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Reception of Mandelbrot and his economic ideas in Russia

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In this article, I analyze the Russian-language academic literature mentioning and discussing Benoit Mandelbrot's economic ideas. The main findings are that Mandelbrot's economic ideas about the fractal nature of markets have a limited popularity among Russian-speaking scholars. The peak was reached in the middle of the 2010s, and now every year we see a smaller number of publications mentioning him. He stays more recognized in the field of mathematics and geometry, compared to economics. However, in the works of Russian-speaking scholars mentioning Mandelbrot we can see that his ideas were met with quite a positive attitude. His novelty and originality are recognized. The reception of fractal theory in economics varies from being the only working strategy for building an adequate model of the market and predicting financial collapses to not having many benefits in comparison to the classical probabilistic theory. Nevertheless, evidence shows that markets have fractal (not random) nature, and new works support that idea. Some scholars regret the undeserved unpopularity of fractal theory, while others explain it by its incompleteness and complexity, which limits the wide practical usage of Mandelbrot's ideas. Despite all limitations, the fractal theory definitely has its own place in economics and finance. Probably the main significance of Mandelbrot's theory is not in its practical tools, but in the general philosophic idea.

Keywords: *Mandelbrot; fractal theory; fractal; economics; finance*

JEL codes: *B00, B17, B31, B59*

Восприятие Мандельброта и его экономических идей в России

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В данной статье проводится анализ научных работ, в которых упоминаются или обсуждаются идеи Бенуа Мандельброта по экономике. Основной вывод состоит в том, что экономическая теория Мандельброта о фрактальной природе рынков пользуется умеренной популярностью среди русскоговорящих ученых. Пик популярности теории пришелся на середину 2010-х гг., и с тех пор с каждым годом количество цитирований падает. Автор остается признанным специалистом в области математики и геометрии, в то время как в области экономики его отмечают все меньше. Среди тех, кто все же ссылается на теорию фракталов, отношение к ней остается скорее позитивным, признается ее новизна и оригинальность. Отношение к теории фракталов в экономике варьируется от признания ее единственной работающей стратегией для построения адекватной модели рынка и предсказания экономических кризисов до утверждения, что она не имеет никаких преимуществ перед классической теорией, основанной на нормальном распределении. Тем не менее, свидетельства указывают на то, что рынки имеют фрактальную (не случайную) природу. Новые исследования также подтверждают это. Некоторые ученые сожалеют о незаслуженно низкой популярности теории Мандельброта, в то время как их коллеги объясняют это чрезмерной ее сложностью, которая делает практическое применение затруднительным. Несмотря на все оговорки, теория фракталов, без сомнения, находит свое место в науке об экономике и финансах. Возможно, главная ценность теории фракталов Мандельброта – в самой ее философской идее, а не в ее практическом применении.

Ключевые слова: *Мандельброт; фрактальная теория; фрактал; экономика; финансы*

Introduction

Mandelbrot is widely known for his impact on mathematics, and especially on the geometry of fractals (he was actually the one who invented that term). However, he insisted that these theoretical ideas have a practical implication and could be used to describe the (mis)behavior of markets. That is the name of his popular book published in 2004. Other works on that topic were published before that year, as well as after it.

He had been developing the theory through almost his whole life. As Richard Hudson wrote in a prelude to Mandelbrot's book, "for Mandelbrot, economics has been both inspiration and curse. His study of financial charts in the 1960s helped stimulate his subsequent fractal theories in the 1970s and 1980s. He taught economics for a year at Harvard; and his first major paper in the field in 1962 (expanded and revised in 1963 and the next few years) was a study of cotton prices. In it, he presented substantial evidence against one of the fundamental assumptions of what became "modern" financial theory. At that time, the theory was beginning to be entrenched in university economics departments and it would soon become orthodoxy on Wall Street. As Mandelbrot continued his fractal studies, he often returned to economics. Each time, he probed how markets work, how to develop a good economic model for them—and, ultimately, how to avoid loss in them." (Hudson, 2004: 31).

Mandelbrot's ideas gained some recognition all around the world, and in Russia as well. In this essay I am going to explore how these economic ideas were perceived among Russian-speaking economists and mathematicians.

Mandelbrot's economic ideas

Let me first briefly explain the main points that Benoit Mandelbrot wanted to indicate in economics. His general idea is that price movements do follow not the Gaussian distribution, but a power law. Prices often leap (not glide), which makes them almost impossible to predict. However, you can estimate the odds of future volatility and make the risks more manageable (Mandelbrot, 1997; Mandelbrot and Hudson, 2004).

