RECURRENCE ANALYSIS OF THE BEHAVIOR OF EDTECH SECTOR AGENTS IN THE CONDITIONS OF COVID-19

Ocheretin D.V., Garanina A.V.
Zaporizhzhia National University
Ukraine, 69063, Zaporizhzhia, Zhukovsky str., 66
odvisua@gmail.com, garanina_av@ukr.net
ORCID 0000-0001-6705-6381

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This article is devoted to the problem of uncertainty in the behavior of EdTech market agents in the context of COVID-19. The relevance of the work is explained by digital transformation, which affects the conditions for the existence and development of EdTech sector agents (corporations and holding companies), as well as the growing need for new knowledge, skills and abilities to study the behavior of such agents during a pandemic. The aim of the work is to study the behavior of educational corporations and holding companies for the provision of educational services, which is described using an indicator of the value of the shares of these EdTech market agents in the context of COVID-19. To achieve this goal, a database was formed, the behavior of the dynamics of the selected time series was analyzed, and its type, the presence of a trend or randomness in the behavior of the time series, was determined. This process is implemented in the software environment for processing, mathematical modeling and graphical visualization of data R. The practical value of the study lies in determining the nature of the behavior of the time series during the pandemic, which will allow using these results when forecasting on the stock market of educational technologies to improve the accuracy of the forecast.

РЕКУРЕНТНИЙ АНАЛІЗ ПОВЕДІНКИ АГЕНТІВ EDTECH СЕКТОРУ В УМОВАХ COVID-19

Очеретін Д.В., Гараніна А.В.
Запорізький національний університет
Україна, 69063, Запоріжжя, вул. Жуковського, 66

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Дана стаття присвячена проблемі невизначеності в поведінці агентів EdTech ринку в умовах COVID-19. Актуальність роботи пояснюється цифровою трансформацією, яка впливає на умови існування та розвитку агентів EdTech сектору (корпорацій та холдингових компаній), а також у зростанні потреби в нових знаннях, уміннях та навичках для дослідження поведінки таких агентів в період пандемії. Мета роботи полягає у дослідженні поведінки освітніх корпорацій та холдингових компаній з надання освітніх послуг, яка описується на основі вартості акцій цих агентів EdTech ринку в умовах COVID-19. Для реалізації поставленої мети сформовано базу даних, проаналізовано поведінку динаміки обраного часового ряду та визначено її тип, наявність тренду чи випадковість в поводженні часового ряду. Цей процес реалізовано в програмному середовищі для обробки, математичного моделювання та графічної візуалізації даних R. Практична цінність дослідження полягає у визначенні характеру поведінки часового ряду в період пандемії, що дозволить використовувати ці результати при прогнозуванні на фондовому ринку освітніх технологій для підвищення точності прогнозу.

Statement of the problem

Digital transformation affects the processes of social life, provides new opportunities and ways of communication, changes the conditions of work, training, and everyday activities. The consequence of this is the growing need for new knowledge, skills and abilities and the increasing integration of education with various sectors of the economy.

In the context of the COVID-19 pandemic, new living conditions draw attention directly to the model of our behavior, determine that the issues of adhering to the rules

of safe interaction and the possibility of developing within the new established boundaries are priority basic goals for each of us. All over the world, offices and educational institutions have been forced to close and go online. New challenges and updated values have actualized the demand for specific goods and services that provide a solution to complex issues of the socio-economic security of everyone in a pandemic, have led to a fundamental change in the behavior of subjects in all online and offline markets of educational services. At the moment, timely monitoring of changes in the behavior of corporations and holding companies that manage educational institutions or provide educational services leads to the formation of a new quality of management, faster business adaptation, changes in the basic principles of interaction and functioning of subjects in all areas, explanation of current trends and prediction of the formation of new trends of key indicators.

