area accounts for business continuity solutions such as collaborative platforms, data sharing tools, SaaS, and remote corporate access services. The group of solutions demonstrates high dynamics score, which is about 0,52 and the highest significance score among all services, 0,26. Such a high significance might be determined by the long-term character of the trend. Notably, after been implemented during the outbreak, business continuity solutions that don't need to be removed can be used afterward. Moreover, the pandemic has been influencing the work habits and the way business prefers to operate, in particular, it demonstrated the advantages of remote work. For instance, Facebook changed its work policy, allowing homework to all full-time employees after the pandemic, if job tasks can be done completely in distance [Forbes, 2021]. Thus, the growth in the use of business continuity solutions seems to be a long-term trend, which might be top-of-the agenda after the pandemic.

Telemedicine services include remote monitoring of patients' health status, virtual consultations tools as well as such breakthrough technologies as the Internet of Medical Things (IoMT), robotic medical systems, recommendation systems for making medical decisions, which have become more widespread after the COVID-19 outbreak. The results of the semantic analysis demonstrate the biggest difference between significance and dynamics scores with 0,03 and 0,7 respectively. This means that external shock provoked sharp changes in the telemedicine diffusion, boosting its extensive usage. However, very low significance score means immature nature of the trend.

Medium impact

The second group of technological areas consists of solutions that have been being a mature upward trend even before the pandemic and got an incentive to grow since the outbreak broke out. This explains the middle dynamics score and quite various significance scores over the group. The

category includes e-commerce, digital logistics and entertainment online services. Like videoconferencing tools, this group of technologies has a replacement function of traditional, «in presence» communications and activities.

One of the challenges for the global economy during the pandemic was the disruption of global supply chains. Notably, the pandemic has been interrupting supply chains organised in a leaner manner with a lack of communications between siloed stakeholders [World Bank, 2021]. What is more, the global supply chains disruption threatened vaccine and medical equipment supply, which is essential in the combat against the pandemic. Digital logistics refers to advanced data analysis tools, applied for managing supply chains. One of the pandemic trends in the field of logistics is the growth in the use of Digital Supply Chain Management Systems (DSCMS), forming digital supply networks (DNS), which are more flexible, connected, and visible [Deloitte, 2020]. The results of the big text data analysis demonstrate a large difference between dynamics and significance, which equal 0,42 and 0,09 respectively. The trend seems to be very similar to telehealth diffusion. Low significance score may be determined by the niche character of the services, less hype creation in media unlike videoconferencing or telehealth. Like business continuity tools, digital logistics are seen to be a long-run as once installed, they can be used after the end of the COVID-19.

In case of e-commerce the COVID-19 also had a lasting stimulating effect on the expansion towards business and consumers. The pandemic has accelerated dynamics of the e-commence, first of all, by forcing SMEs to shift to electronic sales. Moreover, such policy measures as introduction of digital currencies, like digital yuan tasting or the concept of digital euro, issued by European Central Bank, also accelerated the growth of e-commerce over the globe. Consumers' purchasing habits have been changed as well, so delivery services became more familiar to the consumers, and more segments got included in e-commerce. The results of the semantic analysis illustrate a moderate dynamics rate and relatively high significance score, 0,34 and 0,19 respectively. The findings allow characterising the trend as mature, since the dynamics is not jumped up since the outbreak, but the services are still very critical for the continuity of economic activities over the world. Despite, retail trade totally went down as the pandemic started, turnover of e-trade approximately doubled in April and May 2020 [OECD, 2020]. In addition, the findings are confirmed by the fact that Google search of «delivery» in OECD countries multiplied twofold since the start of the lockdown measures [OECD, 2020]. Overall, e-commerce as one of the responses to the pandemic seems to be a long-term trend which might keep its transformative effects after the pandemic.