Mandelbrot refers to irregularity and scaling as important features of fractal geometry: "When irregularity is present at all scales, it is simplest when, whatever the magnification, the fine details seen under the microscope are the same (scale aside) as the gross features seen by the naked eye. Using the vocabulary of geography, the fine details seen on a very precise map are the same as the gross features seen on a rough map" (Mandelbrot, 1983: 152). Similar patterns could be seen not only in geographical maps, but also in the graphs of price changes.

Talking about markets, Mandelbrot calls them uncertain, deceptive, turbulent and even wild. However, he claims that they have a fractal nature (that is his most famous finding), which means that on a small scale they are self-similar to a larger scale, and vice versa. If we better understand their fractal nature, we will see that "in all places and ages" they work alike (Mandelbrot and Hudson, 2004: 506).

In his book (Mandelbrot and Hudson, 2004) and other works (Mandelbrot, 1963; 1966; 1999; Mandelbrot and Taylor, 1967[1]), Mandelbrot compares his theory with the classical investment theory that is used in modern finance, also known as the Random Walk model, the probabilistic model, or the Bachelier model. I believe it is also important to indicate some particular details of this theory, and specify which of them Mandelbrot disagrees with.

The first claim of the probabilistic model is that the best guess of tomorrow's price is the price you see today. This is what Mandelbrot (Mandelbrot and Hudson, 2004) generally agrees with, altogether with remarking that it is not proven by the data. That influence is also called the memory of the market: "markets keep the memory of past moves, particularly of volatile days, and act according to such memory. Volatility breeds volatility; it comes in clusters and lumps"[2].

The second claim of the Random Walk model is that prices are independent, so they are basically a sequence of non-related and identically distributed random variables. Contrariwise, Mandelbrot suggests that prices are dependent, and markets have "memory". However, he is talking about dependence without correlation. Dependence with correlation would mean that growth is followed by growth, while decrease is followed by decrease. Dependence without correlation is that "large price changes tend to be followed by more large changes, positive or negative. Small changes tend to be followed by more small changes. Volatility clusters" (Mandelbrot and Hudson, 2004: 522).

The third claim is that mostly the price changes are small, while big leaps happen rarely. This can be illustrated using the bell curve (or the normal distribution) with very thin tails: about 68% of movements are within one standard deviation, 95% are within 2 standard deviations, 99% are within three deviations. Mandelbrot, on the contrary, says that price movements cannot follow a bell curve, because the tails are actually thick (Mandelbrot, 1963; 1999). In other words, radical changes in prices happen more often than one may expect.

While Mandelbrot agrees that the probabilistic model shows some degree of accuracy during most market conditions, he implies that it fails to predict and work properly during economic crises and price turbulence. While the Random Walk model explains the clusters of volatility by the change of markets and the pricing mechanisms in particular, Mandelbrot says that market processes are "stationary". In his opinion, bubbles and crashes of the market are not an anomaly. They are inherent to markets (Mandelbrot, 1999; Mandelbrot and Hudson, 2004).

Above I have mostly spoken about theoretical matters, but, as with any economic theory, these ideas ought to have some practical implications. Mandelbrot repeats many times that stock prices cannot be predicted in any useful sense. However, with the usage of the multifractal model you can estimate the pattern of risk, which can be useful in investing (Mandelbrot, 1967; 1997; 1999; 2005).

A very clear description of an implication of the multifractal model was given in one of the books by Mandelbrot: "[The diagram of the] financial fractal begins with a box, one unit wide by one unit tall […]. Inside the box, we draw a straight line rising from the bottom left corner, at coordinate (0,0), to the top right corner, at coordinate (1,1). This is the underlying trend line – the assurance that our final chart will eventually show a profit, no matter how much prices fluctuate along the way. If we wanted to model a market drop, we could as easily do so by starting with a line that falls from top left to bottom right. Then, you see a zigzag shape called generator that fits over the straight line. It is in three parts, as shown: It rises, breaks downward at a critical point, then breaks upward again. Exactly where it breaks and how frequently is crucial to the outcome." (Mandelbrot and Hudson, 2004: 268).

This technique can be used for backward and forward analysis of price movements. The first one means using the past price data, estimating the parameters of the fractal model and creating an artificial graph that follows the same statistical pattern. The second one, forward analysis, means constructing artificial price charts from the fractal seeds.

In one of his books, Mandelbrot presents several graphs that were simulated using the multifractal theory. You can see two of them in Figures 1 and 2 below. The first one is created without randomization to better understand how you simulate the movement of prices using fractals and generator lines. The second one is basically the same, but with some pieces of its generator "scrambled" (Mandelbrot and Hudson, 2004: 271).