Digital technologies are the basis for new ways of obtaining knowledge (both in educational institutions and outside them). In modern conditions of life, the concept of «lifelong learning» becomes relevant, since information and knowledge quickly become obsolete. As a result, there is an active development of educational technologies (EdTech), in particular online courses, mobile applications, etc. [1].

The most popular areas in the EdTech sphere are [2]: educational marketplaces (online courses, interactive textbooks, webinars) for self-study of educational material; programs and platforms for communication between participants in the educational process; technology and learning aids to detect plagiarism and identify online learners; learning bots to help you get assignments and check them. In a pandemic, educational technologies (EdTech) are developing especially actively, and the widespread use of such methods of obtaining knowledge provides an opportunity for participants in the EdTech sphere to choose.

Analysis of recent studies and publications

Modern means of the educational process (information and communication and interactive methods, distance learning methods) have gained wide popularity in the world due to the variability of the structure of educational technologies. The tutorial [3] reveals the theoretical aspects of the technologization of education, analyzes the most common educational technologies of modern educational institutions in Ukraine and Poland. The authors of the tutorial characterize educational, educational, social and educational, information technologies and management technologies. Particular attention is paid to the ways of formation of media literacy of students and protection from harmful informational influences.

The complexity of the EdTech system and the rationale for a systematic approach to EdTech research are discussed in the article [4]. The authors propose a network view of EdTech to provide insight into stakeholder roles, interactions, and influence points that can lead to significant improvements in learning outcomes. Building a robust EdTech knowledge graph can be a valuable tool for understanding and researching EdTech.

The creation of EdTech startups favors the development of online education. The article [5] is devoted to the study of the directions and prospects for the development of online education as a powerful accumulator of educational innovative technologies, namely, the analysis of the features of the global EdTech market, the study of global trends in the sphere of education, the diagnosis of problems in the Ukrainian development of educational startups and the study of educational technologies in terms of investment attractiveness. The research identified the main inhibitory factors for the active use of educational technologies in Ukraine, such as the lack of a sufficient number of customers, limited resources in educational institutions and insufficient state interest in innovative projects. It was also proposed to economically stimulate Ukrainian developers, actively popularize AR / VR technologies and form ecosystems (fast track), the task of which is to help in the development and rapid growth of educational startups.

Technology allows students to be more involved in the learning process and remember more. Also, educational technologies (EdTech) increase motivation for learning and promote better academic performance due to factors such as ease of use, psychological satisfaction and interest in new learning tools [6]. Promoting motivation to learn is especially important during the COVID-19 pandemic.

A significant number of publications have been devoted to the development of EdTech in the context of the COVID-19 pandemic in recent years. Indian researcher Damini Dutta [7] describes the role of business intelligence in EdTech organizations to adapt to regular changes. Porter's five forces analysis is the basis of the study of the influence factors on EdTech of the organization and competitors. The use of skills and different roles of business analysts determines the competitiveness and positioning of educational organizations.

The authors of the article [8] consider how the coronavirus crisis and broad quarantine rules boost online education or help the system prepare for the next crisis. The example of Learning Management Systems and Language Learning Platforms illustrates how EdTech companies can adapt their business models to changing market conditions and situational customer needs. In addition, with the help of user behavior data, the company has the opportunity to constantly innovate in existing EdTech systems.

The article [9] considers the problems associated with learning foreign languages during the lockdown during COVID-19. The authors conducted a SWOC analysis to identify possible strengths, weaknesses, opportunities and challenges associated with online learning during a pandemic. Based on the results of the content analysis, it was concluded that the flexibility of the time and location of students, the reach of a wide audience and quick feedback are the strengths of educational technologies. The weak side is the lack of eye contact and technical shortcomings in students. But the development of EdTech and academic flexibility are opportunities for distance learning under quarantine restrictions.

The problems that arise when commercial decisions are made too quickly for digital learning in the context of the COVID-19 pandemic are discussed in [10]. The authors state that an urgent task in the context of the COVID-19 pandemic is to actively engage people, networks, projects,

research and public discussions to promote the critically and reflexively informed practice of digitalization of education.