Entertainment online services have been impacted by the COVID-19 outbreak as relatively moderate as e-commerce. The findings of semantic analysis show 0,3 for dynamics score and 0,1

for significance score, which both are not as high as for previous services. The figures also allow considering online entertainment as mature survives, being transformed by the COVID-19 crisis. The pandemic had forced the development of entertainment services in various dimensions. Firstly, the number of users of the services went up dramatically as online entertainment compensates the lack of traditional one and became one of responses to the pandemic fatigue. For example, according to McKinsey research, about 41% of consumers in the UK started to use more online streaming services during the COVID-19 and 5% used it for the first time [McKinsey, 2021]. Secondly, the pandemic provoked not only the growth in the whole segment but also the development of new digital-based models of entertainment. Not only well-known video streaming platforms like Netflix or Amazon have been touches by stimulating effect, but also such niche and developing markets as sports streaming, music and theatre online events, virtual exhibitions, and online museum tours. For instance, the same McKinsey study argues that 12% of the UK consumers watching more e-sports and about 1% just become engaged in it.

Indirect impact

A growth in the use of digital technologies leads to increased cybersecurity risks for all categories of users: business, individuals, and public bodies. In that context, unlike the rest of the services studied, cybersecurity has been impacted by the pandemic indirectly, and address not to the pandemic-based challenges but to mitigate digitalisation side-effects. The findings show the lowest dynamics score, which is equal 0,23 while significance score accounts for 0,14. Increased mentioning of cybersecurity-related topics in the document corpus might be provoked by a set of reasons. Firstly, the cybersecurity risks became a part of an agenda not only for big corporations but also for SMEs, educational institutions and entertainment. For example, estimated spending on cybersecurity worldwide jumped up on approximately 37% in 2020 [Canalys, 2021]. The increased use of digital technologies by new users leads to the need to guarantee data flows security. Secondly, as business continuity tools became a basement for economic activities, critical importance of protecting business continuity infrastructure started to play central role. Finally, cybersecurity is pushed up by the regulatory activities and heated debates in the field of data confidentiality. To sum up, the specifics of the cybersecurity technologies refer to its dependence on the development of other digital services, which might determine how and in what direction cybersecurity will progress.

Thus, each technological area has been affected by the pandemic to varying degrees. The significance of business continuity, videoconferencing and telehealth was boosted the most. Moreover, telehealth services illustrated the highest dynamics (most notable short-run shift). E-commerce, digital logistics and entertainment online services were already relatively mature and widespread trends and have been less influenced over the pandemic period. Cybersecurity seems

to be the least affected by the COVID-caused conditions. In order to better understand the nature of changes, technological diffusion should be investigated in dynamics.

