DOI: 10.17323/2587-814X.2023.1.37.52

Diffusion of digital technologies in the face of external shocks: The case of the COVID-19 pandemic

Roman A. Shcherbakov
Email: rashcherbakov@hse.ru

Sofya G. Privorotskaya
E-mail: sprivorotskaya@hse.ru

Konstantin O. Vishnevskiy
E-mail: kvishnevsky@hse.ru

HSE University
Address: 20, Myasnitskaya Street, Moscow 101000, Russia

Abstract

This paper investigates the impact of external shocks on the spread of digital technologies. Using the example of the COVID-19 pandemic, we identify and describe four patterns that reflect the uneven response of different digital technologies to external conditions undergoing transformation. The patterns differ in both the magnitude of the pandemic's impact and the timing of the resulting effects. Video conferencing, business continuity and telemedicine services showed a dramatic increase in demand at the beginning of COVID-19 and a gradual decline in the later stages. A more moderate response in the early weeks of the pandemic is typical of e-commerce and online entertainment. Delayed effects are seen in digital logistics services and digital currencies, which reacted much later than other technologies. Finally, a slow decline

in significance after the pandemic began has been observed for biometrics and cybersecurity technologies. Similar patterns may describe the transformation of the spread of digital technologies not only under the influence of COVID-19, but also in the face of dramatic economic and social changes of other origins.

Keywords: digital transformation, digital technology, digital diffusion, economic shock, market adaptation, COVID-19

Citation: Shcherbakov R.A., Privorotskaya S.G., Vishnevskiy K.O. (2023) Diffusion of digital technologies in the face of external shocks: The case of the COVID-19 pandemic. *Business Informatics*, vol. 17, no. 1, pp. 37–52. DOI: 10.17323/2587-814X.2023.1.37.52

Introduction

The COVID-19 pandemic has accelerated the spread of digital technology across economic and social spheres. Many companies, organizations and government agencies have been forced to move to a more intensive digital transformation of key business processes. In particular, due to lockdown restrictions, certain operations have been switched to a remote format [1–3]. The ability to successfully implement and adapt digital technologies has become one of the competitive advantages of business during the crisis [4]. The innovative potential of companies was partly redirected to create effective solutions to combat the social and economic consequences of COVID-19. Thus, during the pandemic, the use of digital solutions (including the spread of online education, remote employment, e-commerce, telemedicine, etc.) significantly increased [5].

The external shock triggered by the pandemic led to shifts in the supply and demand for digital products and services, many of which were already widespread before the pandemic (e.g., streaming or conferencing platforms). Under these kinds of shocks, changes are heterogeneous and may be characterized by different market patterns (e.g., immediate, or delayed demand response, long-term or temporary nature of changes, etc.) [6–7].

Empirical evidence on the impact of COVID-19 on digital diffusion formed the analytical basis for the study. This allowed us to draw conclusions about the possible types of market reactions and their corresponding characteristics of technological directions (including the level of maturity, consumer demand, sensitivity to external factors, etc.).

1. Technology diffusion: theoretical background

The diffusion of new technologies is influenced by a set of factors. The intensification of entrepreneurial activity, the development of international trade and the accompanying economic growth contribute to greater adoption of digital technologies [8]. In addition, the use of digital platforms and the strengthening of network effects contribute to the deepening of cooperation among companies and the creation of partnerships, all of which stimulates the spread of technology, for example, in e-commerce, education, finance, health, agriculture, transport, energy, industry, etc. [9, 10]. The quality of human capital (including the level of managerial competence, technical skills of employees and the general level of education) has a significant impact on the speed and depth of adaptation of new technologies [11].

The process of technology diffusion under the influence of the aforementioned factors is described by various models. Epidemiological models (epidemic models) associate it with the transmission of information from one user to another by analogy with the process of disease transmission [12, 13]. In such models, the spread of information about technologies is described by an S-curve, emphasizing its non-linear nature [14]. Other approaches, such as probit models, describe the factors that affect the adaptation of a new technology at the level of an individual company or person [15]. If the significance of a factor (for example, such as profit from the technology's implementation), exceeds a certain limit, it leads to its successful implementation [16]. However, such models take into account long-term trends and exclude the influence of external shocks – events that can radically change the demand or the way the technology is used. This kind of transformation is the key subject of this study.