[1] See also: Mandelbrot, B., Taleb, N. (2005). How the finance gurus get risk all wrong. *Fortune Magazine*, July 11. https://money.cnn.com/magazines/fortune/fortune_archive/2005/07/11/8265256/index.htm (accessed on December 23, 2023)

[2] Mandelbrot and Taleb, 2005, as cited above.

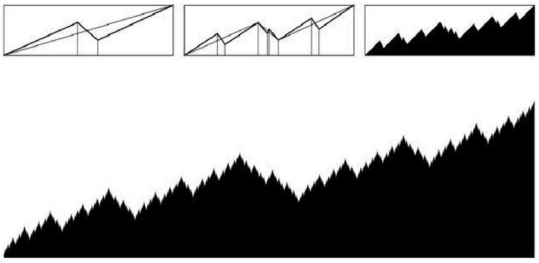

Fig. 1. The cartoon stock chart
Source: Mandelbrot and Hudson, 2004

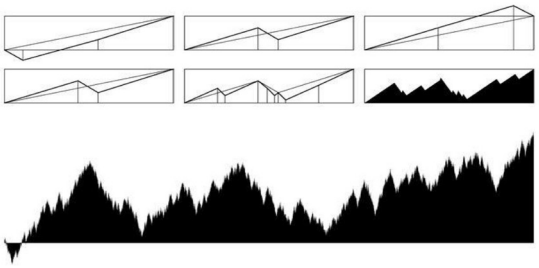

Fig. 2. The randomized cartoon stock chart
Source: Mandelbrot and Hudson, 2004

With understanding of what Mandelbrot's economic ideas generally consist of, we can now move to analyzing their reception in the Russian-speaking academic circles.

Mandelbrot's ideas and Russian-speaking scholars: Growing and falling popularity

Although Mandelbrot developed his ideas about the fractal nature of markets in the 1960s, his works on economics started to gain some recognition among Russian-speaking scholars only in the 1990s. Based on the query '"Mandelbrot" economics' ('"Мандельброт" экономика') and '"Mandelbrot" finance' ('"Мандельброт" финансы'), the first work appears in 2001, and it is a review of one of his books (Tutubalin, 2001). The reason for such delay until any citations in Russian may be the fact that many of his works were not yet translated. For example, his book "The Fractal Geometry of Nature" was originally published in 1982, but translated into Russian only in 2002 (Panchelyuga, 2010). Another of his books, (Mis)Behavior of Markets, was originally published in 2004, but translated into Russian in 2006. After that year we can see a sharp increase in the number of Russian-language publications mentioning him and economics.

In one of the articles published in 2010 the appearance of "The Fractal Geometry of Nature" was described in the following way: "The publication of this book divided the history of fractal geometry into two periods. In the first, before the book was published, the existence and development of fractal geometry was inextricably linked with the personality of its creator — with his efforts to develop and popularize his ideas. The second period is marked by an avalanche-like increase in the number of supporters of fractal geometry, the number of academic publications containing the word "fractal" in the title, the penetration of fractal geometry methods into almost all sections of not only natural sciences, but also humanities and even art" (Panchelyuga, 2010: 189).

Mandelbrot gained popularity over the years, reaching the peak in around 2012–2016 (Fig. 3). The biggest number was in 2014–2016 with 144 publications mentioning his surname and the word "economics" in Russian. After that we see a decrease of publications with a reference to him.

Another evident trend is that citations of him and his works mostly come from the time after his death in 2010:

- The query "Mandelbrot" ("Мандельброт") showed 878 articles before 2010 and 3360 from 2011 onwards.
- The query '"Mandelbrot" economics' ('"Мандельброт" экономика') showed 364 papers before 2010 and 1460 after.
- The query '"Mandelbrot" finance' ('"Мандельброт" финансы') showed 142 academic publications before 2010 and 518 after that year.

While his economic ideas grew in popularity, they were still less popular than his ideas in mathematics and geometry (Figure 4). These two requests '"Mandelbrot" mathematics' and '"Mandelbrot" geometry' ('"Мандельброт" математика' and '"Мандельброт" геометрия') showed 589 and 643 results respectively before 2010, and 2200 and 2380 results since 2011. The above-mentioned numbers were collected from Google Scholar in December, 2023.