4.2 External shock impact on digital technologies diffusion

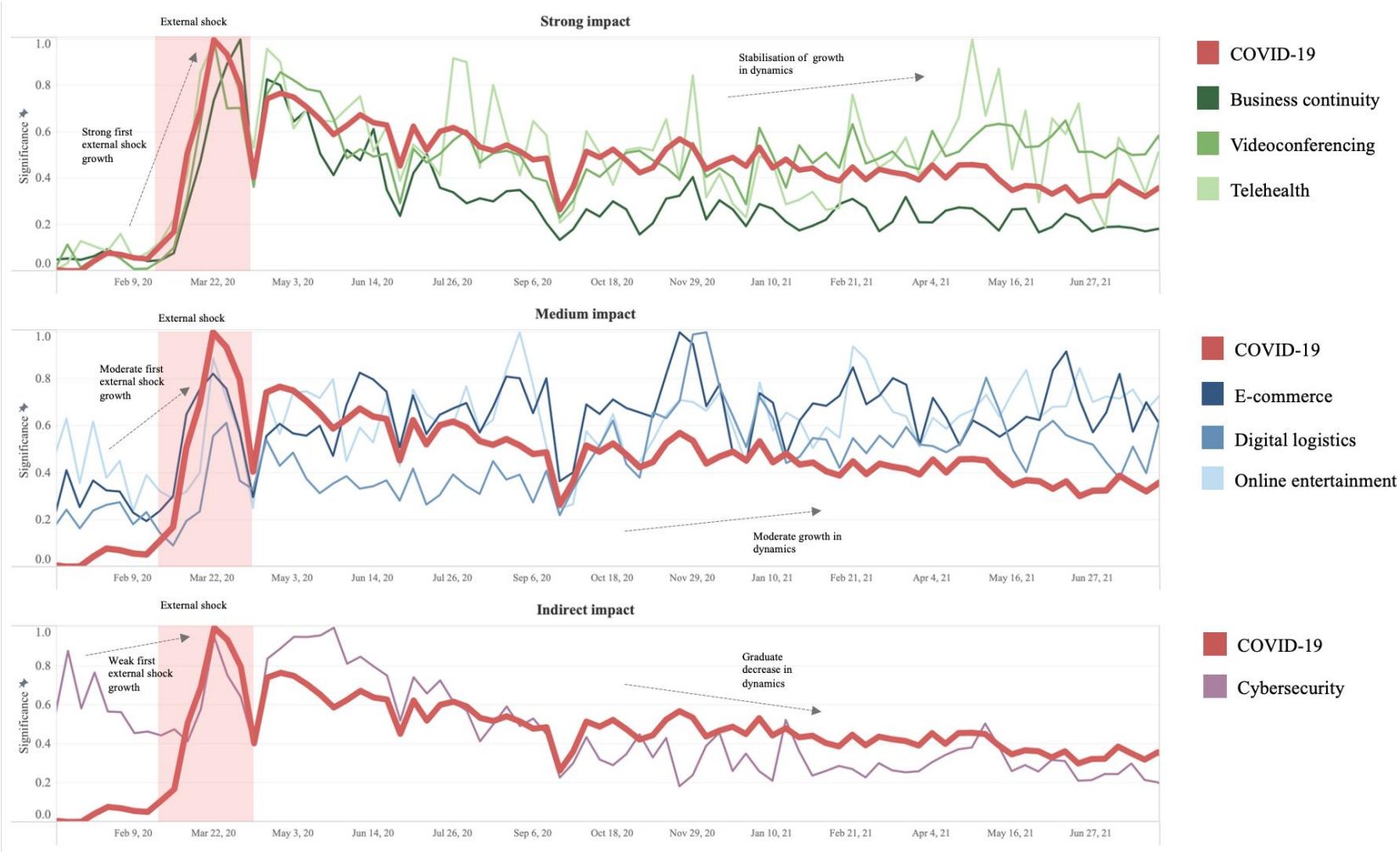
As the hype on COVID-19 has been changing according to the pandemic waves, demand on digital products and services altered as well. Results of big data analysis allowed authors to identify the dynamics of technological diffusion under the COVID-19 external shock conditions. Over the period from January 2020 to August 2021 significance of technological areas has been changing differently among groups (Figure 3). The external shock has impacted all groups of digital technologies. The first group, which includes videoconferencing, business continuity and telehealth, demonstrated the most dramatic changes at the beginning of the pandemic. In January 2020 the relative significance score of the services was less then 0,2 while in March it reached its peak simultaneously with COVID-19 peak. Unlike the second group of services started with 0,2 – 0,5 significance score in pre-COVID-19 period and rocketed when the pandemic broke out. Cybersecurity has shown relative significance in pre-COVID period equals 0,6 which is the highest value among technological areas in pre-COVID-period. Like the other technological areas cybersecurity reached peak in March 2021 which confirms external shock effect. Thus, all the groups of digital technologies demonstrated the same pattern at the early stage of the pandemic.

However, for some services the evolution of digital technologies diffusion over a medium run (the whole pandemic period since present time) indicates obvious discrepancies among services. For the first group of the services, which represents the most impacted technologies, two of them business continuity and videoconferencing reach their top significance scores only once, at the beginning of the pandemic. During the rest of the period both slightly went down but keeping dynamics of diffusion higher than in the pre-COVID era.

Shifts in telemedicine differ from other technological areas. It has reached several peaks of significance, one of which appeared in April – May 2021. The smaller peak was identified in July 2020 and November 2020. High significance rate of telehealth services during the COVID-19 reveals its stable increasing diffusion. Moreover, the results indicate that significance of telehealth services has jumped up by 4,5 time in comparison with pre-pandemic period, which means that external shock has a long-lasting effect on telehealth.

Business continuity services also indicates 4,8 time increase through the long period of the pandemic. Unlike, videoconferencing went up threefold. The findings show that even after the stabilisation of COVID-19 hype all services of the first group has been keeping their significance dynamics higher than in pre-COVID-19 period.

Figure 3. Dynamics of the COVID-19 and technological areas during pandemic (by groups).



Note: COVID-19 hype and digital technologies significance is measured as normalized ratio of mentions in media to the document corpus over the globe during the selected period.

Source: authors' calculations based on the intellectual big data analytical system iFORA evaluation.