2. The impact of the COVID-19 pandemic on digital technologies

The emergence of external shocks in the economy distorts the trajectories of technology diffusion and greatly increases the level of uncertainty, making it difficult to predict its future development. The COVID-19 pandemic has had a significant impact on the level of use of technological solutions already widely available on the market, as well as less mature ones. In particular, the rapid proliferation of technologies that enable the support of remote working formats is considered one of the most significant effects of the pandemic, which overcame a few negative consequences [4, 17]. At the same time, the increased demand for such solutions led to increased data security risks, which also stimulated an increased need for cybersecurity technologies [18, 19].

The impact of COVID-19 on the digital transformation of particular industries (especially those most affected by the pandemic) has received considerable attention in scientific literature. The most tangible effects have been observed in health care [3, 20, 21]. In particular, the pandemic has increased the demand for telemedicine and accelerated its adoption [21]. The disruption of traditional supply chains has also been a driver for the introduction of technologies related to transportation and logistics. The restructured supply chains have actively involved solutions that had previously been used on a smaller scale, in particular drones [22, 23]. For example, drones have been actively used to ensure the delivery of medicines, medical devices, and essential goods, especially in areas that are difficult to reach by conventional transport [24].

The spread of technology in a pandemic has been extensively researched in the academic field. However, there are a few gaps in this field. There are virtually no studies comparing the response of individual digital solutions, including products and services, to the effects of the pandemic. There is also a lack of attention to the changing patterns and nature of digital diffusion under the influence of the pandemic.

In order to fill the existing gaps, the following research objective was set: to identify possible patterns of digital diffusion under the influence of external shocks by analyzing the dynamics of digital diffusion under the COVID-19 pandemic.

3. Methodology

We applied statistical methods to evaluate and interpret quantitative metrics derived from intelligent analysis of big data. This approach allows one to answer the questions posed, since it makes it possible to measure metrics that characterize technological trends and their dynamics. Descriptive empirical research provides an opportunity to present an integral picture of the development of digital technology in the context of the pandemic, as well as to complement existing scientific works on this topic.

To collect empirical data, we used the system of intellectual foresight analysis of big data developed at the Institute of Statistical Studies and Economics of Knowledge of the National Research University Higher School of Economics (HSE) – iFORA (Intellectual foresight analytics) [25]. We used the indicators of *significance and dynamics* of a particular topic in professional English-language media for two periods:

2018–2019 (pre-pandemic period) and 2020–2022 (pandemic and post-pandemic period) to assess the dynamics of digital technologies. The media corpus includes 548,000 sources. The corpus includes news publications in professional business and specialized industry media, as well as official press releases from digital technology companies.

The following indicators were calculated based on the results of intelligent analysis of big data.

Significance is the relative frequency of occurrence of the topic in the documents on the analyzed area:

$$FREQ = \sum_{i=1}^{T} f_i, \quad (1)$$

where $FREQ$ is the frequency index;

f_i – occurrence of the term in the i-th year;

T – length of years interval, $i = 1, ..., T$.

Dynamics is the average annual growth rate of frequency of mentions:

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

where $AAGR$ is the indicator of the growth rate;

f_i – occurrence of the term in the i-th year;

T – length of years interval, $i = 1, ..., T$.

The indicators are calculated based on selected keywords (*Appendix 1*) by technology areas (clusters), which include digital solutions that have become relevant in use during the pandemic. The technology areas were selected based on the OECD OPSI COVID-response Tracker database, which compiles digital solutions applied to mitigate the pandemic effects in various countries and reflect the technology agenda during the pandemic period [26]. The study is based on an analysis of nine clusters, including: video conferencing, business continuity services, telemedicine, digital logistics services, digital currencies, e-commerce, online entertainment services, cybersecurity and biometrics. Based on the OECD database, a compilation of key terms reflecting the most common digital solutions, grouped into nine clusters, was formed. Terms missing from the corpus of texts, as well as outliers (terms with a frequency of mention close to zero and general terms with an inflated frequency) were removed from the list of keywords.

The selected toolkit allows tracking current changes in digital dynamics with little delay, which is achieved by constantly updating the iFORA document database. Thus, it becomes possible to obtain data for 2021 and early 2022, which cannot be achieved with traditional statistical metrics. Moreover, normalized metrics evaluated from big data analysis allow one to compare different technology trends using a single scale. In contrast to traditional studies based on the analysis of internet search data from an unspecified list of sources, the analysis using iFORA is based on a corpus of digital-specific documents from a professional media database (including industry and business media, company press releases on digital topics, etc.).

