Financial Innovation

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Analysis of financial development and open innovation oriented fintech potential for emerging economies using an integrated decision-making approach of MF-X-DMA and golden cut bipolar q-ROFSs

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Abstract

The purpose of the paper is to identify the factors of financial development that have the greatest impact on open innovation in 7 emerging countries. The analysis was performed featuring the MF-X-DMA method, as well as its further verification for autocorrelation and heteroscedasticity. The time period covers years from 2002 to 2020. The article states that the main indicators to improve financial development should enhance the process of bank lending and equity market development. An important area is the development of competition by providing equal access to information to all market participants in a continuously refining technical infrastructure. Regression analysis with the MF-X-DMA method confirms the statistical significance of this influence. The article fills the knowledge gap into the link between open innovations and the relatively low capitalization of the modern emerging countries' financial market, low liquidity in small cap stocks at the financial market and concentration of the banking sector, as well as risks arising in the process of globalization. Another analysis has also been conducted by generating a novel fuzzy decision-making model. In the first stage, the determinants of open innovation-based fintech potential are weighted for the emerging economies. For this purpose, M-SWARA methodology is taken into consideration based on bipolar q-ROFSs and golden cut. The second stage of the analysis includes evaluating the emerging economies with the determinants of open innovation-based fintech potential. In this context, emerging seven countries are examined with ELECTRE methodology. It found the most significant factor is the open innovation-based fintech potential.

Keywords: Financial depth, Economic monetization, Macroeconomic impact, Banking sector, Concentration

Introduction

All innovations in financial markets are based on a growing threat to data. Despite these efforts, banks and other financial institutions continue to face serious challenges. In addition to highly competitive fintech startups, there is a threat from major social networks and retail players: Facebook, Google, Apple and Amazon—which continue to expand in the financial services market as they are sitting on a mountain of customer data, namely demographics, interests, preferences and payments. These social media companies provide themselves with a significant informational advantage over financial institutions, which will have to solve these problems by cooperating with each other and entering partnerships with fintech sector players who can help financial institutions overcome information asymmetry.

Companies operating in highly competitive capital markets are often among the first to introduce new technologies in order to overtake competitors. However, they face quite a lot of difficulties due to constant interaction with old systems. Therefore, striving for improvement in the past has led to mixed results in the industry as a whole. This has changed in 2021: investments in technology are doubling as companies strive to maintain their relevance. In particular, the transition to cloud platforms is on the forefront of technological innovations, along with simplicity and modularity and investments in automation. Let us take a closer look at this (Sisodiya et al. 2013; Wallusch et al. 2020; Tiniç et al. 2021).

As expected, rapid growth and innovation continued in the fintech sector throughout 2020. To a large extent, this has been a continuation of the trends of at least the last five years. The younger generation of customers continues to avoid traditional financial institutions or abandon them in favor of fully digital banks and embedded financial services. In response, traditional financial institutions are trying to compete by increasing the pace of innovation and digitalization in various ways. This trend will continue in the following years. Accordingly, the modern open innovations and the determinants of open innovation-based fintech potential can be: transitioning to the cloud, simplicity and modularity, automation, digitalization of processes, platform upgrade, artificial intelligence (AI) and machine learning (ML).

Historically, it has been proven that there is a correlation between financial development and open innovation dynamics in developed and developing countries. However, the nature of this relationship remains a subject of debate for most economists. There are also proponents of the view that the financial system is designed to serve the needs of the economy and is only an intermediate (Podmetina et al. 2012; Pan et al. 2021). The relevance of the chosen topic is explained by the peculiarities of Russia's financial market functioning, characterized by its relative isolation from the real sector, and amid the aggravating geopolitical situation and reduced availability of some long-term funding resources in Western markets, the issue of stimulating the country's financial development and ensuring the most favorable conditions for the financial market is an important aspect.

The influencing factors are as follows: low capitalization of the modern Russian financial market, concentration of the banking sector, low liquidity in small cap stocks on the financial market, low financial literacy and weak public confidence, as well as risks arising in the process of globalization.

Data from the Oxford Economics, Goscomstat and International Monetary Fund were examined and analyzed in this paper using methods of correlation, regression analysis and the MF-X-DMA method. The results of the analysis of the dynamics of macroeconomic and financial development indicators are presented. The identification of financial development indicators that have the greatest impact on open innovation is used for their further use in the construction and interpretation of the regression model.

The results of the analysis of regression models for the presence of residuals autocorrelation revealed that the hypothesis of the absence of autocorrelation in both samples is confirmed. The regression equations are satisfactory, the parameter estimates are effective, the variances of the coefficient estimates are unbiased and the conclusions are statistically valid.

Another evaluation has also been performed by generating a novel fuzzy decision-making model. Firstly, the determinants of open innovation-based fintech potential are weighted for the emerging economies. For this purpose, M-SWARA methodology is taken into consideration based on bipolar q-ROFSs and golden cut. The second stage of the analysis includes evaluating the emerging economies with the determinants of open innovation-based fintech potential. In this context, emerging seven countries are examined with ELECTRE methodology. The main novelty of this study is making analysis by using both econometric methods and fuzzy decision-making techniques. This situation gives information about the measuring the validity of the analysis results.

The literature review section includes an analysis of relevant studies. The methods section answers the questions about methodology. The results section consists of the most important points of empirical analysis. The discussion section includes two major directions of Russian financial market development. The conclusions section highlights the major implications of this research.

Literature review

The impact of the level of financial development on open innovation has been extensively investigated in recent literature using econometric methods, e.g., country-specific and cross-country analysis and panel data studies. However, the results of the research papers on the impact of financial development on open innovation are very mixed. This article aims to provide clarity on the subject and develop conclusions based on its model and data.

Recent studies have different views. There is not only a positive relationship between firm performance and innovations, but it is also improved and proves to be more significant by cooperating partnering with different firms. An isolated firm is more often accustomed to underperforming regarding its potential (Chang et al. 2014; Bozhechkova et al. 2017; Brockman et al. 2018; Zhang et al. 2019; Li et al. 2021, 2022).

Studies have also utilized the Quadruple-helix Model to conclude that national economies are in an unfavorable position if radicalizing a system that intensifies either business and the capitalistic structure or a socialistic structure. Furthermore, results of previous literature highlight three sub-economies, including the innovation market developed by start-up businesses, closed innovations of large businesses and social innovations. It is presumed that these three areas should not be in high balance, as that would lead to

decreased dynamics of a national economy (Faems et al. 2010; Fang et al. 2014; Coyle 2018).

Moreover, based on previous research on the success of large groups-companies, new research methods have been developing. It is recommended that businesses establish a purpose—and this is translated to the use of new innovative technologies in the current paradigm of the information era. The established purpose, depending on the scale of the corporation, as referenced in the previous paragraph, should use innovations, which are open. The developed methods have been reviewed in models of energy efficiency—an industry that requires innovations to be sustainable in the near future (Ghosh et al. 2014; Fernadez et al. 2015).

The corporations in countries with a developed financial system can access cheaper external sources of credit, which contributes to innovation. Financial intermediaries have a large positive effect on overall productivity, which affects GDP growth. For example, the financial development is only favorable for innovation up to a certain threshold. Increasing the volumes of stock markets and the financialization of the economy reduces the impact of financial crisis on innovation (IMF 2015; Liu et al. 2016; Kenda et al. 2019).

Articles have also concluded the necessity of an innovative outlook in a company's culture. It has been proven that the inclination to implement innovations has a positive correlation with corporate performance. This is valuable when considering the size of a firm, as well as its position in the market (Beck 2000a; b; Bianchi et al. 2010).

Considering this, the role of corporate culture is definitive when evaluating the transition to the utilization of more innovations. This, in turn, has raised discussions on the persistence of a Fourth Industrial Revolution. It has been stated that the "creativity" of companies should increase in order to accelerate this process—a fragment of a corporation's culture. There is no doubt amongst researchers that these aspects play key roles when addressing the Fourth Industrial Revolution—an event that would lead to a wider scale of innovation implementation (Murphy et al. 2013; Mashkina et al. 2019; Niftiyev 2020).