The second group consisting of moderately impacted services has shown later increase in digital technology diffusion. In particular, despite the external shock has boosted the significance of the services, none of them reached its peak in March 2020, which indicates less external shock effect than in the first group. E-commerce achieved its highest significance value only in November 2020 and smaller peak in June 2021. Likewise, digital logistics demonstrated the highest significance score in November 2020. Online entertainment has jumped up later than the COVID-19 external shock appeared as well.

In the context of medium-time growth, all services show more moderate results than the first group. In particular, digital logistics and e-commerce has been going up twice since the pre-COVID period. Online entertainment has been increasing 1,5 times in comparison with pre-COVID era. The results indicate that technological diffusion of the second group services got momentum only after the COVID-19 hype started to stabilize.

The third group of services including cybersecurity is the only one with negative difference between significance in pre- and COVID-period. During the short considered period it reached its first significance peak and then in June 2020 attained the second. However, since that time till 2021 the services have been demonstrating graduate decrease in their significance, stabilizing between score of 0,2 and 0,4. The results illustrates that cybersecurity seems to be diminishing trend in the long run, which means that external shock has been influence insignificantly diffusion of the technology.

To sum up, the dynamic changes of technology diffusion over the pandemic period also differ. Despite all technological areas were influenced by the COVID-19 external shock, not all has reached their significance peaks at the beginning of the pandemic. E-commerce digital logistics and online entertainment seem to be late adopted in the pandemic conditions. Telehealth was profoundly influenced by the external shock; it reached several peaks of significance values not only at the beginning of the outbreak but also at its later stages. This makes telehealth a good case for deeper analysis in terms of its diffusion specifics.

4.3 Specifics of the adoption of telehealth

As the pandemic has dramatically increased the burden on the entire healthcare system, digitalisation of patient care is considered as one of the emerging topics. The results of the previous stage of the research showed that since the COVID-19 outbreak broke out, dynamics of telehealth, has gone up as well. The survey of medical experts[5] was conducted in order to investigate diffusion

[5] The authors would like to express their gratitude to Monica Spychala for her contribution to the organization of the survey.

of healthcare digital services during COVID-19, with focus on telehealth. In general, the majority of representatives (75%) claimed that after the start of the pandemic digital technologies have been impacted their job activities.

However, the effects from the use of digital technologies are assessed mostly negative. Despite the respondents reported that they started to use videoconferencing more frequently after the pandemic, most of them noted the negative effect or no effect, they have on the staff's duties. Moreover, for telehealth the same effect was noted as the experts reported negative impact or no effect on day-today activates in most cases. Thus, telehealth application during the COVID-19 has very limited positive impact on of medical personnel day-to-day job activities.

Moreover, the findings indicate several factors, that force the application of telehealth during the COVID-19. Firstly, the experts reported the challenges caused by the pandemic, which they faced. They affirm that telehealth is mostly used technology to overcome communication obstacles, problems in clinical work with patients and to reduce the effect of shortage of personnel. Thus, these challenges force demand on telehealth solutions. Secondly, despite the survey results indicated a gap between public and private organisations in the general use of digital solutions, in case of telehealth the gap is minimum. This means that both public and private sectors are adopting telehealth solutions, which contributes to its dynamic growth over the period of pandemic. Thirdly, although both semantic analysis and experts' survey findings reveal explosive growth in the telehealth use after the external shock, experts also indicated that a lot of organisations still do not apply the solution. This might be interpreted as a low base effect, which should be taken into consideration while assessing technology diffusion dynamics.

The experts were asked to describe the solution that has the biggest impact on medical staff day-to-day duties. Telehealth and videoconferencing tools were mentioned in almost all cases. Experts noted the importance of telehealth solutions not only in clinical work or communication with patients but also in medical staff training. The other features of telehealth application identified by respondents refer to simplification of medical service delivery. In particular, mobile technologies made telehealth easier for remote diagnosis and allowed to broaden services for patients.

To conclude, according to the survey results, the use of telehealth services has gone up in both public and private organizations. However, its positive impact is debatable. Despite the existing needs for telehealth services, driving its significance, it is still not widely used. Thus, the adoption of this technological area to the COVID-19 reality is still in process. Telehealth services potential could be further unleashed in the long run as they gradually become more familiar for both patients and medical personnel.