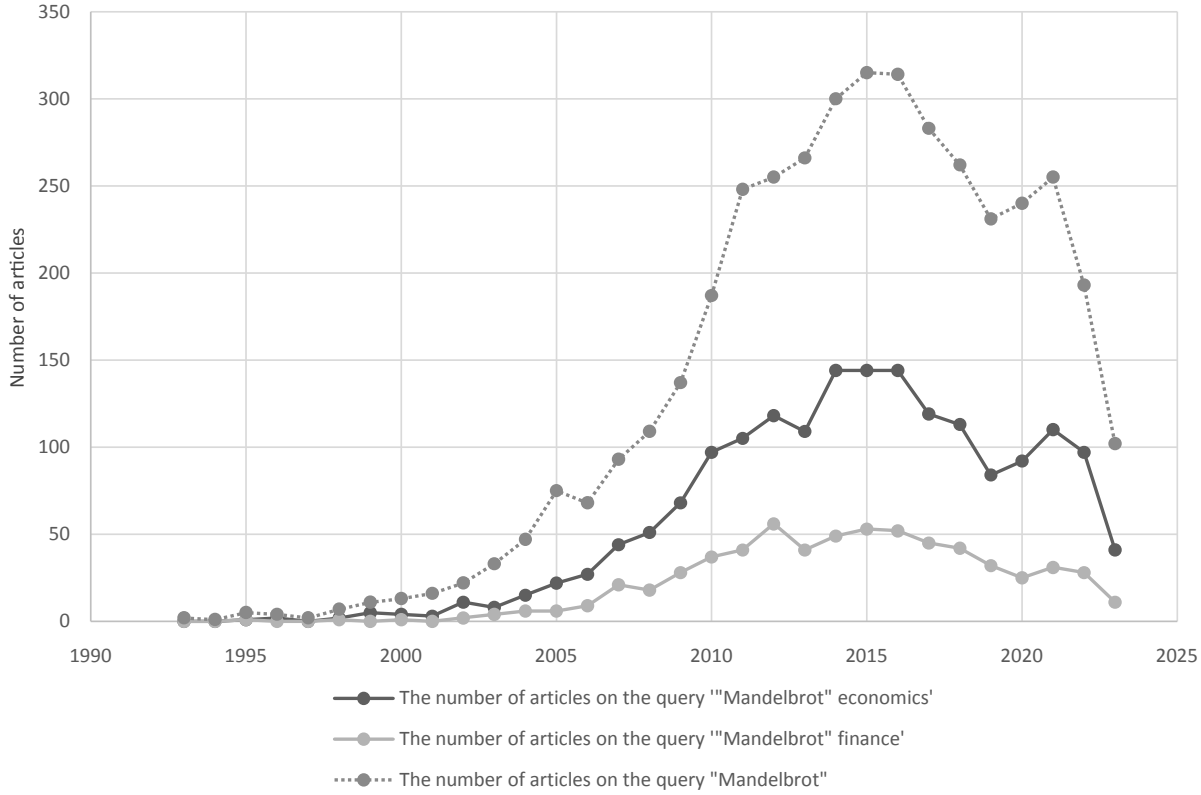

Fig. 3. The number of articles in the Russian language mentioning Mandelbrot alone and him along with the words "economics" and "finance" from 1993 to 2023, based on Google Scholar
Source: Author