The impact of COVID-19 on business model innovation in EdTech startups is discussed in [11]. Since the pandemic was quick and unexpected, companies have had little time to change their own strategy. The authors found that EdTech startups focused their marketing efforts on the benefits of distance learning and the convenience of using products at home. Also, the parents of students and the formation of tariff plans for them became a new goal. Most of the EdTech startups have continued to offer their services free of charge, which has increased the awareness of the tools and the user base.

The research of the nature of structural changes in the behavior of digital agents in the financial market based on the use of recurrence quantification analysis was considered in the article [12]. The behavior of EdTech market agents is also subject to structural changes under quarantine restrictions, so the practical value of the study is to determine the characteristics of the behavior model of EdTech market agents before and after the introduction of quarantine restrictions due to COVID-19.

Objectives of the article

The purpose of the article is to study the behavior of EdTech market agents in the context of COVID-19, therefore, the dynamics of changes in the value of shares of educational corporations and holding companies for the provision of educational services is analyzed using recurrence diagrams. The object of the study is the time series of the value of shares of educational corporations and holding companies for the provision of educational services according to Google Finance. The subject of the study is the methods of nonlinear dynamics.

The main material of the research

Consider the stock price performance of three EDTech companies before and during the COVID-19 pandemic: Chinese holding company that offers after-school education and tutoring services to elementary and high school students TAL Education Group (NYSE: TAL), Chinese private education provider New Oriental Education & Technology Group Inc. (NYSE: EDU) and Adtalem Global Education Inc. from the USA, which operates commercial institutions of higher education (NYSE: ATGE). The dynamics of stock prices of these companies based on data from the Google Finance service [13] for the period from October 22, 2010 to April 07, 2022 (weekly data) is shown in Figure 1.

The imposition of a lockdown in connection with the COVID-19 pandemic with the complete closure of educational institutions [14] (January 23, 2020 in China and March-April 2020 in the USA) caused an active growth in the value of shares of companies in the EdTech sector. The sharp drop in the value of shares of Chinese companies in May 2021 is due to the introduction of restrictions by the Chinese authorities on online educational platforms and companies that provide tutoring services as part of the school curriculum. According to the new rules, all companies in this sector must be registered as non-profit organizations. They will no longer be able to conduct IPOs and attract foreign capital, as well as provide tutoring services to the detriment of public holidays, weekends and school holidays.

American company Adtalem Global Education Inc. is associated with medical schools, so the drop in the value of the shares of this company is caused by an increase in the number of students in medical institutions in the 3rd quarter of 2021 and the emergence of the Omicron COVID-19 strain in February 2022.
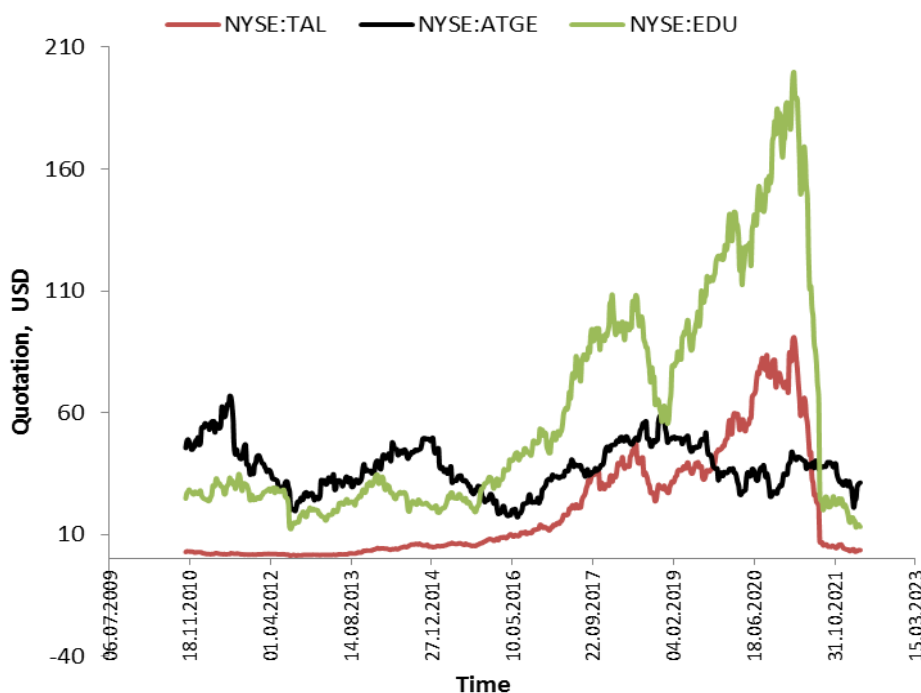