3. Discussion

To summarize the results of the study, some points should be discussed. Initially, differences in significance levels in dynamics among technological areas might be explained by several factors. Firstly, the field of the digital technologies' application can define whether the solution is narrowly or widely applied and respectively how it refers to the pandemic-specific challenges. In this context, if technological areas only aim to support the healthcare system resilience, they might show more significant shifts than broader-applied solutions. However, in terms of stability, narrow applied and pandemic specific digital solutions tend to be less stable and highly depended on the COVID-19 spread. That's why telehealth demonstrated highest dynamics score while low significance refers to its narrow application.

Secondly, exploring of the evolution of technological areas significance and COVID-19 contribute to understanding the character of trends in technological diffusion. Declining significance dynamics of such areas as cybersecurity may be explained by several factors. For example, the difficulties in access to cybersecurity solution of SMEs in comparison with big companies or government might cause deceleration in technology diffusion under COVID-19 external shock conditions.

Finally, late increase in the significance of the second group technologies (e-commerce, digital logistics and online entertainment) might be determined by later market adoptions to the pandemic conditions. This determines later significance peaks of technological areas, which were not reached in March 2020 but much later. In this context, COVID-19 external shock occurred in March 2020 has not been affecting the technologies in the long run but created long-lasting changes in market structure. Moreover, as cybersecurity is indirectly impacted by all other areas, it could be assumed that the pattern of technology diffusion might be the same as of the second group but more long-lasting.

Among weaknesses and limitations of this study the following points might be mentioned. Firstly, the study is based on the English documentary corpus, which on one side allow collecting data from global sources but on the other side lacks representative regional data such as in Russian or Chinese. Secondly, although big data methodological approach allows to investigate quantitative features of technological areas dynamics, it is not useful to study qualitative one.

The obtained results of the present study give implications for further research. The technological areas that were distinguished might be explored in the context of their dependence on the COVID-19 hype. Moreover, the future study can focus on the factors determining the nature of technological areas dynamics during the pandemic. In this context, different patterns of technological diffusion and digitalisation might be identified as a result of further studies in the field.

4. Conclusion

This paper synthesises the pandemic external shock influence on digital technology diffusion in general and some specific issues, concerning the trends lasting during the pandemic. The research investigated 7 technological areas and discussed their application during the COVID-19 and the pandemic impact on their dynamics. Firstly, the study identified different groups of technological areas according to their critical importance. The pandemic has transformed dynamics of all researched areas, in accordance with the most urgent tasks of combating the pandemic. Nevertheless, videoconferencing, business continuity services and telehealth remain the most critical and demanded services over the pandemic period.

Secondly, the study examined the character of dynamical evolution of technological areas significance under the conditions of the COVID-19 hype. The findings illustrated strong differences in dynamics of technological diffusion. Such services as digital logistics, online entertainment and e-commerce were impacted moderately by the COVID-19 external shock in March 2020 while videoconferencing, telehealth and business continuity reached their peak significance at the beginning of the outbreak. In terms of the COVID-19, cybersecurity was the less impacted digital technology at short-run the external shock stage.

Thirdly, the paper presented the specifics of the technological diffusion during mid-term period which covers the pandemic till present time significance value among all groups, e-commerce, digital logistics, online entertainment top values only the stabilisation of the COVID-19 hype which indicates late pandemic effects in a medium run. Moreover, the research revealed a decline in cybersecurity dynamic diffusion over the mid-term period.

Finally, research revealed that despite an explosive growth in the use of digital solutions after the pandemic, their impact on medical staff's job activities remains mostly negative. A broad application of telehealth solutions in both, public and private sector, the ability to address pandemic-related challenges and new medical services opportunities force the technological diffusion. However, telehealth remains unapplied in a part of a sector, which identifies its potential for long-term growth. As a result, although the pandemic may cause significant changes in the digital technology diffusion, some of them might be crucial only in a long run.