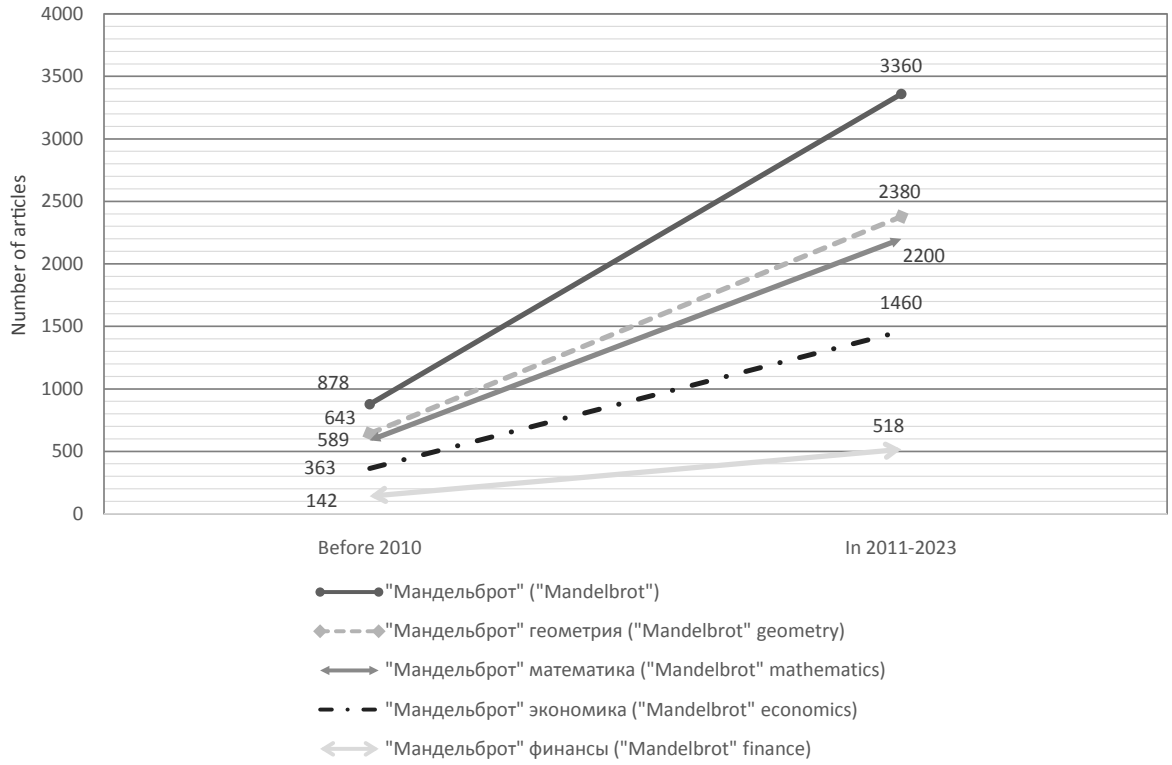

Fig. 4. Number of articles in Russian mentioning Mandelbrot before and after 2010, based on Google Scholar
Source: Author

General characteristics and positive reception of Mandelbrot's ideas

Now let me move to the discussion of the content of the papers mentioning him along with the words "economics" and "finance". Firstly, economics often just stands in the long line of the areas to which Mandelbrot contributed: "Mandelbrot's books are a combination of mathematics and philosophy, plus elements of physics, economics, biology, and history" (Shlyk, 2005: 118). It is often said that he could not be described by any single label: "'mathematician', 'economist', 'physicist', 'hydrologist'… – any cliche does not fully characterize him" (Shlyk, 2005: 116). However, his contribution to economics is still recognized: "B. Mandelbrot is not only the author of fractal geometry as an illustration of the processes of ordering in chaotic changes, but also a pioneer of their analysis in economic processes" (Lavrikova et al., 2023: 83).

Secondly, when Mandelbrot's ideas in economics are mentioned, they are often mentioned without any discussion. That is, the author just states that there are such ideas, and does not say whether they are true or not, widely used or not, valid or not. For example: "In economics, Mandelbrot discovered that seemingly random fluctuations in the price of cotton over a long-time interval (more than a hundred years) follow a hidden mathematical order in time that is not described by standard curves; he traced symmetry in long and short-term price fluctuations" (Rosenberg et al., 2011: 412) or "Fractal analysis is a kind of synergy of a technical, fundamental and statistical approach to forecasting market dynamics" (Zhmurko and Osipov, 2018: 192).

When scholars talk about some specific ideas of Mandelbrot, apart from that broad notion of the fractal nature of markets, sometimes his "Noah effect" and "Joseph effect" are described: "The concepts he introduced of the Noah effect, a sharp fluctuation caused by an external event, and the Joseph effect, long periods of unusually high or low price indexes that violate the "usual" structure of the business cycle, show the complex nature of changes in economic dynamics" (Lavrikova et al., 2023: 83).

Sometimes fractal theory of markets is viewed as the only working strategy: "There are a large number of recommendations and strategies, but only the use of fractals allows you to build an adequate model of stock market behavior. The effectiveness of this approach is supported by the fact that many stock exchange participants spend a lot of money to pay for the services of specialists in this field" (Sandryukova and Dubinina, 2017: 350) or "Fractal analysis used in financial markets is a powerful new paradigm. This approach has revolutionized the nature of research conducted in a wide variety of fields of natural science, leading to completely unthinkable and astounding predictions. Fractals that reveal the basic structure of the financial market make it possible to predict the future with high accuracy" (Astrakhantseva, 2011: 35).

Among the positive aspects of his theory, it is thought that it could predict a future financial crisis: "It is quite possible that with the help of fractals, it will be possible in the future to prevent financial collapses, since it is known that before a market fluctuation, many radical deviations appear on the chart, because the probabilities of various deviations become equal." (Lagun, 2015: 309).

Positive comments about Mandelbrot's economic theory are often followed by the regret of its unpopularity or an urge to make them more recognized: "such a concept as a fractal is of great importance for the market, but, unfortunately, not everyone is familiar with it" (Glazunova, 2019: 616) or "This [theory] cannot be ignored by educational institutions, primarily universities, as natural centers of fundamental scientific research. A modern specialist must know not only classical statistics." (Egorenkov et al., 2009: 140).