Fig. 1 – Stock quotes of EdTech companies for the period from October 22, 2010 to April 07, 2022

Even before the COVID-19 pandemic, the global education industry was facing a chain of challenges, including limited educational infrastructure, lack of qualified teachers, low public spending and high dropout rates, especially in less developed countries. The pandemic has only exacerbated these problems as most schools closed and uncertainty about the future increased.

The study of the time series of the stock of shares of EdTech companies was carried out by means of recurrence analysis. For the generated database of incoming data, the indicators of the first local minimum of the mutual information function (AMI) and the dimension of the time series (using the false nearest neighbor algorithm) are calculated, on the basis of which the recurrence diagram is built [15]. The calculation of the optimal delay time of the time series, the nearest false neighbors and the construction of the recurrent diagram were performed in the R environment using the tseriesChaos and fractal libraries. The analysis of the statistical characteristics of the recurrence diagram makes it possible to determine the measures of complexity of the structures of the recurrent diagrams [12]: recurrence rate (RR), percent recurrence (REC%), percent determinism (DET%), average diagonal line length (ADL) and maximum diagonal line length (MDL) of the recurrent diagram.

Based on the analysis of the statistical characteristics of the recurrence diagram, it is possible to determine the presence of homogeneous processes with independent random values; processes with slowly changing parameters; periodic or oscillating processes corresponding to nonlinear systems. Thus, the analysis of the recurrence surface makes it possible to evaluate the characteristics of a nonlinear object on relatively short time series, which makes it possible to make prompt decisions regarding the management of the object.

Based on the results of the analysis of the value of shares of selected EdTech companies for 599 weeks in 2010–2022, recurrence diagrams were obtained (Figure 2), the topological analysis of which allows us to determine the structure, type, change in the behavior of the object of study, the boundaries of phase transitions, and establish the sensitivity of quantitative measures.