A topic of discussion that also deserves to be developed is capital control—not only from the aspect of corporations, but also from the state. Evidence from emerging countries shows capital movements ushered by the government, which has led to the development of innovations in different industries in the economy. These innovations are also often a result of cooperation between private corporations and state institutes. The role of controlling capital, the allocation of funds into the R&D department, for example, is important when developing financial and resource markets in general. Research shows that amongst these industries, the financial sector—specifically the insurance sector—has a positive correlation with economic growth. Consequentially, this element of the financial sector could benefit from innovating insurance policies and technologies. As for the particularities of financial markets regarding emerging countries, it can be said that the Foreign Exchange market is pivotal when determining investor sentiment. Furthermore, in conjunction with the developing stock market, it is critical to consider these factors when addressing innovation and their price, as they are related to international trade (Obstfeld 2012; Obstfeld and Taylor 2017; Niftiyev 2021).

Furthering the discussion on the mixed views on capital control, research has shown that aspects such as restricting cash flow is ineffective as a policy; however, it can contribute to macroeconomic stabilization through the means of exchange rates

in foreign markets. The overall role and consequences of these policies regarding innovations have not yet been established or researched extensively. That being said, a link could be expected through international trade. The regulation of cash flows in order to incentivize R&D spending is inconclusive and may not be as effective as efforts to subsidize these corporate activities. More recently, new influencing factors have been added. For example, the participation of institutional investors on capital markets increases with the development of the economy. For example, there are studies regarding the impact of a specific sector's development on the financial market: mutual funds and insurance companies. Meanwhile, advanced mutual funds are associated with more developed countries. The relationship between the insurance sector and innovation in 10 European countries has also been found using a fixed effects model. In some countries, the level of financial development does not affect innovation (Daniali et al. 2021; Mikhaylov 2021).

This research focuses on how these factors impact on innovation: low capitalization of the modern Russian financial market, concentration of the banking sector, low liquidity in small cap stocks at the financial market, low financial literacy and weak public confidence, as well as risks arising in the process of globalization.

Methods

The paper uses data from Bank of Russia (2020), Oxford Economics (2022), Goskomstat (2022), regarding the main macroeconomic indicators, including those on the financial development for the period from 2002 to 2020.

To determine the impact of Russia's financial development on innovation, it is necessary to analyze the basic macroeconomic indicators and their dynamics (Table 1). The time horizon of the study covers the years from 2002 to 2020, since the global financial market entered a new stage of development during that period.

The paper proves the agency theory, which explains the relationship between two parties: agents represent the counterparty in day-to-day transactions. Russian companies hire these agents to perform services on their behalf. Furthermore, the paper uses the adaptive market hypothesis method. The key hypothesis to survival is innovation: as the risk/reward relation varies, the better way of achieving a consistent level of expected returns is to adapt to fluctuating market conditions.

Correlation analysis

Based on the presented macroeconomic and financial development indicators, a correlation analysis is conducted and the correlation between the individual indicators is determined.

Table 1 Scale of correspondences of intervals of numerical values of the degree of influence

Interval values of correlation coefficients	Determining the extent of the impact
≤ 0.199	No impact
From 0.2 to 0.499	Slight impact
From 0.5 to 0.799	Impact of medium intensity
From 0.8 to 1	The decisive influence

Sources Author's calculations

In order to assess the intensity of the impact of financial development factors in the Russian market on innovation indicators, the authors construct a scale of correspondence of the degree of influence (Table 1).

The financial market development indicators with the highest coefficient of intensity of influence on innovation dynamics deserve the most attention when designing an effective mechanism of investment support for innovation. The results of the correlation analysis of the sample are presented in Table 2.

The low degree of maturity of the bond market at this point in the development of the Russian financial market has a negative impact on macroeconomic indicators. This may be due to the fact that bonds are mainly used as a long-term lending instrument for firms and the government, which ultimately has a greater negative impact on the real disposable income of the population. These correlation analysis indicators also suggest that bonds are unpopular with the public as an investment target.

A moderate positive effect of the financial depth of the economy only on the dynamics of fixed asset investment suggests that the overall saturation of Russia's economy with various financial instruments has not yet had a significant impact on innovation as compared to other developed and developing countries.

A monetization ratio (M2/GDP) value of over 50% is an indicator that there is enough money to settle the economy. During the analyzed period, the monetization ratio reached a maximum of only 44.7%. A ratio of less than 50% can lead to factorization of a large part of the economy not served by the monetary and banking system, which has a moderate negative impact on the dynamics of innovation and the growth rate of fixed capital investment.

Thus, it can be said that the functioning of the financial market is not isolated from processes in the real sector, although it does not have a strong impact on the economy. On this basis, Russia's financial market can be identified as a promising driver of innovation.

Table 2 Correlation coefficients between the main macroeconomic indicators and indicators of financial development, 2002–2020

Indicator	Real GDP dynamics	Industrial output growth rate	Fixed capital investment growth RATE	Growth rate of real disposable income
Share of commercial bank assets in total banking sector assets	− 0.384	− 0.283	− 0.322	− 0.290
Concentration of the banking market (total market share of the three largest banks)	− 0.635	− 0.292	− 0.479	− 0.561
Domestic bank credit/GDP	− 0.967	− 0.593	− 0.859	− 0.836
Equity capitalization/GDP	0.852	0.580	0.886	0.732
Bond capitalization (state and corporate)/GDP	− 0.638	− 0.247	− 0.469	− 0.536
Financial depth (amount of loans, equity and bond capitalization to GDP)	0.429	0.387	0.586	0.370
M2/GDP	− 0.681	− 0.139	− 0.546	− 0.472

Sources Goskomstat (2022), Bank of Russia (2020), author's calculations

Regression modeling

The regression equation is a mathematical model of the statistical relationship of the variables. A pairwise linear regression model includes one independent (explanatory) variable X and a dependent (explanatory) variable Y and has the form:

$$M(Y|X = x) = f(x) \tag{1}$$

The relationship is as follows:

$$Y = M(Y|x) + \varepsilon \tag{2}$$

where ε is the random deviation.

The theoretical pairwise linear regression model is as follows:

$$Y = \beta 0 + \beta 1X + \varepsilon \tag{3}$$

where X is the non-random variable, Y and ε are random variables and β0 and β1 are regression coefficients (parameters).

The individual values of yi are expressed using the formula:

$$yi = b0 + b1xi + \varepsilon i \tag{4}$$

where i varies from 1 to n.

The method of least squares (OLS) is a common method of finding estimates of b0 and b1 of parameters β0 and β1 of a general sum.

$$Qe = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} \left(yi - ykpi\right)^2 = \sum_{i=1}^{n} \left(yi - (b0 + b1xi)\right)^2 \tag{5}$$

where ykpi is the estimated value of the variable y,

yi − ykpi is the difference between the observed and estimated values of the variable Y at X = xi, and are called residuals, denoted by ei. ykpi = b0 + b1xi is a regression equation where coefficients are obtained from the sample (x, y) and Qe is a quadratic function that has a minimum (the figure is a parabola with branches upwards).

MF-X-DMA method

In this study, the MF-X-DMA method is used as one of the ways to measure the mutual influence of the dynamics of innovation on the low capitalization of the modern Russian financial market, concentration of the banking sector, low liquidity in small cap stocks at the financial market and relatively low financial literacy, as well as risks arising in the process of globalization.

Consider two stationary time series zj and wj, j = 1, 2,..., N, where N is the length of the series. Equations (6) and (7) are intended to define two separate time series. Cross-correlation and multifractal analysis is carried out between the named time series.

Stage 1 Divide the two time series into Nv = [N/v] non-overlapping boxes of equal size v. Construct the sequence of cumulative sums within the nth box [cn + 1, cn + v], where cn = (n − 1)v.

$$\mathrm{Z_n(m)} = \sum_{\mathrm{j=1}}^{\mathrm{m}} \mathrm{z}\left(\mathrm{c_n} + \mathrm{j}\right), \quad \mathrm{j} = 1, 2, 3 \ldots, \mathrm{v} \tag{6}$$

$$W_n(m) = \sum_{j=1}^{m} w\left(c_n + j\right), \quad j = 1, 2, 3 \ldots, v \tag{7}$$

Stage 2 Calculate the moving average function for each series of cumulative sums in a moving window. This is due to the evidence from several other studies: it was revealed that the implementation of this approach led to more accurate estimates and an all-around better performance.