A similar approach, based on the analysis of the significance of topics in the media in the iFORA system, is widely used by researchers to identify and describe market trends in various economic sectors (agriculture and food sector [25]; mobile commerce [27]; extractive industries [28, 29].

4. Results and discussion

The results of the analysis demonstrated that the pandemic has had a highly uneven impact on the spread of individual technology areas (*Table 1*). Business continuity and videoconferencing services, digital currencies, and telemedicine showed the sharpest growth in 2020. At the same time, the dynamics for several clusters, including biometrics and cybersecurity, was negative in the same period. In 2021, there is a slowdown in pandemic effects: the level of dynamics for business continuity services, digital currency videoconferencing, and telemedicine is significantly lower than in 2020. For other clusters, less dramatic changes are observed during this period – there is a gradual adaptation of markets.

An analysis of the spread of technology areas from 2018 to early 2022 revealed four patterns of digital diffusion in the COVID-19 pandemic: (1) shock effect, (2) moderate effect, (3) delayed effect, (4) negative effect.

Table 1.

Dynamics of the spread of technology areas in 2019–2021

Technology areas (clusters)	Significance growth rate (dynamics), in % to the previous year		
	2019	2020	2021
Business continuity services	1.4%	214.8%	1.6%
Video conferencing services	10.1%	156.8%	–11.5%
Digital currencies	17.9%	120.2%	52.4%
Telemedicine	3.3%	74.4%	23.9%
Digital Logistics	2.7%	28.4%	10.2%
E-commerce	–10.8%	15.0%	6.1%
Online Entertainment	25.5%	9.5%	–4.0%
Biometrics	1.0%	–17.2%	10.2%
Cybersecurity	3.0%	–19.5%	21.9%

Source: the authors' calculations based on the results of intelligent analysis of big data in the iFORA system.

Pattern 1: Shock effect

The pattern is characterized by a sharp increase in significance in the short term (at the beginning of the pandemic) and a gradual downward trend during the rest of the observation period.

This kind of trend trajectory during the COVID-19 pandemic is typical of such technological areas as business continuity services, video conferencing and telemedicine. A surge in significance for all services in this group occurred between March and mid-April 2020 (*Fig. 1*). However, after peaking in April, the clusters showed a sharp decline in significance until September–October 2020, indicating a weakening of the effects during this period.

The shock response is primarily due to the fact that all of the technologies in this cluster were directly used to deal with the effects of the pandemic. The results of the present study are consistent with previously published findings of a shocked increase in demand for telemedicine in the early weeks of the pandemic [30]. At the same time, despite a gradual decline in relevance across these clusters by early 2022, it remains at higher levels than before the pandemic, suggesting a profound, long-term impact.

At the same time, the trajectory of development in telemedicine differs from the other two clusters: the significance indicators achieved in March–April 2020 (shock period) turn out to be more stable and do not decrease as significantly as the pandemic recedes. Such trend behavior may indicate gradual adaptation of telemedicine technologies to conditions after COVID-19 pandemic and gradual expansion of their application. A few studies have found a qualitative change in the status of telemedicine, which has gained greater acceptance among both healthcare profession-