The topology of recurrence plots for Chinese EdTech stocks traded on the New York Stock Exchange (NYSE: TAL and NYSE: EDU) shows abrupt changes in system dynamics, which causes white areas or stripes to appear. There is a gradual change in the behavior of representatives of the EdTech sphere, a drift of the attractor (white lower and upper corners of the diagram, a diagonal line) and the formation of a new structure during the period of influence of the consequences of COVID-19.
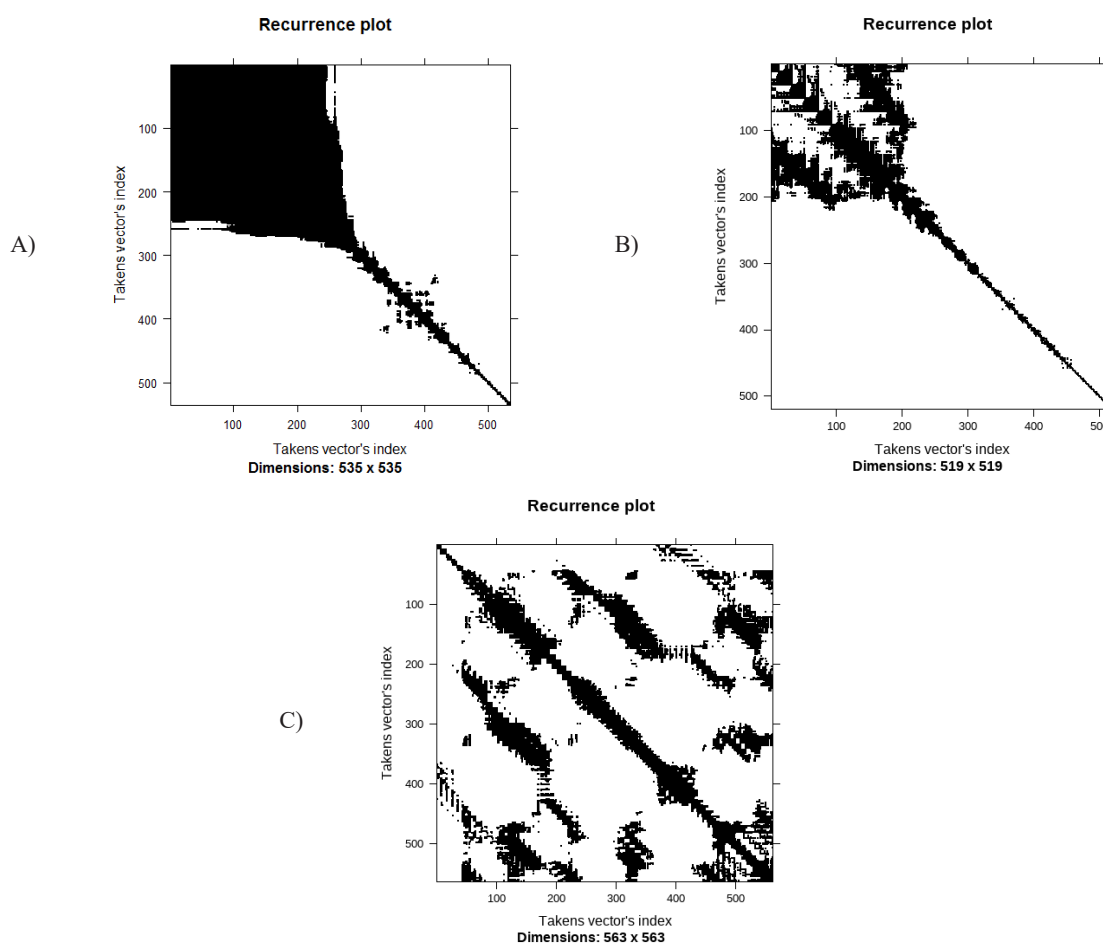

Fig. 2 – Recurence plots of the stock of shares of educational corporations and holding companies providing educational services for the period from October 22, 2010 to April 07, 2022: A) NYSE: TAL, B) NYSE: EDU, C) NYSE: ATGE

Topology of the recurrence diagram for the value of shares on the New York Stock Exchange of the American Adtalem Global Education Inc. (NYSE: ATGE) contains short diagonal stripes, which indicates the stochastic behavior of the company in the EdTech market and the return of the trajectory to the same region of phase space at different time periods.

Quantitative characteristics of recurrence diagrams are given in Table 1.

Since the value of the percent recurrence (REC%) for all charts of stock prices of EdTech companies is more than 5 %, we can conclude that the time series behavior of the stock prices of these companies is irregular. For NYSE: EDU stocks, the average percent recurrence is moderate, while for NYSE: TAL and NYSE: ATGE it is high.

The percent determinism (DET%) characterizes the level of predictability of the time series. Diagonal structures show the time during which a segment of the trajectory passes very close to another segment of the trajectory. For all three time series considered, the level of predictability is over 90 %.

The average diagonal line length (ADL) characterizes the average time during which two sections of the trajectory pass close to each other and can be considered as the average predictability time of the series. According to the results of calculations, the shortest average predictability

time has the time series NYSE: ATGE (7.024 points), and the longest – NYSE: TAL (67.181 points).