Stage 3 Find cross-correlation for each sample:

$$F_n(v) = \sum_{m=1}^{v} \left[Z_n(m) - \tilde{Z}_n(m)\right]\left[W_n(m) - \tilde{W}_n(m)\right] \tag{8}$$

Stage 4 Calculate the qth order cross-correlation:

$$F_{z,w}(q, v) = \left[\frac{1}{k}\sum_{n=1}^{k} |F_n(v)|^{q/2}\right]^{1/q} \tag{9}$$

When q = 0, we have the following:

$$F_{z,w}(0, v) = exp\left[\frac{1}{2k}\sum_{n=1}^{k} log|F_n(v)|\right] \tag{10}$$

Stage 5 For different values of segment length v, we have the power-law relationship:

$$\mathrm{Fz, w(q,v)} \sim \mathrm{vhz, w(q)} \tag{11}$$

According to the standard multifractal formalism, the multifractal scaling exponent τ (q) can be used to characterize the multifractal nature:

$$\begin{aligned} \alpha_{z,w}(q) &= \frac{d\tau_{z,w}(q)}{dq}; \quad fz, w(q) \\ &= q\alpha z, w - \tau z, \quad w(q) \end{aligned} \tag{12}$$

If the two cross-correlated series have a monofractal nature, then the values of αz,w = const., and for multifractal nature there occurs a distribution of αz,w values. The width of the spectrum describes the strength of multifractality and can be determined by Δαz,w = max (αz,w) − min (αz,w). The broader spectrum is evident for robust multifractality nature, and the narrow spectrum is evident for the weak multifractality nature of the cross-correlated time series.

Bipolar q-rung orthopair fuzzy sets with golden cut

IFSs are created by Atanassov (1999) while identifying membership and non-membership degrees shown with (μ_I, n_I) as in Eq. (13).

$$I = \{\vartheta, \mu_I(\vartheta), n_I(\vartheta)/\vartheta \epsilon U\} \tag{13}$$

Equation (14) includes the requirement.

$$0 \leq \mu_I(\vartheta) + n_I(\vartheta) \leq 1 \tag{14}$$

PFSs are generated by Yager (2013) to cope with uncertainties in this process more effective. The details and requirement are shown in Eqs. (15) and (16).

$$P = \{\vartheta, \mu_P(\vartheta), n_P(\vartheta)/\vartheta \epsilon U\} \tag{15}$$

$$0 \leq (\mu_P(\vartheta))^2 + (n_P(\vartheta))^2 \leq 1 \tag{16}$$

Yager (2016) introduced q-ROFSs and the details are explained in Eqs. (17) and (18).

$$Q = \left\{\vartheta, \mu_Q(\vartheta), n_Q(\vartheta)/\vartheta \epsilon U\right\} \tag{17}$$

$$0 \leq \left(\mu_Q(\vartheta)\right)^q + \left(n_Q(\vartheta)\right)^q \leq 1, \quad q \geq 1 \tag{18}$$

Zhang (1994) generated BFSs fort his purpose by introducing the satisfaction degree (μ_B^+) and satisfaction of the same element (μ_B^-) as in Eq. (19).

$$B = \left\{\vartheta, \mu_B^+(\vartheta), \mu_B^-(\vartheta)/\vartheta \epsilon U\right\} \tag{19}$$

Equations (20)-(25) represent the integration with fuzzy sets.

$$B_I = \left\{\vartheta, \mu_{B_I}^+(\vartheta), n_{B_I}^+(\vartheta), \mu_{B_I}^-(\vartheta), n_{B_I}^-(\vartheta)/\vartheta \epsilon U\right\} \tag{20}$$

$$B_P = \left\{\vartheta, \mu_{B_P}^+(\vartheta), n_{B_P}^+(\vartheta), \mu_{B_P}^-(\vartheta), n_{B_P}^-(\vartheta)/\vartheta \epsilon U\right\} \tag{21}$$

$$B_Q = \left\{\vartheta, \mu_{B_Q}^+(\vartheta), n_{B_Q}^+(\vartheta), \mu_{B_Q}^-(\vartheta), n_{B_Q}^-(\vartheta)/\vartheta \epsilon U\right\} \tag{22}$$

$$0 \leq \left(\mu_{B_I}^+(\vartheta)\right) + \left(n_{B_I}^+(\vartheta)\right) \leq 1, \quad -1 \leq \left(\mu_{B_I}^-(\vartheta)\right) + \left(n_{B_I}^-(\vartheta)\right) \leq 0 \tag{23}$$

$$0 \leq \left(\mu_{B_P}^+(\vartheta)\right)^2 + \left(n_{B_P}^+(\vartheta)\right)^2 \leq 1, \quad 0 \leq \left(\mu_{B_P}^-(\vartheta)\right)^2 + \left(n_{B_P}^-(\vartheta)\right)^2 \leq 1 \tag{24}$$

$$0 \leq \left(\mu_{B_Q}^+(\vartheta)\right)^q + \left(n_{B_Q}^+(\vartheta)\right)^q \leq 1, \quad -1 \leq \left(\mu_{B_Q}^-(\vartheta)\right)^q + \left(n_{B_Q}^-(\vartheta)\right)^q \leq 0 \tag{25}$$

These sets are compared in Fig. 1.

Bipolar q-ROFSs are computed with Eqs. (26)-(29).

$B_{Q1} = \left\{\vartheta, \mu_{B_{Q1}}^+(\vartheta), n_{B_{Q1}}^+(\vartheta), \mu_{B_{Q1}}^-(\vartheta), n_{B_{Q1}}^-(\vartheta)/\vartheta \epsilon U\right\}$ and

$$B_{Q2} = \left\{\vartheta, \mu_{B_{Q2}}^+(\vartheta), n_{B_{Q2}}^+(\vartheta), \mu_{B_{Q2}}^-(\vartheta), n_{B_{Q2}}^-(\vartheta)/\vartheta \epsilon U\right\}$$

$$B_{Q1} \oplus B_{Q2} = \left(\left(\left(\mu^{+}_{B_{Q1}}\right)^{q} + \left(\mu^{+}_{B_{Q2}}\right)^{q} - \left(\mu^{+}_{B_{Q1}}\right)^{q} \cdot \left(\mu^{+}_{B_{Q2}}\right)^{q} \right)^{\frac{1}{q}}, \left(n^{+}_{B_{Q1}} \cdot n^{+}_{B_{Q2}}\right), -\left(\mu^{-}_{B_{Q1}} \cdot \mu^{-}_{B_{Q2}}\right), -\left(\left(n^{-}_{B_{Q1}}\right)^{q} + \left(n^{-}_{B_{Q2}}\right)^{q} - \left(n^{-}_{B_{Q1}}\right)^{q} \cdot \left(n^{-}_{B_{Q2}}\right)^{q} \right)^{\frac{1}{q}} \right) \tag{26}$$

$$B_{Q1} \otimes B_{Q2} = \left(\left(\mu^{+}_{B_{Q1}} . \mu^{+}_{B_{Q2}}\right), \left(\left(n^{+}_{B_{Q1}}\right)^{q} + \left(n^{+}_{B_{Q2}}\right)^{q} - \left(n^{+}_{B_{Q1}}\right)^{q} \cdot \left(n^{+}_{B_{Q2}}\right)^{q} \right)^{\frac{1}{q}}, \left(\left(\mu^{-}_{B_{Q1}}\right)^{q} + \left(\mu^{-}_{B_{Q2}}\right)^{q} - \left(-\left(\mu^{-}_{B_{Q1}}\right)^{q} \cdot \left(\mu^{-}_{B_{Q2}}\right)^{q} \right)^{\frac{1}{q}}, -\left(n^{-}_{B_{Q1}} \cdot n^{-}_{B_{Q2}}\right) \right) \tag{27}$$

$$\lambda B_{Q1} = \left(\left(1 - \left(1 - \left(\mu^{+}_{B_{Q1}}\right)^{q} \right)^{\lambda} \right)^{1/q}, \left(n^{+}_{B_{Q1}}\right)^{\lambda}, -\left(-\mu^{-}_{B_{Q1}}\right)^{\lambda}, -\left(1 - \left(1 - \left(-n^{-}_{B_{Q1}}\right)^{q} \right)^{\lambda} \right)^{1/q} \right), \quad \lambda > 0 \tag{28}$$

$$B^{\lambda}_{Q1} = \left(\left(\mu^{+}_{B_{Q1}}\right)^{\lambda}, \left(1 - \left(1 - \left(n^{+}_{B_{Q1}}\right)^{q} \right)^{\lambda} \right)^{1/q}, -\left(1 - \left(1 - \left(-\mu^{-}_{B_{Q1}}\right)^{q} \right)^{\lambda} \right)^{\frac{1}{q}}, -\left(-n^{-}_{B_{Q1}}\right)^{\lambda} \right), \quad \lambda > 0 \tag{29}$$