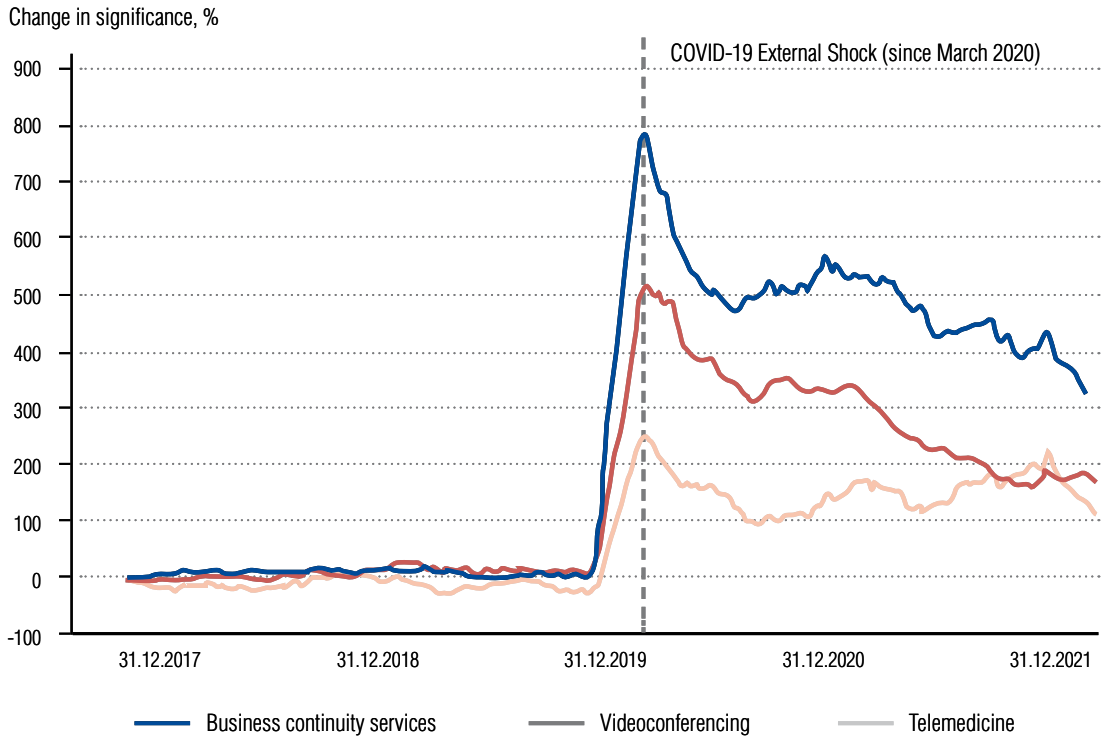

Fig. 1. Pattern 1: Change in significance in 2018–2022 (in percentage to the level as of December 31, 2017).
Source: authors' calculations based on iFORA big data mining.

als and patients [31]. At the same time, further growth in demand in this area, as confirmed by other authors, is limited by barriers related to data privacy, immaturity of technology, etc. [32].

Pattern 2: Moderate effect

The pattern is characterized by a moderate increase in the significance of technological areas at the beginning of the pandemic. In contrast to the first pattern, there is no sharp decrease in significance after the period of external shock (March–April 2020).

Since March 2020, the significance for e-commerce and online entertainment clusters has increased sharply. Just as in the previous pattern, high values were achieved in April 2020, but the scale of the changes does not allow us to conclude on their shock nature (*Fig. 2*). In particular, the change in significance for March–April 2020 was 30–35 percentage points (p.p.), while for the video conferencing, business continuity and telemedicine clusters the increase was over 100 p.p. Meanwhile, the April 2020 figures do not demonstrate peak values for these clusters. Overall, there is weak growth in the initial period of the pandemic (*Table 1*), which also indicates that there are no signs of shock changes as in the case of the previous pattern. At the same time, growth rates for both clusters declined after 2021.

The more moderate response to the pandemic may be due to the fact that technologies in the two clusters analyzed were not used directly as a response to the pandemic, like telemedicine or video services. More-