The maximum diagonal line length (MDL) characterizes the length of the trend. The shortest trend has a time series NYSE: EDU (315 points), and the longest – NYSE: ATGE (519 points).

Recurrence quantification analysis (RQA) can be used not only to quantify the dynamics of the entire time series, but also to study changes in the dynamics of the series. Windowed recurrence quantification is potentially a very powerful tool for detecting changes in subsets of a time series. To study the time structure, the series were divided into two adjacent windows that do not intersect, 128 data points each, and the statistical characteristics of each of them were calculated. The windows are chosen in such a way as to analyze the behavior of EdTech companies before and after the introduction of quarantine restrictions. The first window covers the period from May 19, 2017 to October 25, 2019, and the second window covers the period from November 1, 2019 to April 07, 2022.

Recurrence plots for the windows of the TAL Education Group shares are shown in Figure 3, and the statistical characteristics of these plots are shown in Table 2.

Values of the percent recurrence (REC%) in the periods before the start of the pandemic and after did not change much and indicate the irregular behavior of the time series.

Table 1 – Statistical characteristics of recurrence plots of stock prices of EdTech companies in 2010–2022

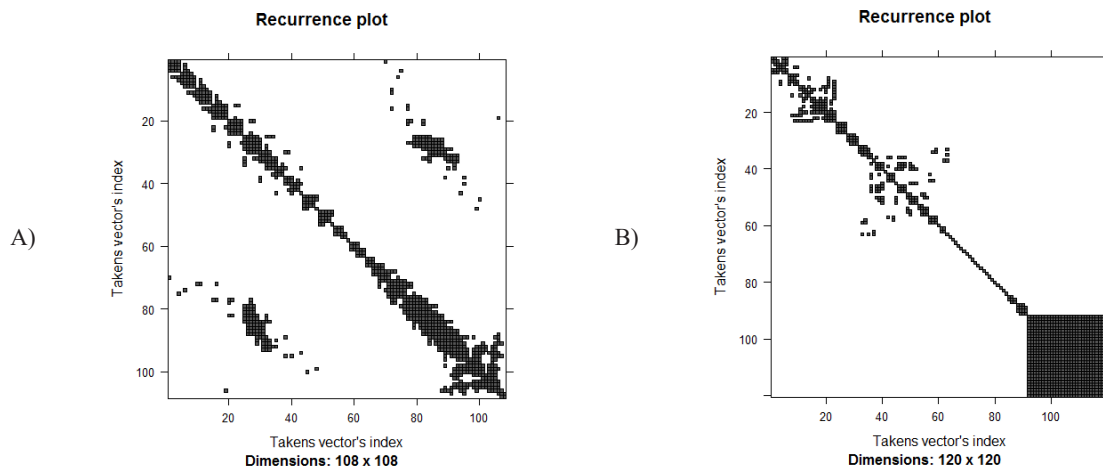| Measures of the recurrence plot	NYSE: TAL	NYSE: EDU	NYSE: ATGE
REC%	25.800	8.261	16.098
DET%	99.255	94.634	92.902
ADL	67.181	8.191	7.024
MDL	458	315	519

Fig. 3 – Recurence plots of the stock of shares of NYSE: TAL for the period:
A) May, 19, 2017 – October, 25, 2019, B) November, 01, 2019 – April, 07, 2022

Table 2 – Statistical characteristics of recurrence plots of stock prices of NYSE: TAL

Measures of the recurrence plot	May, 19, 2017 – October, 25, 2019	November, 01, 2019 – April, 07, 2022
REC%	8.52	8.53
DET%	84.31	90.23
ADL	5.48	9.01
MDL	44	28

After the start of quarantine measures, the predictability of the time series increased from 84.31 % to 90.23 %. The average predictability time also increased from 5.48 points to 9.01 points.