Equations (30)-(32) represent defuzzification process.

$$S(\vartheta)_{B_I} = \left(\left(\mu^{+}_{B_I}(\vartheta)\right) - \left(n^{+}_{B_I}(\vartheta)\right) \right) - \left(\left(\mu^{-}_{B_I}(\vartheta)\right) - \left(n^{-}_{B_I}(\vartheta)\right) \right) \tag{30}$$

$$S(\vartheta)_{B_P} = \left(\left(\mu^{+}_{B_P}(\vartheta)\right)^{2} - \left(n^{+}_{B_P}(\vartheta)\right)^{2} \right) + \left(\left(\mu^{-}_{B_P}(\vartheta)\right)^{2} - \left(n^{-}_{B_P}(\vartheta)\right)^{2} \right) \tag{31}$$

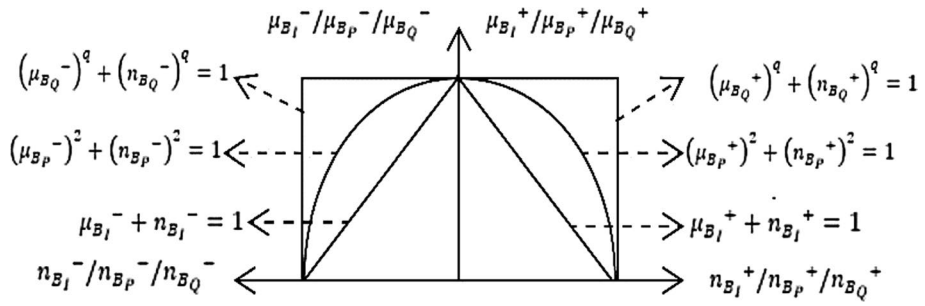

Fig. 1 Comparison of fuzzy sets

$$S(\vartheta)_{B_Q} = \left(\left(\mu^{+}_{B_Q}(\vartheta)\right)^q - \left(n^{+}_{B_Q}(\vartheta)\right)^q\right) - \left(\left(\mu^{-}_{B_Q}(\vartheta)\right)^q - \left(n^{-}_{B_Q}(\vartheta)\right)^q\right) \tag{32}$$

Golden ratio (φ) is considered in this study to compute the degrees. In this process, a and b show the large and small quantities while new degrees are indicated by ($\mu_{G_{B_Q}}$, $n_{G_{B_Q}}$). The details are demonstrated in Eqs. (33)-(35) (Belluscio et al. 2021).

$$\varphi = \frac{a}{b} \tag{33}$$

$$\varphi = \frac{1+\sqrt{5}}{2} = 1.618\ldots \tag{34}$$

$$\varphi = \frac{\mu_{G_{B_Q}}}{n_{G_{B_Q}}} \tag{35}$$

Equations (36)–(38) are used regarding the adoption of golden ratio with bipolar q-ROFSs.

$$G_{B_Q} = \left\{\vartheta, \mu^{+}_{G_{B_Q}}(\vartheta), n^{+}_{G_{B_Q}}(\vartheta), \mu^{-}_{G_{B_Q}}(\vartheta), n^{-}_{G_{B_Q}}(\vartheta)/\vartheta \epsilon U\right\} \tag{36}$$

$$0 \le \left(\mu^{+}_{G_{B_Q}}(\vartheta)\right)^q + \left(n^{+}_{G_{B_Q}}(\vartheta)\right)^q \le 1, \quad -1 \le \left(\mu^{-}_{G_{B_Q}}(\vartheta)\right)^q + \left(n^{-}_{G_{B_Q}}(\vartheta)\right)^q \le 0 \tag{37}$$

$$0 \le \left(\mu^{+}_{G_{B_Q}}(\vartheta)\right)^{2q} + \left(n^{+}_{G_{B_Q}}(\vartheta)\right)^{2q} \le 1, \quad 0 \le \left(\mu^{-}_{G_{B_Q}}(\vartheta)\right)^{2q} + \left(n^{-}_{G_{B_Q}}(\vartheta)\right)^{2q} \le 1 \quad q \ge 1 \tag{38}$$

M-SWARA method with bipolar q-ROFSs

SWARA was introduced by Keršuliene et al. (2010) to compute the weights of the items while making comparison. Relation matrix is constructed in Eq. (39).

$$Q_k = \begin{bmatrix} 0 & Q_{12} & \cdots & \cdots & Q_{1n} \\ Q_{21} & 0 & \cdots & \cdots & Q_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ Q_{n1} & Q_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{39}$$

Equations (40)–(42) include the computation of the values of k_j (coefficient value), q_j (recalculated weight), s_j (comparative importance rate) and w_j (weights of the criteria).

$$k_j = \begin{cases} 1 & j = 1 \\ s_j + 1 & j > 1 \end{cases} \tag{40}$$

$$q_j = \begin{cases} 1 & j = 1 \\ \frac{q_{j-1}}{k_j} & j > 1 \end{cases} \tag{41}$$

$$If\ s_{j-1} = s_j,\ q_{j-1} = q_j; If\ s_j = 0,\ k_{j-1} = k_j$$

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k} \tag{42}$$

While transposing and limiting the matrix with the power of "2t + 1", stable values are defined.

ELECTRE with bipolar q-ROFSs

ELECTRE was generated by Benayoun et al. (1966) to rank alternatives by making binary superiority comparisons. In this study, this approach is integrated with bipolar q-ROFSs. Equation (43) indicates the decision matrix.

$$X_k = \begin{bmatrix} 0 & X_{12} & \cdots & \cdots & X_{1m} \\ X_{21} & 0 & \cdots & \cdots & X_{2m} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ X_{n1} & X_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{43}$$

Equation (44) represents the normalization.

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}}. \tag{44}$$

Equation (45) shows the weighting of the values.

$$v_{ij} = w_{ij} \times r_{ij} \tag{45}$$

Equations (46)–(51) include the concordance and discordance interval matrixes.

$$C = \begin{bmatrix} - & c_{12} & \cdots & \cdots & c_{1n} \\ c_{21} & - & \cdots & \cdots & c_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ c_{n1} & c_{n2} & \cdots & \cdots & - \end{bmatrix} \tag{46}$$

$$D = \begin{bmatrix} - & d_{12} & \cdots & \cdots & d_{1n} \\ d_{21} & - & \cdots & \cdots & d_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ d_{n1} & d_{n2} & \cdots & \cdots & - \end{bmatrix} \tag{47}$$

$$c_{ab} = \{j | v_{aj} \geq v_{bj}\} \tag{48}$$

$$d_{ab} = \left\{ j | v_{aj} < v_{bj} \right\} \tag{49}$$

$$c_{ab} = \sum_{j \in c_{ab}} w_j \tag{50}$$

$$d_{ab} = \frac{max_{j \in d_{ab}} \left| v_{aj} - v_{bj} \right|}{max_j \left| v_{mj} - v_{nj} \right|} \tag{51}$$

Equations (52)–(59) demonstrate the concordance E, discordance F and aggregated G index matrixes.

$$E = \begin{bmatrix} - & e_{12} & \cdots & \cdots & e_{1n} \\ e_{21} & - & \cdots & \cdots & e_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ e_{n1} & e_{n2} & \cdots & \cdots & - \end{bmatrix} \tag{52}$$

$$F = \begin{bmatrix} - & f_{12} & \cdots & \cdots & f_{1n} \\ f_{21} & - & \cdots & \cdots & f_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ f_{n1} & f_{n2} & \cdots & \cdots & - \end{bmatrix} \tag{53}$$

$$G = \begin{bmatrix} - & g_{12} & \cdots & \cdots & g_{1n} \\ g_{21} & - & \cdots & \cdots & g_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ g_{n1} & g_{n2} & \cdots & \cdots & - \end{bmatrix} \tag{54}$$

$$\begin{cases} e_{ab} = 1 & if \ c_{ab} \geq \overline{c} \\ e_{ab} = 0 & if \ c_{ab} < \overline{c} \end{cases} \tag{55}$$

$$\overline{c} = \sum_{a=1}^{n} \sum_{b}^{n} c_{ab} / n(n-1) \tag{56}$$

$$\begin{cases} f_{ab} = 1 & if \ d_{ab} \leq \overline{d} \\ f_{ab} = 0 & if \ d_{ab} > \overline{d} \end{cases} \tag{57}$$

$$\overline{d} = \sum_{a=1}^{n} \sum_{b}^{n} d_{ab} / n(n-1) \tag{58}$$

$$g_{ab} = e_{ab} \times f_{ab} \tag{59}$$

In these equations, e_{ab}, f_{ab}, g_{ab} represent the sets of concordance, discordance, and aggregated index matrixes. Additionally, $\bar{c}$ and $\bar{d}$ show the critical values and c_a, d_a, o_a demonstrate the superior, inferior, and overall values. Equations (60)–(62) are used for ranking the factors.