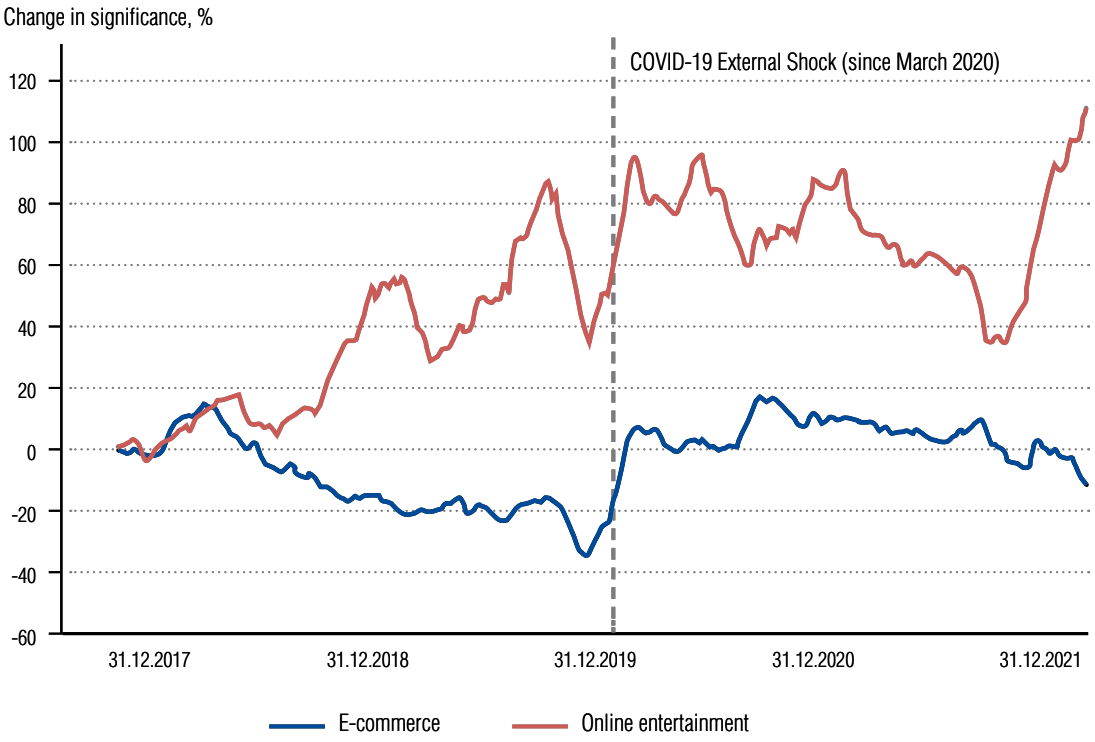

Fig. 2. Pattern 2: Change in significance in 2018–2022 (in percentage of the level as of December 31, 2017).
Source: authors' calculations based on iFORA big data mining.

over, several studies show that disruptions in global supply chains have also negatively impacted supply in e-commerce, in the presence of high demand, confirming its limited growth over the observed period [33]. In addition, in the online entertainment sector, despite the increased demand for digital platforms during the pandemic, supply and demand for other services changed, such as exhibitions, festivals, limited film production, etc. became impossible. [34]. As a result, in the case of these clusters we can conclude there was a less visible response to the impact of the pandemic.

Pattern 3: Delayed effect

The pattern is characterized by a much later attainment of peak significance over the observed period, as well as a lack of shock response at the beginning of the pandemic, indicating a delayed nature of the transformational effects.

The delayed nature of the pandemic effects on the spread of these technological areas is related to the need to adapt technologies to the new conditions. For example, the significance of digital logistics reached its highest levels only by the end of 2020 (*Fig. 3*). A similar trajectory over the same period was demonstrated by the significance indicators for digital currencies.

Deferred pandemic effects have also been mentioned in earlier studies. According to several authors, only in the long term will innovative supply chains play an important role in meeting the demand for certain products, which helps to reduce the negative effects of the pandemic [23]. At the same time, the growth of