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Annex 1

List of keywords for the semantic big text data analysis

1. voice assistants	2. remote workforce
3. computer aid diagnosis	4. biometric
5. image recognition	6. multi factor authentication
7. disinfection robot	8. data protection right
9. infrared camera	10. healthy lifestyle
11. telehealth	12. contactless point
13. personalized healthcare	14. digital currency
15. proactive health care	16. virtual tourism
17. online diagnosis	18. vr tourism
19. chat-bot	20. vr sports
21. conversational bot	22. virtual entertainment
23. wearable	24. share social experience
25. medical sensor	26. cybersecurity
27. healthcare monitoring device	28. teleworking
29. remote patient monitoring device	30. more flexible work environment
31. logistic	32. improve work life balance
33. video conferencing	34. cloud collaboration tool
35. e-government	36. collaborative work platform
37. contactless payment	38. social media marketing
39. touchless device	40. mobile media
41. wireless nfc	42. digital marketing
43. online education	44. cloud platform
45. online music	46. process analytic
47. video game	48. robotisation
49. online sport	50. social monitoring tool
51. ecommerce	52. budget management
53. delivery services	54. business continuity
55. mobile application	56. streaming service

Annex 2

A list of technological areas, obtained as a result of the semantic big text data analysis

Technological areas	Technological areas clusters	Significance	Normalised significance	Dynamics	Normalised dynamics
Video conferencing app	Videoconferencing	214	0,22	1,9601	1,00
Video conferencing platform	Videoconferencing	220	0,23	1,851	0,94
Video conferencing software	Videoconferencing	93	0,09	1,7894	0,91
Zoom app	Videoconferencing	50	0,04	1,6821	0,86
Video conference	Videoconferencing	100	0,10	1,6766	0,86
Video conferencing service	Videoconferencing	121	0,12	1,5826	0,81
Popular video conferencing app	Videoconferencing	12	0,00	1,5789	0,81
Video meeting	Videoconferencing	44	0,04	1,5053	0,77
Cisco Webex	Videoconferencing	17	0,01	1,4117	0,72
Video conferencing tool	Videoconferencing	99	0,10	1,2771	0,65
Video conferencing solution	Videoconferencing	18	0,01	1,2727	0,65
Microsoft teams	Videoconferencing	233	0,24	1,0274	0,52
Huawei equipment	Videoconferencing	87	0,08	0,16	0,08
5G network	Videoconferencing	446	0,47	0,0372	0,02
Online class	Business continuity services	213	0,22	1,8888	0,96
Online education	Business continuity services	728	0,78	1,5543	0,79
Remote work	Business continuity services	817	0,88	1,8174	0,93
Remote working	Business continuity services	346	0,37	1,7846	0,91
Remote workforce	Business continuity services	364	0,38	1,5142	0,77
Remote worker	Business continuity services	324	0,34	0,8326	0,42
Remote employee	Business continuity services	55	0,05	0,6315	0,32
Business continuity plan	Business continuity services	104	0,10	1,7333	0,88
Real time intelligence	Business continuity services	203	0,21	1,5555	0,79
Business continuity	Business continuity services	355	0,37	1,502	0,77
Good VPNs	Business continuity services	83	0,08	0,2439	0,12
Critical infrastructure	Business continuity services	135	0,14	0,2093	0,11
Online faxing	Business continuity services	13	0,00	0	-
Desktop and server management tool	Business continuity services	11	0,00	0	-
Business solution application	Business continuity services	11	0,00	0	-
Logistic centre	Digital logistics systems	45	0,04	1,7021	0,87
Logistic supplier	Digital logistics systems	13	0,00	1,6923	0,86