Windowed recurrence diagrams for the stock price of New Oriental Education & Technology Group Inc. are presented in Figure 4, and the statistical characteristics of these plots are shown in Table 3.

Values of the percent recurrence (REC%) in the periods before and after the onset of the pandemic indicates the irregular behavior of the time series. After the start of quarantine measures, the predictability of the time series increased from 79.87 % to 86.81 %. The average predictability time also increased from 3.67 points to 8.91 points.

Windowed recurrence plots of Adtalem Global Education Inc stock prices are presented in Figure 5, and the statistical characteristics of these plots are shown in Table 4.

Values of the percent recurrence (REC%) in the periods before and after the start of the pandemic indicate the irregular behavior of the time series. After the start of quarantine measures, there is a slight decrease in the predictability of the time series from 96.40 % to 93.69 %. The average predictability time also decreased from 11.39 points to 6.80 points.

The presence of black strips in Figure 5.B indicates the non-stationarity of the behavior of the shares of Adtalem Global Education Inc., which means the formation of a transition period. Periodic patterns characterize the
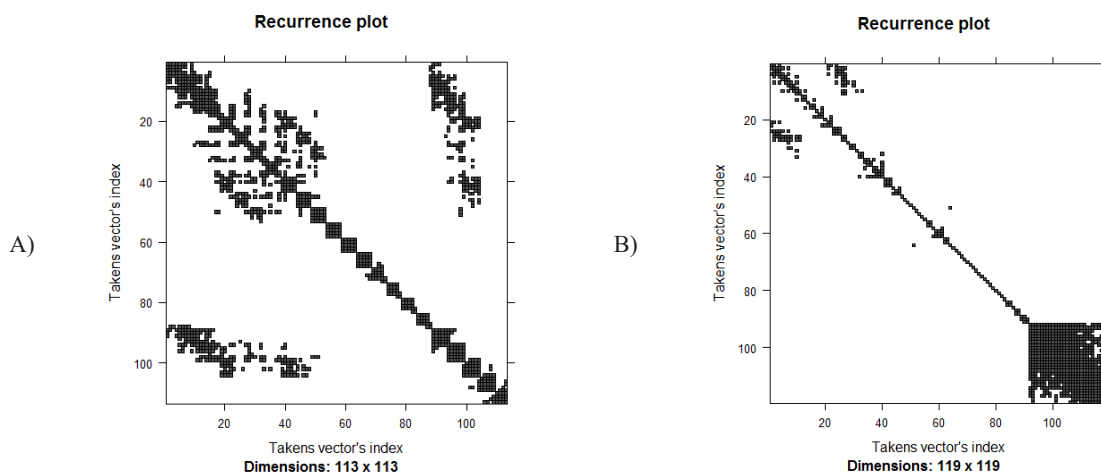

Fig. 4 – Recurence plots of the stock of shares of NYSE: EDU for the period:
A) May, 19, 2017 – October, 25, 2019, B) November, 01, 2019 – April, 07, 2022

Table 3 – Statistical characteristics of recurrence plots of stock prices of NYSE: EDU