$$c_a = \sum_{b=1}^{n} c_{ab} - \sum_{b=1}^{n} c_{ba} \tag{60}$$

$$d_a = \sum_{b=1}^{n} d_{ab} - \sum_{b=1}^{n} d_{ba} \tag{61}$$

$$o_a = c_a - d_a \tag{62}$$

Results

Indicators of financial development

While studies covering a period of 20–25 years are considered more statistically reliable, this paper intends to examine data from the last 10 years, beginning with the period of the global economic crisis (Fig. 2, Table 3).

The 13% decline in GDP in current RUB (GDP) dynamics by 2009 was accompanied by a decline in the growth rate of industrial production to − 10.7% and a maximum drop in fixed capital investment to − 13.5% over the whole analyzed period. The growth rate of retail trade turnover also fell sharply by 18.8% (Bank of Russia 2020).

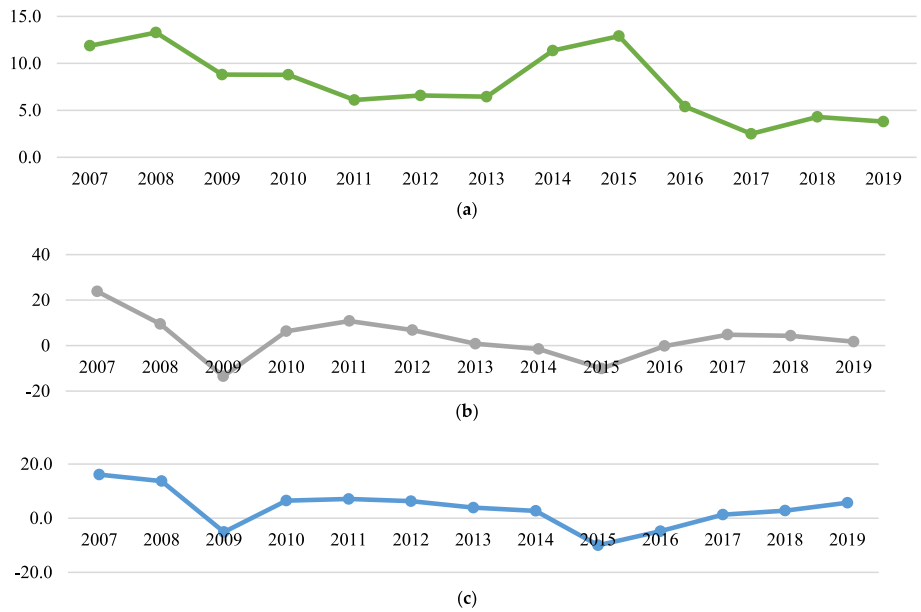

Fig. 2 **a** Inflation rate (CPI), %. **b** Growth rate of investment in fixed assets, %, **c** Growth rate of retail trade turnover, %. *Sources*: Goskomstat (2022), Bank of Russia (2020), author's calculations

Table 3 The main macroeconomic indicators of Russia in 2007–2019

Indicator	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
GDP (current prices), RUB bln	33,248	41,277	38,807	46,309	60,283	68,164	73,134	79,200	83,233	86,010	92,089	103,627	110,046
GDP (current prices), %	8.5	5.20	− 7.80	4.50	4.30	3.70	1.80	0.70	− 3.70	− 0.20	1.50	2.30	1.30
Growth of industrial production, RUB bln	23.8	9.5	− 13.5	6.3	10.8	6.8	0.8	− 1.5	− 10.1	− 0.2	4.8	4.3	1.7
Growth rate of industrial production, %	10.4	2.4	3	5.9	0.5	4.6	4	− 1.2	− 2.4	− 4.5	− 0.5	0.1	0.8
Growth of fixed capital investment, RUB bln	16.1	13.7	− 5.1	6.5	7.1	6.3	3.9	2.7	− 10.0	− 4.8	1.3	2.8	5.7
Growth rate of fixed capital investment, %	11.9	13.3	8.8	8.8	6.1	6.6	6.5	11.4	12.9	5.4	2.5	4.3	3.8
Growth of real disposable income, RUB bln	31.6	452.1	359.1	285.6	343.5	497.3	525.9	524.7	516.7	397.0	301.6	467.5	351.9
Growth of real disposable income, %	15.6	240.5	228.5	182.2	182.9	287.0	315.2	317.2	305.7	228.9	167.3	267.1	199.7
Growth of retail trade turnover, RUB bln	16.0	211.6	130.6	103.4	160.6	210.3	210.7	207.5	211.0	168.1	134.3	200.4	152.2
Growth rate of retail trade turnover, %	69.29	94.4	61.06	78.2	109.35	110.52	107.88	97.6	51.23	41.9	53.03	70.01	63.59

Sources Goskomstat (2022), Bank of Russia (2020), author's calculations

The weakening ruble and a spike in inflation led to a decline in real disposable income to − 2.4% and weakened consumer demand (Bank of Russia 2020).

At the end of 2019, the GDP in current RUB grew by 1.3%. Inflation for 2019, despite all of the pessimistic expectations and the effect of the VAT increase, fell below the target of 4.0–3.8%. Real disposable income grew amid rising interest payments, and weak aggregate demand was only 0.1% in 2018.

The slowdown in global innovation has led both to a deterioration in the price environment of commodity markets and to a reduction in demand for Russian exports. In 2019, the investment growth rate was 1.7% after 4.3% in 2018 (Fig. 3).

Next, Russia's key financial development indicators for the period from 2007 to 2019 were examined, which are presented in Table 4.

The banking sector is an important part of the Russian economy, and its development indicators are shown in Fig. 4. A major weakness of the Russian financial market is considered to be the significant share of commercial bank assets at 63–77%, with a small share of non-bank financial institutions in the total assets of the banking sector, which creates the risk that the economy is not fully supplied with domestic credit.

Banks' liquid liabilities in GDP have a positive trend from 34% of the GDP in 2007 to 60.45% of the GDP in 2016, which generally characterizes a steady increase in the banks' ability to meet their obligations to depositors, creditors and other customers on time and without losses. At the end of the analyzed period, the indicator stood at 54.5% of the GDP. The degree of public confidence in the banking system can be measured by the ratio of bank deposits to GDP. Over the period from 2007 to 2013, the ratio rose from 17.8 to 25% of the GDP. Then, after a short-term decline of 2% in 2014, the trend increased again, peaking in 2016 at 32.3% of the GDP. By 2019, the indicator had fallen to 27% of the GDP (IMF 2020). In addition, the low value of this indicator entails a high interest rate on loans.

Russia has a rather low credit-to-GDP ratio compared to other developed economies (US: 183%, Switzerland: 172%, China: 151%, UK: 131%, Sweden: 128%). The ratio varies between 30–55% over the analyzed period, peaking in 2015, which was preceded by a prolonged increase since 2010.