Big logistical challenge	Digital logistics systems	34	0,03	1,6428	0,84
Logistical arrangement	Digital logistics systems	21	0,01	1,3962	0,71
Logistical challenge	Digital logistics systems	513	0,55	1,0763	0,55
Logistic firm	Digital logistics systems	33	0,03	0,909	0,46
Logistical issue	Digital logistics systems	198	0,20	0,888	0,45
Logistic issue	Digital logistics systems	29	0,02	0,8059	0,41
Logistic operation	Digital logistics systems	24	0,02	0,5084	0,26
Logistic support	Digital logistics systems	86	0,08	0,3712	0,19
Logistic hub	Digital logistics systems	34	0,03	0,1443	0,07
Logistic company	Digital logistics systems	182	0,19	0,1185	0,06
New supplier	Digital logistics systems	77	0,07	0,1016	0,05
Logistic service	Digital logistics systems	63	0,06	0,0719	0,04
Health protection measure	Telehealth services	27	0,02	1,9166	0,98
Telehealth visit	Telehealth services	47	0,04	1,619	0,83
Telehealth provider	Telehealth services	14	0,01	1,5789	0,81
Telehealth company	Telehealth services	15	0,01	1,5714	0,80
Telehealth platform	Telehealth services	13	0,00	1,5555	0,79
Telehealth service	Telehealth services	149	0,15	1,4037	0,72
Virtual care	Telehealth services	43	0,04	1,2	0,61
Telehealth vendor	Telehealth services	10	0,00	0	-
Online delivery service	E-commerce	24	0,02	1,6	0,82
E-krona	E-commerce	13	0,00	1,5789	0,81
Pickup and delivery service	E-commerce	11	0,00	1,3043	0,67
Home delivery service	E-commerce	106	0,11	1,1757	0,60
Online shopping	E-commerce	183	0,19	0,8078	0,41
Grocery delivery service	E-commerce	90	0,09	0,8	0,41
Ecommerce business	E-commerce	111	0,11	0,7692	0,39
Food delivery service	E-commerce	423	0,45	0,7468	0,38
Grocery delivery	E-commerce	52	0,05	0,5758	0,29
Ecommerce store	E-commerce	50	0,04	0,5714	0,29
Most complex design challenge	E-commerce	22	0,01	0,56	0,29
Food delivery	E-commerce	159	0,16	0,5479	0,28
Delivery service	E-commerce	932	1,00	0,5229	0,27
Delivery giant	E-commerce	18	0,01	0,3783	0,19
Ecommerce company	E-commerce	47	0,04	0,1886	0,10
Last mile delivery	E-commerce	87	0,08	0,1736	0,09
E-commerce	E-commerce	466	0,50	0,1572	0,08
Digital marketing	E-commerce	519	0,55	0,1273	0,06

Social medium marketing	E-commerce	106	0,11	0,0909	0,05
Central bank digital currency	E-commerce	316	0,33	1,2513	0,64
Central bank	E-commerce	238	0,25	0,9204	0,47
Digital market	E-commerce	82	0,08	0,3195	0,16
Financial service	E-commerce	319	0,34	0,2026	0,10
Own digital currency	E-commerce	169	0,17	0,1632	0,08
Google pay	E-commerce	148	0,15	0,0643	0,03
Dashlane password manager	E-commerce	23	0,02	0	-
Native digital currency	E-commerce	19	0,01	0	-
New cryptocoin	E-commerce	9	-	0	-
Home broadcast	Entertainment online services	26	0,02	1,5	0,77
World large streaming service	Entertainment online services	11	0,00	1,3333	0,68
Hisense TV	Entertainment online services	14	0,01	1	0,51
Complimentary trial	Entertainment online services	240	0,25	0,9863	0,50
Popular video game	Entertainment online services	173	0,18	0,7889	0,40
Late streaming service	Entertainment online services	12	0,00	0,6666	0,34
Company streaming service	Entertainment online services	27	0,02	0,6341	0,32
Standalone subscription	Entertainment online services	36	0,03	0,5882	0,30
Most popular streaming service	Entertainment online services	42	0,04	0,4242	0,22
Netflix arrival	Entertainment online services	17	0,01	0,421	0,21
Lead streaming service	Entertainment online services	16	0,01	0,4	0,20
Top streaming service	Entertainment online services	12	0,00	0,4	0,20
Streaming platform	Entertainment online services	362	0,38	0,3664	0,19
Amazon prime video	Entertainment online services	490	0,52	0,3618	0,18
Many streaming service	Entertainment online services	16	0,01	0,3333	0,17
AT&T tv	Entertainment online services	77	0,07	0,2857	0,15
Prime video streaming service	Entertainment online services	704	0,75	0,2222	0,11
Good streaming service	Entertainment online services	46	0,04	0,2222	0,11
Various streaming service	Entertainment online services	35	0,03	0,1666	0,08
Annual subscription	Entertainment online services	209	0,22	0,155	0,08
CBS all access streaming service	Entertainment online services	17	0,01	0,1333	0,07
Netflix stock	Entertainment online services	52	0,05	0,0869	0,04
Disney streaming service	Entertainment online services	159	0,16	0,0402	0,02