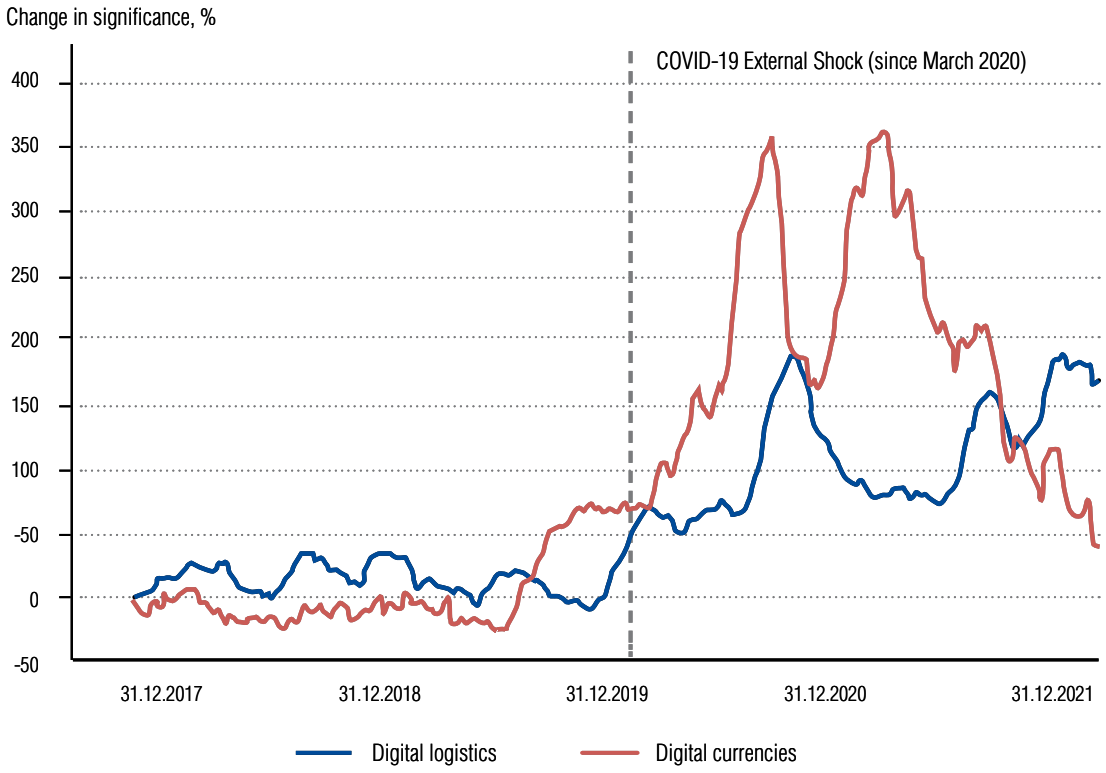

Fig. 3. Pattern 3: Change in significance in 2018–2022 (in percentage to the level as of December 31, 2017).
Source: authors' calculations based on iFORA big data mining.

digital currencies is justified by the gradual adaptation of financial regulation to the pandemic and the use of digital currencies to stimulate economic recovery. Other studies also confirm the positive stimulative effect of digital currencies on e-commerce in China, which has made them subject to financial regulation and led to accelerated diffusion [35, 36].

Pattern 4: Negative effect

This pattern is characterized by a lack of significant growth after the pandemic began and a persistence of negative dynamics throughout the observation period.

The significance of biometrics and cybersecurity technologies, unlike the others, demonstrated a smooth downward trend throughout the entire observation period (*Fig. 4*). At the beginning of the pandemic (March–April 2020), a decline in the significance of both technological areas was observed, which, however, was not sharp and amounted to about 15–20 p.p. At the same time, despite positive growth rates in 2021 (*Table 1*), the significance of both technological areas did not return to pre-pandemic levels. We can say that after the pandemic their significance in the business agenda did not fall significantly, but at the present rate of increase in significance there was no return to pre-pandemic levels. It will only be possible to draw conclusions about the depth of the pandemic's impact on these clusters in the longer term.

At the same time, the results of this study do not confirm the results of previously published works. In particular, a number of authors have concluded

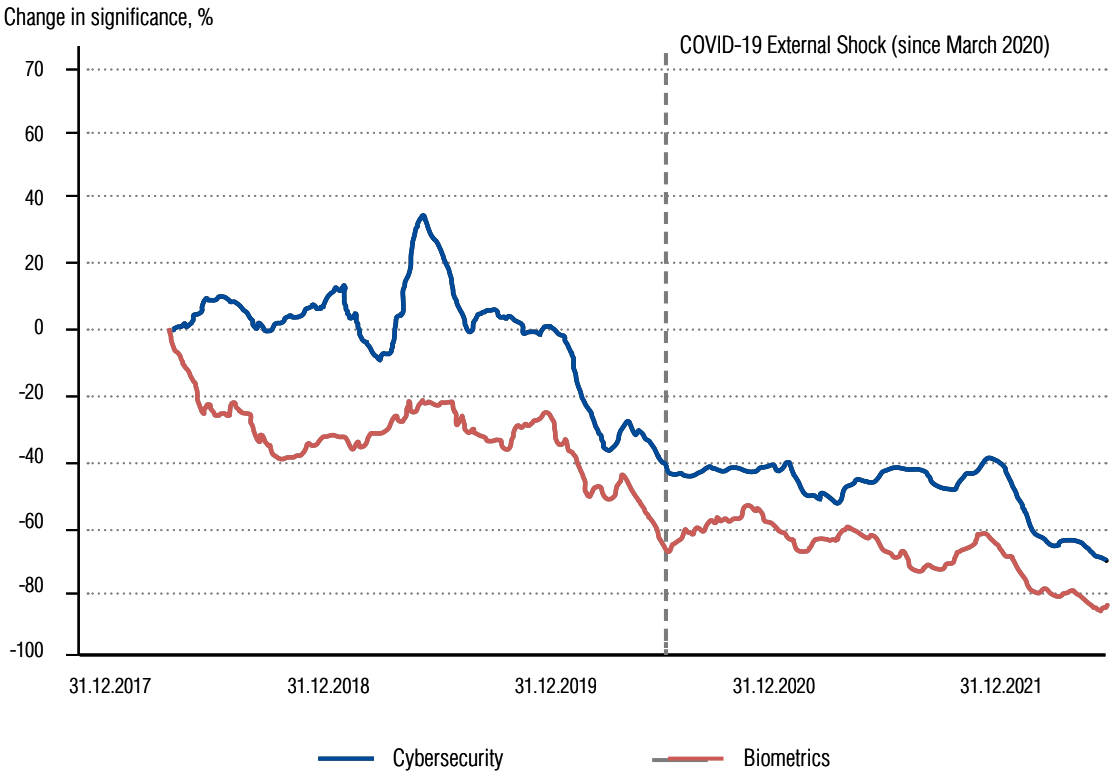

Fig. 4. Pattern 4: change in significance in 2018–2022 (in percentage to the level as of December 31, 2017).
Source: authors' calculations based on intelligent analysis of big data in the iFORA system.