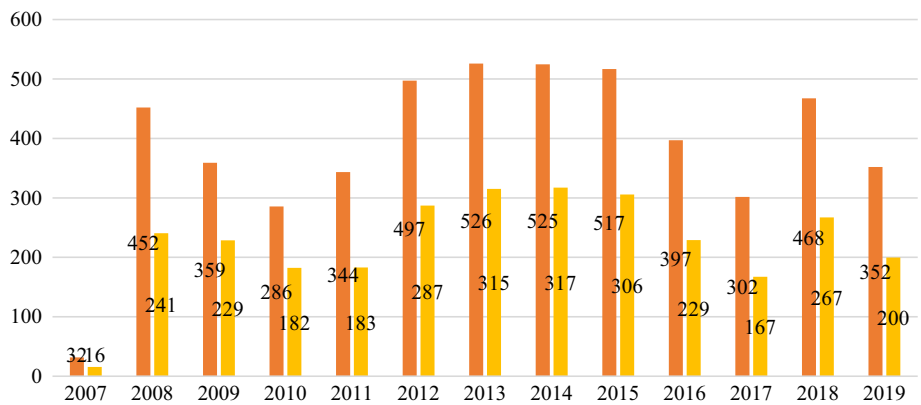

Fig. 3 Dynamics of export (orange) and import (yellow) in Russia in 2007–2019. *Sources*: Goskomstat (2022), Bank of Russia (2020), author's calculations

Table 4 The indicators of the financial development of Russia in 2007–2019

Indicator	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Ratio of commercial bank assets to total banking sector assets, %	71.04	69.27	63.43	68.68	72.83	72.73	73.57	77.49	71.61	69.61	74.62	75.33	71.04
Liqud liabilities of banks/GDP, %	33.98	34.94	43.32	43.18	44.14	44.81	47.68	51.11	57.88	60.45	52.44	55.20	54.50
Bank deposits/GDP, %	17.80	21.20	21.30	24.60	24.00	25.10	25.00	23.10	29.60	32.30	28.30	27.00	27.00
Commercial bank assets/GDP, %	60.53	67.89	75.84	73.00	69.05	72.63	78.52	98.05	99.72	93.09	92.51	90.79	87.76
Domestic bank credit/GDP, %	29.08	33.84	42.64	37.73	37.69	40.35	44.55	51.61	55.32	54.36	51.13	46.00	46.60
Banking market concentration ratio (sum of market shares of the three largest banks), %	20.85	21.59	28.47	28.51	26.93	29.84	28.79	31.57	47.56	41.76	60.60	53.59	55.48
Equity capitalization/GDP, %	100.83	61.90	61.16	57.45	43.87	35.63	34.39	25.14	23.63	38.17	42.61	32.02	47.87
Bond capitlazation (state and corporate)/GDP, %	7.90	6.36	11.91	11.38	9.94	11.14	11.94	8.02	12.49	18.92	19.96	18.06	19.91
Financial depth (amount of loans, equity and bond capitalization to GDP), %	137.81	102.11	115.70	106.57	91.50	87.12	90.89	84.77	91.44	111.44	113.70	96.08	114.38
Economic monetization ratio (M2/GDP), %	35.36	31.10	35.34	39.44	36.36	36.30	39.48	38.06	39.34	42.36	43.56	43.32	44.70

Sources Goskomstat (2022), Bank of Russia (2020), author's calculations

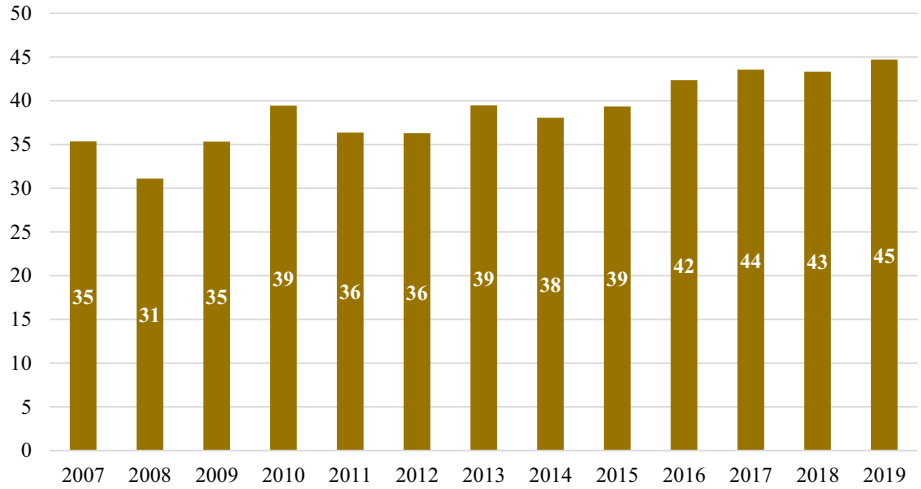

Fig. 4 Indicators M2/GDP of the Russian economy in 2007–2019. *Sources*: Goskomstat (2022), Bank of Russia (2020), author's calculations

The concentration of banking activity is an indicator of the degree of monopolization of the banking market. Competition in the banking market is an objective process that contributes to the most rational redistribution of revenues in the sector. Over the period from 2007 to 2013, the aggregate market share of the three largest banks remained at 20–29%. In 2017, there was a sharp increase in the figure to 60.6% of the GDP, which was due to a significant reduction in the number of banks due to the Central Bank's tightening policies. By 2019, banking market concentration was 55.5%. The depth of financial markets in the domestic economy fell sharply to 102% of the GDP in 2008; then, after a brief period of recovery from 2010, this again showed a downward trend. The period from 2014 to 2017 was characterized by steady growth, reaching 113.7% of the GDP. By 2019, the figure had risen by 18% after a short-term decline. Meanwhile, the volume of total assets of Russian banks in GDP has a stable rising trend from 60.5% in 2007 to 99.7% of the GDP in 2015. Thus, bank assets occupy a major share of the financial depth of the Russian economy (Fig. 4).

In Russia, the rate of monetization of the economy was 44.7% at the end of 2019. By analyzing the indicator, a steady increase is observed, but its rate is not high enough. The coefficient is less than 50%, indicating that there is insufficient money to settle the economy.

It should be noted that the financial market is characterized by markedly low stock and bond market capitalization to GDP ratios. For example, the share of equity capitalization in GDP has shown a negative trend over the period from 2007 to 2015, falling from 100.8 to 23.6% of the GDP. Thereafter, there is an increase to 47.87% of the GDP in 2019. The bond market is characterized by a smaller share of the GDP. Until 2015, the figure fluctuated slightly between 6–12% of the GDP; a significant increase to 18.82% occurred in 2016, and by 2019, it had reached 19.91%. The analysis of financial development indicators has shown that Russia's financial sector has a normal level of financial depth with a predominance of the banking sector, which in turn has a high degree of concentration of

assets of the largest banks and a steadily low share of non-bank financial institutions in the total assets of the banking sector.

Two indicators with a determining influence on innovation were chosen to build a regression model: the share of domestic bank credit in GDP and the share of equity capitalization in GDP (Tables 5, 6, 7).

The presence of high correlation between the factors makes it impossible to determine their isolated impact on the outcome indicator, and the parameters of the regression equation, in turn, prove to be uninterpretable. The results of the correlation analysis revealed a relationship between domestic bank credit in GDP and stock capitalization in GDP at −0.7726. Since this interdependence exceeds 0.7, this paper will examine the impact of these factors on innovation separately using two pairwise linear regression equations.

Results of MF-X-DMA

Next, an analysis of the two regression equations is conducted: the dependence of real GDP dynamics on the domestic bank credit/GDP ratio and the dependence of real GDP dynamics on the equity/GDP ratio (Table 8).

The sample coefficient of determination R2 is a measure of the overall quality of the regression equation, reflecting the fit of the constructed equation to the statistical data.

The value of the coefficient of determination 0.9342 in the equation of dependence of the GDP dynamics on the share of bank credit in GDP shows that the obtained regression equation explains the observed values well. The coefficient of determination 0.7259 in the second equation suggests that the regression equation explains the observed values worse.