Overall, it can be said that Mandelbrot is mainly seen as a multidisciplinary scholar who created an unusual conception about market functioning. While his contributions to economics are acknowledged, they often remain understudied or simply mentioned without thorough exploration. Nevertheless, some scholars express optimism about the transformative potential of fractal theory.

Criticism and concerns about Mandelbrot's theory

At that point, a reasonable question appears: if the ideas of Mandelbrot are said to be so effective, why are they not widely used? Some authors, while admitting the new approach as an interesting suggestion, voice certain concerns regarding this theory:

1. Incompleteness: the theory is not very detailed (Panchelyuga, 2010; Tutubalin, 2001). "Currently, Mandelbrot's fractal model of the financial market is still incomplete and its results can be found only in some articles, as well as on Mandelbrot's website" (Zinenko and Semenov, 2013: 53). However, the virtues of the theory are also recognized in the same article: "For all its imperfection, there are many theoretical and practical arguments in its favor" (Ibid.). Reviewing one of Mandelbrot's books, the author claims that "the book does not provide definitive answers or practical recipes for modeling financial data, but it is such a classic work from which you can get inspiration or ideas for self-development, or just enjoy the original and elegant philosophy and the author" (Tutubalin, 2001: 204). Thus, Mandelbrot's ideas are sometimes seen as philosophical rather than economic or financial.
2. Underdeveloped mathematical apparatus: "it is difficult to verify the correctness of the fractal modeling result" (Lagun, 2015: 309; see also Efimova and Nikulin, 2013).
3. "Novelty and inconsistency with classical methods make it difficult to use it [the theory] widely" (Efimova and Nikulin, 2013: 65). By classical methods the authors mean methods based on probability (probabilistic theory) and bell curve distribution.
4. Fractal is a lagging indicator: "it only confirms the current trend in the market" (Lagun, 2015: 309).
5. Randomness and complexity: even very small changes in the input data can lead to inconsistency and severe mistakes (Lagun, 2015; Efimova and Nikulin, 2013).
6. Low effectiveness on small periods of time, compared to the long timeframes (Lagun, 2015).
7. While showing us the general pattern, the theory does not really help to understand the future movement of prices because of the undetermined size of generators: "Chaos theory is not intended to 'eliminate chaos', and the patterns it reveals do not allow us to determine the vector of movement of the studied indicator. […] Economic indicators are inherently cyclical. However, the frequency of this cyclicity is unstable, which makes it difficult to predict the length of cycles" (Zhmurko and Osipov, 2011: 192).

To sum up the critical comments about Mandelbrot's theory, the main claim is that the theory is not fully developed and the result is excessively influenced by many factors, such as input data and generator sizes. Also, it is said to be questionable that the theory is too different from most widely used theories.

Verification of Mandelbrot's theory

Based on the fact that there are ambivalent views on the issue of validity of the theory, the need for verification is evident. I have found three experiments made by Russian-speaking scholars to establish the effectiveness of the theory in terms of price prediction. In these experiments, the retrospective analysis was used. However, the results are contradictory.

In the first experiment there was a replication of experiments by Mandelbrot, Peters and Neumann, but on modern stock index quotations (Zinenko, 2012). The findings were the following: "The changes in stock index quotations are most reminiscent of Mandelbrot's illustration of a persistent process". The results were verified in three ways, and the last one showed the greatest significance. It was the "calculation of the Hurst index on mixed data. In the presence of long-term memory, the order of the elements is important, so the mixed data should show a lower value of the Hurst index". In the case of that experiment, "the mixed data gave an anti-persistent process, therefore, the test confirmed the hypothesis" that markets have "memory" (Zinenko, 2012: 30).

Another experiment took the data from the official FOREX website – FXTMPIRE and calculated the Hurst indicator for EUR / USD at closing prices (Nekrasova, 2015). The results also have shown the effectiveness of fractal theory: "Our calculations have shown that market phenomena and economic indicators are not random phenomena. The market is inertial, i.e. it has memory. <…> Various types of financial products form the fractal structure of the market. This, in its turn, confirms the validity of the Fractal Market Hypothesis (FMH), which is an alternative to the Effective Market Hypothesis (EMH)" (Nekrasova, 2015: 90).

From these two experiments we see that it was proved that markets have not random, but persistent characteristics, which is consistent with the fractal theory.