that there was increasing need for cybersecurity services after the beginning of COVID-19 [18, 19]. This study demonstrates a gradual recovery of the positive dynamics of the significance of cybersecurity by the end of 2020 and 2021, which may be due to the gradual adaptation of society to the increased use of other digital technologies and the growing demand for cybersecurity solutions.

Thus, in the face of an external shock, there have been significant shifts in the markets of all the analyzed technological areas, with tangible differences in their nature. The "behavior" of each individual cluster is determined by the specifics of the technologies included in it, including their level of maturity, the breadth of application in industries, the degree of influence of the pandemic on key areas of their application, etc. Similar patterns may describe changes in the trajectories of spread of digital technology under conditions of turbulence in the external environment caused by various kinds of economic and social shocks.

Conclusion

Dramatic conjuncture changes and an increase in the level of uncertainty significantly complicate the decision-making process for economic actors. The approach proposed in this paper reveals regularities in the response of digital products and services markets to external shocks and, thus, makes it possible to increase the predictability of possible changes.

Empirical observations during the COVID-19 pandemic (2020–2022), obtained using big data mining,

allowed us to systematize the possible types of digital technology responses to external shocks. Due to its versatility, the proposed approach can be applied to assess the effects of external shocks of different origins. First, metrics reflecting the significance in the agenda allow us to quantify the scale of response of different technological trends and to compare them with each other. Second, access to the most up-to-date information makes it possible to quickly track and respond to such changes. Third, as a result, it becomes possible to identify certain patterns and further classify them.

The analysis results reflect the highly uneven impact of shocks on the trajectories of digital diffusion. The four patterns identified differ both in the strength of the transformational impact (from moderate to pronounced) and in the timing of the resulting effects (from immediate to delayed long-term response).

A sharp growth "in the moment" and a subsequent slowdown while maintaining the overall positive trend are characteristic of the technological solutions of the first pattern. For clusters in this group, we can conclude that there are deeper structural changes that persisted in the post-pandemic period. Less pronounced or delayed effects in the medium term are characteristic of the second and third patterns. This reaction is associated with a less pronounced sensitivity of technologies to changes in the conjuncture and the presence of a certain time lag for adaptation to the changed situation.

As the influence of COVID-19 wears off, there is an inverse process of "de-digitalization" for those areas where the costs of accelerated digitalization were too high. Within the fourth pattern, there are negative dynamics in response to external changes. In this context, temporary external shocks may not lead to long-term structural transformation, but only accelerate the existing trend (with a possible subsequent "rollback").

Identification of such patterns is an important element of forecasting economic and social development both for the state and for business. The results we have presented can be generalized for a comprehensive analysis of the factors contributing to changes in business processes, restructuring of value chains, shifts in digital products and services markets, and the breakdown of relevant technological trends. ■

Acknowledgements

This article was prepared within the Basic Research Program of the National Research University Higher School of Economics.

Appendix 1.

List of keywords for technology clusters

Clusters	Keywords
Videoconferencing	Video conferencing app
	Video conference
	Video conferencing tool
	Video conferencing solution
	Video conferencing
	Video conferencing platform
	Cisco webex
Videoconferencing	Video conferencing service
	Video conferencing software
	Video meeting
	Microsoft teams
	Zoom
	Teleconferencing
	Video communication

Clusters	Keywords
Videoconferencing	Video conferencing service
	Video conferencing software
	Video meeting
	Microsoft teams
	Zoom
	Teleconferencing
	Video communication
	Virtual conference room
	Virtual conferencing
	Online conferencing
	Videoconferencing solution
	Videoconferencing software
Business continuity services	Business continuity plan
	Business continuity
	Remote workforce
	Business solution application
	Remote collaboration
	Remote worker
	Real time intelligence
	Remote employee
	Business continuity tool
	Remote work
	Remote collaboration tool
	Virtual workspace
	Virtual collaboration
	Online collaboration tool
	Virtual collaboration platform
	Collaboration software