Table 5 GDP in current prices (annual changes), %

Country	Mexico	Turkey	China	Russia	Brazil	Indonesia	India
2003	−0.06	0.33	0.13	0.25	0.08	0.20	0.16
2004	0.07	0.28	0.18	0.37	0.19	0.09	0.16
2005	0.12	0.24	0.17	0.29	0.34	0.11	0.17
2006	0.11	0.09	0.20	0.30	0.23	0.28	0.14
2007	0.08	0.24	0.29	0.31	0.27	0.19	0.27
2008	0.06	0.13	0.29	0.28	0.22	0.20	0.10
2009	−0.19	−0.16	0.11	−0.26	−0.01	0.04	−0.02
2010	0.17	0.19	0.19	0.24	0.30	0.29	0.29
2011	0.12	0.08	0.24	0.25	0.18	0.18	0.14
2012	0.02	0.05	0.13	0.07	−0.06	0.03	−0.01
2013	0.06	0.09	0.13	0.05	0.00	0.00	0.03
2014	0.03	−0.02	0.08	−0.09	−0.01	−0.03	0.07
2015	−0.11	−0.08	0.05	−0.34	−0.26	−0.04	0.04
2016	−0.08	0.01	0.02	−0.06	0.00	0.08	0.07
2017	0.08	−0.01	0.10	0.22	0.14	0.09	0.15
2018	0.05	−0.09	0.13	0.05	−0.07	0.03	0.07
2019	0.04	−0.03	0.03	0.02	−0.03	0.07	0.04
2020	−0.14	−0.06	0.03	−0.12	−0.22	−0.05	−0.08

Sources Oxford Economics (2022), author's calculations

Table 6 Loans From foreign banks to household and non-financial corporations to GDP (annual changes), %

Country	Mexico	Turkey	China	Russia	Brazil	Indonesia	India
2003	0.06	−0.34	−0.02	−0.08	−0.06	0.15	−0.01
2004	−0.13	−0.19	−0.03	0.12	−0.22	0.22	0.12
2005	−0.13	−0.23	0.04	0.13	−0.26	0.34	−0.07
2006	0.00	0.12	0.16	−0.22	0.10	−0.31	0.36
2007	−0.06	−0.03	0.07	0.17	−0.16	0.60	0.16
2008	−0.06	0.03	−0.12	−0.11	0.04	−0.05	0.19
2009	0.26	0.07	−0.19	0.32	0.04	−0.21	−0.02
2010	0.08	−0.07	−0.26	0.36	0.01	−0.35	0.08
2011	0.05	−0.10	−0.19	0.43	0.10	−0.04	0.03
2012	0.35	−0.15	−0.14	0.25	0.06	−0.08	0.22
2013	0.08	−0.08	−0.11	0.48	0.17	0.33	−0.07
2014	0.08	0.13	−0.06	0.28	0.01	−0.23	−0.14
2015	0.27	0.20	−0.02	0.32	0.48	0.04	−0.02
2016	0.00	−0.03	0.03	−0.04	−0.18	−0.24	−0.17
2017	−0.01	−0.01	−0.05	−0.07	−0.18	−0.02	−0.13
2018	−0.01	0.16	−0.14	−0.06	0.04	−0.09	−0.04
2019	−0.01	0.00	−0.12	0.09	0.02	−0.03	0.12

Sources Oxford Economics (2022), author's calculations

Table 7 Total external debt to GDP (annual changes), %

Country	Mexico	Turkey	China	Russia	Brazil	Indonesia	India
2003	0.04	−0.16	−0.04	−0.03	−0.07	−0.13	−0.07
2004	−0.06	−0.22	0.01	−0.25	−0.16	−0.08	−0.14
2005	−0.06	−0.11	−0.11	−0.10	−0.29	−0.10	0.02
2006	−0.09	0.06	−0.02	−0.04	−0.28	−0.23	−0.09
2007	−0.06	−0.07	−0.10	−0.01	−0.07	−0.16	−0.03
2008	0.07	0.15	−0.09	0.06	−0.01	−0.04	0.22
2009	0.18	0.15	−0.32	0.32	0.17	0.07	0.12
2010	0.10	−0.06	0.29	−0.15	0.04	−0.10	−0.06
2011	0.03	−0.03	0.03	−0.12	−0.04	−0.06	−0.01
2012	0.20	0.06	0.09	0.10	0.17	0.09	0.15
2013	0.08	0.04	−0.13	0.10	0.09	0.06	0.05
2014	0.05	0.05	0.23	−0.09	0.15	0.13	0.00
2015	0.10	0.05	0.34	0.31	0.26	0.10	0.00
2016	0.08	0.00	0.00	0.05	0.02	−0.05	−0.11
2017	−0.02	0.12	0.13	−0.17	−0.13	0.01	−0.02
2018	−0.03	0.03	0.00	−0.16	0.07	0.04	−0.05
2019	0.00	0.01	0.02	0.06	0.04	0.00	0.04

Sources Oxford Economics (2022), author's calculations

Thus, according to the data on the dependence of the dynamics of real GDP on the ratio domestic bank credit/GDP and the dependence of the dynamics of real GDP on the ratio stock capitalization/GDP, two pairwise linear regression equations were constructed, and their examination was carried out. As a result of checking the statistical significance of the coefficient of determination 2, it has been proven that the pairwise

Table 8 Regression model for Russia

Indicator	Dependence loans from foreign banks to household and non-financial corporations on GDP ratio	Dependence total external debt on GDP ratio
R2	0.934	0.725
SE	0.673	1.374
F	127.702	23.841
b0	16.055	− 1.769
b1	− 0.302	0.102
Sb0	1.168	1.071
Sb1	0.026	0.020
t b0	13.742	− 1.651
t b1	− 11.300	4.882

Sources Author's calculations

linear regression equations obtained are of satisfactory quality and are statistically significant, so they can be used for further forecasting. The confirmed significance of the coefficients of b1 indicates a linear relationship between the dynamics of real GDP and both the domestic bank credit/GDP indicator and the equity capitalization/GDP indicator. Additionally, the confidence intervals of the coefficients, which do not include zero, have been constructed, which confirms their statistical significance (apart from the coefficient b0 of the second regression equation). Next, to confirm the reliability of the conclusions made, it is necessary to analyze the model for the presence of heteroscedasticity and autocorrelation.

The results of the correlation analysis suggest that there is a moderate correlation between Russia's macroeconomic indicators and financial development. Increasing banking market concentration has a negative impact on innovation and the dynamics of the population's real disposable income. Increased monopolization of the banking sector has a negative impact on competition between banks, allowing them to tighten their lending terms. This situation negatively affects both real household income and the economy as a whole.

A high negative impact on GDP dynamics, the growth rate of fixed capital investment and real disposable income is caused by the share of domestic bank credit to GDP, as well as a negative impact of the average intensity on the growth rate of industrial output. This can be attributed to the application of high interest rates by banks, which take up a large share of household expenditure, and also hinder the expansion and re-equipment of fixed assets of organizations, ultimately slowing down GDP growth dynamics.

A low degree of positive influence of the share of equity capitalization in GDP dynamics and the growth rate of fixed capital investment was also found. This result demonstrates the promise of increasing the financial depth of the economy precisely through the development of the equity market and an increase in the financial literacy of the population in this direction. An increase in equity capitalization also has a favorable effect on the dynamics of fixed asset renewal and modernization and stimulates an improvement in the dynamics of industrial production and the welfare of society.

For the research, the MF-X-DMA method was used to assess the quantitative indicator of cross-correlation. We used logarithmic graphs of the fluctuation function Fq (s) versus the time scale s for the named factors and innovation factor (Fig. 5). The low

capitalization of the modern Russian financial market (a) and concentration of the banking sector (b) are no so important factors, but low liquidity in small cap stocks at the financial market (c) and low financial literacy (d) are crucial factors.

The parameter q was enclosed in the gap [−10, 10]. In this study, the v timescale range was v = [v = 5, 20, 100, 120, 433]. This range was used in violation of the above-mentioned rule for window sizes to improve the clarity of the convergence of all chart lines.

Thus, the results of the analysis of regression models for the presence of residuals autocorrelation revealed that the hypothesis of the absence of autocorrelation in both samples is confirmed. The regression equations are satisfactory, the parameter estimates are effective, the variances of the coefficient estimates are unbiased and the conclusions are statistically valid.

The regression models built can be used to forecast the dynamics of innovation. The study confirms the existence of a direct relationship between innovation and equity market capitalization. There is an inverse relationship between domestic bank credit and GDP dynamics, which is due to the insufficient ratio of domestic credit to GDP, which does not fully serve the real economy.

Analysis of hybrid decision making approach

In the final part of the analysis, a fuzzy decision-making model is created. In the first stage, the determinants of open innovation-based fintech potential are weighted for the emerging economies. Table 9 defines the determinants of open innovation-based fintech potential.

Table 10 explains the scales and degrees considered in the analysis.

Evaluations are given in "Appendix". Mexico is the most successful emerging economy with respect to the open innovation-based fintech potential. India and Turkey are other high-performance countries.