Physical hearing	Cybersecurity	21	0,01	1,9238	0,98
Zero trust	Cybersecurity	97	0,10	1,2619	0,64
Cybersecurity tool	Cybersecurity	27	0,02	1,125	0,57
Strong security feature	Cybersecurity	63	0,06	0,8	0,41
Dark web monitoring	Cybersecurity	24	0,02	0,6666	0,34
Cybersecurity service	Cybersecurity	53	0,05	0,5641	0,29
Cybersecurity concern	Cybersecurity	51	0,05	0,5454	0,28
Cybersecurity agency	Cybersecurity	15	0,01	0,5454	0,28
Cyber risk	Cybersecurity	173	0,18	0,5312	0,27
Cybersecurity leader	Cybersecurity	31	0,02	0,5	0,26
Chief information security officer	Cybersecurity	84	0,08	0,4509	0,23
Cybersecurity researcher	Cybersecurity	177	0,18	0,3898	0,20
UK national cyber security centre	Cybersecurity	37	0,03	0,375	0,19
Cybersecurity expert	Cybersecurity	571	0,61	0,3174	0,16
Cybersecurity community	Cybersecurity	57	0,05	0,2666	0,14
Cyber defense	Cybersecurity	54	0,05	0,2564	0,13
Cybersecurity policy	Cybersecurity	170	0,17	0,2424	0,12
Cybersecurity industry	Cybersecurity	139	0,14	0,2352	0,12
Cybersecurity strategy	Cybersecurity	86	0,08	0,2168	0,11
Ransomware attack	Cybersecurity	379	0,40	0,1951	0,10
Cybersecurity product	Cybersecurity	31	0,02	0,1463	0,07
Data protection	Cybersecurity	124	0,12	0,1152	0,06
Cybersecurity company	Cybersecurity	240	0,25	0,0928	0,05
Cyber threat	Cybersecurity	324	0,34	0,0844	0,04
Cyber attack	Cybersecurity	435	0,46	0,0401	0,02
Cyber criminal	Cybersecurity	194	0,20	0,0341	0,02
Cyber criminal	Cybersecurity	194	0,20	0,0341	0,02
Datum security	Cybersecurity	149	0,15	0,0144	0,01

Annex 3

The questionnaire form of medical experts' survey

Section 1 – Your role in healthcare
1. What type of organization are you involved with?
• Public healthcare organisation • Private healthcare organisation • Industry • Other
2. How would you categorise your role?
• Management/Administration • Researcher • Medical Student/Trainee • Clinician • Other
3. Highest level of completed education?
• High School/GED • Associate Degree • Bachelor's Degree • Master's Degree (including MPH/MBA/ME/MSW) • Ph.D (Academic) • Professional Medical Degree (MD/DO/DMD/DDS) • Doctoral Degree (DPT/PharmD)
4. What field of medicine are you involved in?
5. In which region/country are you employed?
Section 2 - Impact of the pandemic on your day-to-day job.
1. Do you feel that technology or digitalization has impacted your job since the beginning of the COVID-19 pandemic?
• Yes • No
2. With today in mind, please indicate whether the level of patient care became better, worse or remained the same since before the start of the pandemic?
• Better • Worse • The same as before COVID-19
3. Please indicate if you have started to use digital solutions in your professional activity more often, less often, or the same as before the pandemic?
• More often • Less often • The same as before COVID-19
4. Do you feel that video conferencing/telehealth has a positive, negative, or no effect on how you perform your job?
• Positive effect - can perform my job better

• No effect - same as in-person • Negative effect - telehealth has a negative impact on my job outcomes
5. Which challenges, and to what extent, have influenced your work during the pandemic? (1- not significant impact, 5 - very significant)
• Communication obstacles • Personal protective equipment (PPE) shortages • Disruption of drug suppliers • Increased paperwork • Shortage of personnel • Funding gaps • Obstacles in clinical work with patients
Section 3 - Digital solutions in healthcare
1. What digital solutions do you commonly use in your work? Please indicate whether they were used before or after the start of the COVID-19 pandemic.
• Telehealth • Medical image recognition • Disinfection robotics • Chat-bots for medical communication • Unmanned vehicle delivery • AI for drug design • Personalized treatment tools • Electronic healthcare records • Contact-tracking apps • Pandemic prediction tools
2. Please briefly describe the digital solution that has the biggest impact on your day-to-day tasks.