Clusters	Keywords
Business continuity services	Digital work environment
	Collaboration technology
	Virtual whiteboard
	Cloud base collaboration
	Cloud base communication
	Online collaboration platform
	Enterprise collaboration platform
Digital logistics	Logistic supplier
	Logistical arrangement
	Logistic centre
	Logistical challenge
	Logistic app
	Supply chain AND digital service
	Transport AND digital service
	Logistic AND digital service
	Supply chain AND digital solution
	Management tool AND supply chain
	Logistics AND digital solution
	Logistic hub
	Digital logistics
Telemedicine	Telehealth vendor
	Telehealth service
	Telemedicine service
	Telehealth visit
	Telehealth platform

Clusters	Keywords
Telemedicine	Telehealth provider
	Telehealth company
	Virtual doctor
	Telehealth consultation
	Telehealth program
	Telehealth solution
	Virtual care
	Telehealth
	Telemedicine
	Remote consultation
	Mobile telehealth
	Telehealth policy
	Telehealth policy
	Telemedicine consult
	Online care
E-commerce	Online delivery service
	Pickup and delivery service
	Grocery delivery service
	Food delivery service
	Delivery service
	Delivery service
	Home delivery service
	Online shopping
	Food delivery
	Google pay
	E commerce
	E commerce platform
	Ecommerce business

Clusters	Keywords
E-commerce	Ecommerce store
	Last mile delivery
	Digital commerce
	E commerce delivery
	Virtual marketplace
Online entertainment	Home broadcast
	Virtual museum
	Online entertainment
	Streaming service
	Streaming platform
	Virtual sport
Online entertainment	Virtual tourism
	Digital entertainment
	Streaming content
	Virtual gallery
	Virtual tour
	Virtual travel
	Virtual entertainment
	Virtual fashion
Cybersecurity	Cybersecurity policy
	Cybersecurity concern
	Cyber risk
	Cyber criminal
	Cyber threat
	Cybersecurity company
	Cybersecurity service
	Cybersecurity strategy
	Cybersecurity industry

Clusters	Keywords
Cybersecurity	Cybersecurity tool
	Cybersecurity product
	Cyber defense
	Zero trust
	Information security
	Critical infrastructure protection
	Cybersecurity solution
	Cybersecurity technology
	Cybersecurity innovation
	Information security solution
	Data security
Digital currency	E krona
	Digital fiat currency
	Digital dollar
	Digital euro
	Digital yuan
	Central bank digital currency
	Digital fiat
	Bank issue digital currency
	Digital ruble
	Bank digital currency
	Digital renminbi
	CBDC
	Digital RMB
	DFC

Clusters	Keywords
Biometrics	Face recognition
	Biometric identification
	Fingerprint biometric
	Biometric data
	Retina scan
	Face biometric
	Biometric technology
	Voice biometric
	Biometric solution
	Iris recognition
	Biometric research
	Mobile biometric
	Biometric application
	Biometric method
	Facial biometric
	Biometric reader
	Biometric identification system
	Biometric device
	Biometric information
	Multimodal biometric

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About the authors

Roman A. Shcherbakov

Research Assistant, Laboratory for Science and Technology Studies, Institute for Statistical Studies and Economics of Knowledge, HSE University, 20, Myasnitskaya Street, Moscow 101000, Russia;

E-mail: rashcherbakov@hse.ru

ORCID: 0000-0002-5054-3869

Sofya G. Privorotskaya

Cand. Sci. (Econ.);

Head of the Digital Technologies Research Unit, Digital Economics Centre, Institute for Statistical Studies and Economics of Knowledge, HSE University, 20, Myasnitskaya Street, Moscow 101000, Russia;

E-mail: sprivorotskaya@hse.ru

ORCID: 0000-0002-4552-4938

Konstantin O. Vishnevskiy

Cand. Sci. (Econ.);

Director of Digital Economics Centre, Institute for Statistical Studies and Economics of Knowledge, HSE University, 20, Myasnitskaya Street, Moscow 101000, Russia;

Senior Research Fellow, Laboratory for Science and Technology Studies, Institute for Statistical Studies and Economics of Knowledge, HSE University, 20, Myasnitskaya Street, Moscow 101000, Russia;

E-mail: kvishnevsky@hse.ru

ORCID: 0000-0003-3621-0504