The third experiment compared Mandelbrot's theory with the classical investment theory (Zinenko, 2015). "The results of the analysis in most cases disprove the hypothesis of Mandelbrot, who emphasized on the large number of deviations above three sigma. This behavior of quotations was demonstrated only by the Chinese Shanghai Comp index. Among other indices, a deviation of three sigma does not occur at all, or in the case of the American DJIA index – within the norm provided for by the "three sigma rule" <…> The result of testing the second hypothesis [verifying whether the Pareto rule is applicable] is the same as in the first case. The superiority of Mandelbrot's theory over classical investment theory (the one based on probability) has not been directly proven, but it has been proven that they have the right to exist on absolutely equal terms" (Zinenko, 2015: 15–17). These results are particularly interesting, as they show how fractal theory performs in comparison to classical theory, not just whether Mandelbrot's ideas are overall valid.

Although the data available in the Russian-speaking academic community is limited, we may still draw some conclusions about the applicability of Mandelbrot's theory. Firstly, it has not been refuted as false, which is already important evidence. Even when the authors point out some drawbacks, they do not say that the theory is baseless and wrong. Secondly, its usage is not very wide, probably because it does not show a major advantage compared to the classical investment theory, or because of other reasons stated above.

Factors determining the reasonableness of using Mandelbrot's theory

Speaking of limited usage, some authors established certain factors that justify whether fractal theory should or should not be used:

1. Existence of non-periodic cycle (Zhmurko and Osipov, 2018). If the cycle is periodic, there is presumably no need in fractal theory. However, other authors state that unstable cyclicity makes the fractal theory more difficult to use, as it becomes difficult to establish the correct generator size (Zhmurko and Osipov, 2018: 192). Taking this into account, it can be said that non-periodic cycles in price movements complicate the prediction overall, but Mandelbrot's theory is preferable in such cases as it assumes the long-tail distribution.
2. Existence of fractal structure on different timeframes. "If it is not detected on other timeframes, there is a high probability that the cycle is only informational (market) noise" (Zhmurko and Osipov, 2018: 192).
3. Comparing fractal theory with other methods of trading, some authors suggest that fractals depict the direction, while indicators show the current state: "they are more convenient in the sense that they can be used to find the most key points for entering or exiting the market. But the indicators show the general direction of the price very poorly, which is their significant disadvantage" (Almazov, 2009: 10). Thus, it is better to use the method that fits the present needs.

Compliance with these principles indicates that fractal theory may be used more effectively in a certain case.

Summary and conclusion

To conclude, Mandelbrot's economic ideas have a limited popularity among Russian-speaking scholars. The peak was reached in 2015. Every year since that time we see a smaller number of publications mentioning him. He still stays more recognized in the field of mathematics and geometry, compared to economics and finance.

However, in the works mentioning him we can see that his ideas were met with quite a positive attitude. His novelty and originality are recognized. The reception of fractal theory in economics varies from being the only working strategy for building an adequate model of the market and predicting financial collapses to not having many benefits in comparison to the classical probabilistic theory. Nevertheless, research evidence shows that markets have fractal (not random) nature, and new works support that idea.

Some scholars regret the undeserved unpopularity of fractal theory, while others explain it by its incompleteness and complexity, which limits the wide practical usage of Mandelbrot's ideas. Despite all limitations, the fractal theory definitely has its own place in economics and finance, and it is still of major importance in this field.

What makes it so valuable? As it was written in one of the book reviews: "It has long been noticed in the philosophy of science that the researcher does not see the features of factual data that do not have a form of a theoretical conception. <…> And so, *before Mandelbrot, science did not notice fractals in the world around us, and now this concept has entered the system of basic theoretical concepts, and it is clear to everyone that there are many fractals around*" (Tutubalin, 2001: 199 [emphasis added]). Probably the main significance of Mandelbrot's theory is not in its practical tools, but in the general philosophic idea.

References

Almazov, A. (2009). *Fractal Theory of the Forex Market*. St. Petersburg: Admiral Markets Publ. (in Russian).

Astrakhantseva, I. (2011). *Methodology of Nonlinear Dynamic Management of the Company's Value*. Ivanovo: Ivanovo State Power Engineering University Publ. (in Russian). https://www.elibrary.ru/qusmwl

Efimova, D., Nikulin, A. (2013). The role of fractals in the economy. *International Scientific Research Journal* **7**(38), 87–91 (in Russian). https://www.elibrary.ru/uyedzx

Egorenkov, N., Drozd, S., Starodubtsev, I., Starodubtseva, M. (2009). Problems of developing and teaching financial and economic statistics. Gomel: State Technical University of Gomel (in Russian). https://elib.gstu.by/handle/220612/12101

Glazunova, K. (2019). Fractals and their application in economics. *Actual Problems of Modern Science: The View of the Young*, 610–616 (in Russian). https://www.elibrary.ru/kvhbem

Hudson, R. (2004). Prelude. Introducing a maverick in science. In: Mandelbrot, B. (2004). *The Misbehavior of Markets*. New York: Basic Books, pp. 18–37.