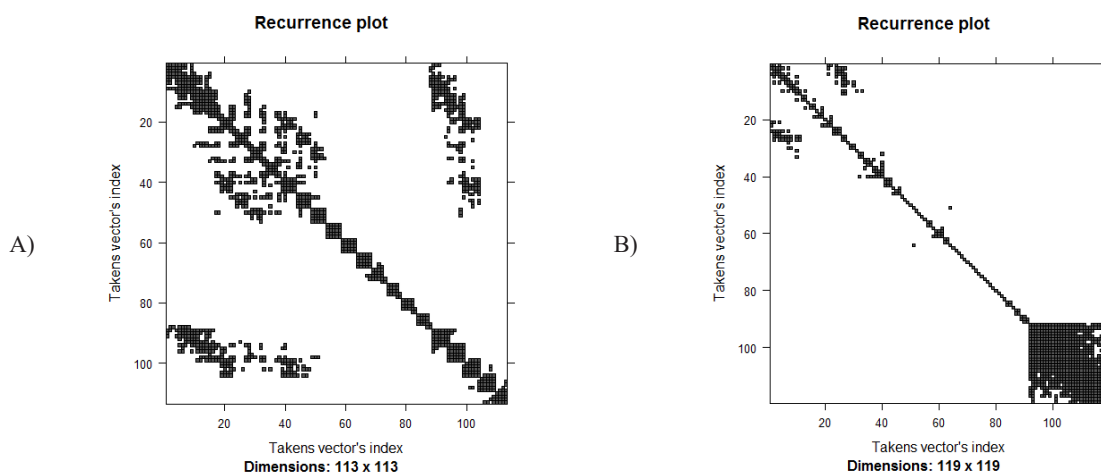| Measures of the recurrence plot	May, 19, 2017 – October, 25, 2019	November, 01, 2019 – April, 07, 2022
REC%	10,97	6,74
DET%	79,87	86,81
ADL	3,67	8,91
MDL	37	27

Fig. 5 – Recurence plots of the stock of shares of NYSE: ATGE for the period:
A) May, 19, 2017 – October, 25, 2019, B) November, 01, 2019 – April, 07, 2022

Table 4 – Statistical characteristics of recurrence plots of stock prices of NYSE: ATGE

Measures of the recurrence plot	May, 19, 2017 – October, 25, 2019	November, 01, 2019 – April, 07, 2022
REC%	46.4	51.59
DET%	96.40	93.69
ADL	11.39	6.80
MDL	111	100

cyclicality of certain changes in the value of shares, the distance between which determines the period. Black isolated dots characterize random interest in the value of shares of this company, its rapid change.

Conclusion

The research revealed the nature of the behavior of educational corporations and holding companies for the provision of educational services in the context of COVID-19. New York Stock Exchange share recurrence plots were plotted for a Chinese holding company that offers post-secondary education and tutoring services to elementary and high school students TAL Education Group (NYSE: TAL) and Chinese private education provider New Oriental Education & Technology Group Inc. (NYSE: EDU). For this, weekly data for 599 weeks from 2010–2022 were selected. The dynamics of the value of the shares of both companies has a similar behavior – the time series are non-stationary, but the NYSE: EDU time series has a lower level of predictability than the NYSE: TAL time series. This can be explained by the fact that post-secondary education and tutoring services for primary and secondary school students were less affected by quarantine restrictions than language courses for adults and courses for preparing for professional exams inside China and abroad.

A windowed recurrence analysis was also performed for periods of 128 weeks before and after the introduction of quarantine restrictions. In accordance with its results, it was revealed that the introduction of quarantine restrictions led to an increase in the level of predictability of the time series by 7% for the shares of TAL Education Group and by 8.7% for the shares of New Oriental Education & Technology Group Inc.

In the research, a recurrence plot of the value of shares of Adtalem Global Education Inc. (USA, NYSE: ATGE) on the New York Stock Exchange was built (weekly data for 599 weeks in 2010–2022). This company operates commercial higher institutions. An analysis of the topology of the recurrence plot indicates that the time series of the value of the shares of this company is non-deterministic and has a stochastic character, and the trajectory returns to the same area of the phase space at different times.

Windowed recurrence analysis of Adtalem Global Education Inc. stock price for periods of 128 weeks before and after the introduction of quarantine restrictions indicates a decrease in the predictability of the time series by 2.8% after the introduction of quarantine restrictions in the USA in March-April 2020. Also, this is due to the fact that Adtalem Global Education Inc. manages medical schools that have experienced an increase in demand for medical education during the pandemic.

The behavior of EdTech sector agents in the context of COVID-19 requires further research, since the EdTech sector in the financial market is represented not only by companies that provide educational services, but also by educational technology companies, scientific publishers, etc.

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