Lagun, A. (2015). Fractals in economics. *Education and Science Without Borders: Social and Humanitarian Sciences* (2), 307–309 (in Russian). https://www.elibrary.ru/uoacsd

Lavrikova, Yu., Buchinskaia, O., Myslyakova, Yu. (2023). Chaos theory: Expanding the boundaries of economic research. *AlterEconomics* **20**(1), 79–109 (in Russian). DOI: 10.31063/AlterEconomics/2023.20-1.5

Mandelbrot, B. (1963). New methods in statistical economics. *Journal of Political Economy* **71**(5), 421–440. DOI: 10.1086/258792

Mandelbrot, B. (1966). Forecasts of future prices, unbiased markets, and "martingale" models. *The Journal of Business* **39**(1), 242–255. DOI: 10.1086/294850

Mandelbrot, B., Taylor, H. (1967). On the distribution of stock price differences. *Operations Research* **15**(6), 1057–1062. DOI: 10.1287/opre.15.6.1057

Mandelbrot, B. (1983). *The Fractal Geometry of Nature*. New York: Henry Holt and Company.

Mandelbrot, B. (1997). *Fractals and Scaling in Finance: Discontinuity, Concentration, Risk*. New York: Springer.

Mandelbrot, B. (1999). A multifractal walk down Wall Street. *Scientific American* **280**(2), 70–73. DOI: 10.1038/scientificamerican0299-70

Mandelbrot, B., Hudson, R. (2004). *The Misbehavior of Markets*. New York: Basic Books.

Muller, N. (2009). Forecasting the risk of occupational traumatism by means of wavelet and fractal analysis. *Vestnik of Samara State University* (2), 146–154 (in Russian). https://elibrary.ru/pgcmld

Nekrasova, I. (2015). Hurst indicator as a measure of fractal structure and long-term memory of financial markets. *International Scientific Research Journal* **7-3**(38), 87–91 (in Russian). https://www.elibrary.ru/ucqpxd

Panchelyuga, V. (2010). Benoit Mandelbrot: The way to fractal geometry of nature. *Hypercomplex Numbers in Geometry and Physics* **7**(14-2), 172–191 (in Russian). https://www.elibrary.ru/onszgd

Rosenberg, G., Chuprunov, E., Gelashvili, D., Iudin, D. (2011). "Nature's geometry has a fractal face" (In memory of Benoit Mandelbrot). *Vestnik of Lobachevsky University of Nizhni Novgorod* (1), 411–417 (in Russian). https://www.elibrary.ru/onszgd

Sandryukova, E., Dubinina, E. (2017). Application of elements of fractal theory in the study of economic processes. *Bulletin of Economic Security* (4), 349–352 (in Russian). https://www.elibrary.ru/ovkrfh

Shlyk, V. (2005). He left a scratch on the surface of everything: For Benoit Mandelbrot's 80th anniversary. *Proceedings of the Chelyabinsk Scientific Center of the Ural Branch RAS* (3), 116–132 (in Russian). https://www.elibrary.ru/hrukmx

Taylor, J. (2020). Black Death, "Industrial Revolution" and Paper Age collapse. *Terra Economicus* **18**(3), 22–48. DOI: 10.18522/2073-6606-2020-18-3-6-17

Tutubalin, V. (2001). Book review: Mandelbrot B.B., Ageal M. "Fractals and Scaling in Finance. Discontinuity, Concentration, Risk". *Theory Probab. Appl.* **46**(1),198–204 (in Russian). DOI: 10.4213/tvp4040

Zhmurko, D., Osipov, A. (2018). Forecasting indicators of the sugar industry development using fractal analysis methods. *Bulletin of Udmurt University. Economics and Law Series* **28**(2), 185–193 (in Russian). https://www.elibrary.ru/lvbfmt

Zinenko, A. (2012). R/S stock market analysis. *Business Informatics* (3), 24–30 (in Russian). https://www.elibrary.ru/peoskn

Zinenko, A. (2015). Pareto's law on the stock market. *Finance and Credit* **21**(38), 11–19 (in Russian). https://www.elibrary.ru/umrkev

Zinenko, A., Semenov, S. (2013). Modern theories of financial investments. *Finance and Credit* **19**(25), 48–53 (in Russian). https://www.elibrary.ru/qcmykf