Discussion

Development of financial technology

The results include that correlation and regression analysis has identified two factors that have the greatest impact on Russia's innovation: domestic bank credit and equity

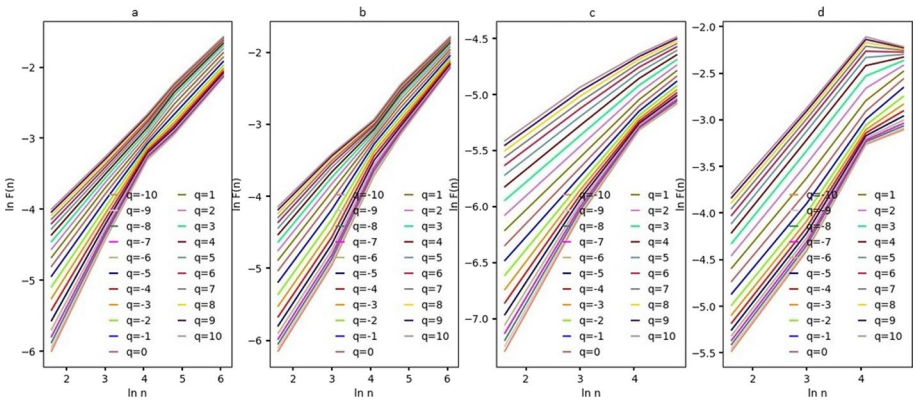

Fig. 5 MF-X-DMA summary: low capitalization of the modern Russian financial market (**a**), concentration of the banking sector (**b**), low liquidity in small cap stocks at the financial market (**c**), low financial literacy (**d**). *Sources*: Goskomstat (2022), Bank of Russia (2020), author's calculations

Table 9 Selected criteria for the open innovation-based fintech potential

Criteria	Supported literature
Transitioning to the cloud (criterion 1)	Nezami et al. (2022)
Simplicity and modularity (criterion 2)	Chhiba et al. (2018)
Automation (criterion 3)	Khraisha and Arthur (2018)
Artificial intelligence (ai) and machine learning (mL) (criterion 4)	Zhong and Enke (2019)
Platform upgrade (criterion 5)	Li and Wang (2021)
Digitalization of processes (criterion 6)	Ivanov et al. (2020)

Table 10 Linguistic scales, golden cut-based positive and negative membership and non-membership degrees

Linguistic scales		Positive degrees (PEG)		Negative degrees (NEG)	
Criteria	Economies	Membership degrees (MRE)	Non-membership degrees (NRE)	Membership degrees	Non-membership degrees
No (n)	Weakest (w)	0.40	0.25	− 0.60	− 0.37
Some (s)	Poor (p)	0.45	0.28	− 0.55	− 0.34
Medium (m)	Fair (f)	0.50	0.31	− 0.50	− 0.31
High (h)	Good (g)	0.55	0.34	− 0.45	− 0.28
Very high (vh)	Best (b)	0.60	0.37	− 0.40	− 0.25

market capitalization. Measures to improve financial development should cover ways to improve bank lending and equity market development.

An important focus is to stimulate the development of financial technology, creating conditions for digitalization and a favorable environment for the introduction and use of information technology. This will reduce transaction costs, expand and diversify credit product distribution channels and facilitate equal access to infrastructure and data for all market participants. Introducing proportional regulation and optimizing the regulatory burden on banks will improve the competitive environment. It is also necessary to continuously improve the risk management system by modifying and improving methods of dealing with overdue loans to improve the quality of the loan portfolio (Sisodiya et al. 2013; Wallusch et al. 2020; Tiniç et al. 2021).

Development of confidence and financial literacy

For a more efficient and successful equity market, forces should be directed towards the development of lagging sectors of the economy, which would provide a solid foundation for the potential growth of the securities market as a whole. Easing the requirements of the securities issuance procedure could be realized by reducing the tax burden on companies conducting securities offerings in the primary stock market. Full access to issuer information should be provided to increase confidence in the stock market and attention should be given to protecting investor rights and legitimate interests by developing a legal system to provide investor assistance. At the same time, measures to improve financial literacy should be undertaken to generally stimulate demand for financial market products and increase their liquidity. The inverse relationship between domestic

bank credit and GDP dynamics was found in previous research (Obstfeld 2012; Obstfeld and Taylor 2017).

As globalization progresses, there is a need to develop cooperation with foreign regulators, rapidly implement universally recognized standards of financial regulation, monitor consumer compliance and build geopolitical relationships with partner countries.

For the successful implementation of financial innovations, companies need to switch to machine learning methods. In this way, the data will be analyzed more comprehensively and accurately. This will help businesses to manage the process more successfully and save time. As a result, customer expectations will be more clearly understood. Thus, companies will be able to offer products that meet their customers' expectations. This will help companies to increase their performance. In addition, the sustainability of financial innovation projects will be ensured. Similarly, Chen (2018), Zhong and Enke (2019), Depren et al. (2021) highlighted the significance of the machine learning system for the performance improvement of the financial innovation techniques.

The functioning of the financial market is not isolated from the real sector, although it does not have a strong impact on the economy. The analysis reveals a direct correlation between innovation dynamics and equity market capitalization, which confirms the significant potential for the further expansion and development of this market.

In turn, the domestic bank credit indicator has a negative impact on GDP dynamics due to the insufficient ratio of domestic credit to GDP, which does not fully serve the real economy. Insufficient credit leads to a shortage of funds in the economy, which further inhibits the redistribution of material resources and continuous reproduction processes, prevents the expansion of fixed assets and disrupts the development of non-cash circulation channels by means of payments.

The main measures to improve financial development should cover ways to improve bank lending and equity market development. An important area is the development of competition by providing equal access to information to all market participants in a continuously improving technical infrastructure. The article fills the gap in the following body of knowledge: the link between innovations and low capitalization of the modern Russian financial market, concentration of the banking sector, low liquidity in small cap stocks at the financial market, low financial literacy and weak public confidence, as well as risks arising in the process of globalization.

Conclusions

In order to qualitatively improve the functioning of the capital market, efforts should be directed towards reducing transaction costs, regulating financial sector institutions in a proportionate way, with increased transparency of market operation, elimination of unscrupulous behavior and management of conflicts of interest. In order to mitigate the risks arising from globalization, cooperation with foreign regulators should be developed and universally recognized standards of financial regulation should be promptly introduced.

In addition, this paper has some practical and theoretical implications that this work highlights. Firstly, a high negative impact on GDP dynamics, the growth rate of fixed capital investment and real disposable income is caused by the share of domestic bank credit to GDP. Secondly, the paper confirms the existence of a direct relationship

between innovation and equity market capitalization. The article has limitations as there is a lack of data on any macroeconomic indicators (inflation, unemployment), including those on the financial development for the period from 2002 to 2020.

Another analysis has also been conducted by generating a novel fuzzy decision-making model. In the first stage, the determinants of open innovation-based fintech potential are weighted for the emerging economies. For this purpose, M-SWARA methodology is taken into consideration based on bipolar q-ROFSs and golden cut. The second stage of the analysis includes evaluating the emerging economies with the determinants of open innovation-based fintech potential. In this context, emerging seven countries are examined with ELECTRE methodology. Artificial intelligence (ai) and machine learning is found as the most significant factor for the open innovation-based fintech potential. Transitioning to the cloud and platform upgrade are other important criteria. On the other side, Mexico is the most successful emerging economy with respect to the open innovation-based fintech potential. India and Turkey are other high-performance countries.

Appendix

See Table 11.

Table 11 Linguistic evaluations for criteria

	C1		C2		C3		C4		C5		C6	
	PEG	NEG	PEG	NEG	PEG	NEG	PEG	NEG	PEG	NEG	PEG	NEG
Decision maker 1												
C1			S	N	S	H	M	N	M	H	H	VH
C2	H	H			M	VH	H	H	M	N	VH	H
C3	M	H	H	H			M	VH	H	M	S	M
C4	S	M	S	H	M	VH			VH	M	VH	N
C5	M	H	M	H	H	H	M	N			S	VH
C6	H	S	S	H	M	H	H	VH	S	VH		
Decision maker 2												
C1			S	H	S	N	M	N	M	H	H	N
C2	H	H			M	VH	H	H	H	N	M	H
C3	M	H	H	H			M	VH	M	M	S	M
C4	S	M	H	N	M	VH			VH	VH	H	H
C5	M	H	M	H	H	H	M	N			M	M
C6	H	M	M	H	M	M	H	VH	S	VH		
Decision maker 3												
C1			S	N	S	N	M	N	M	N	H	H
C2	H	H			S	M	M	H	S	N	M	H
C3	VH	N	VH	H			M	M	S	N	M	H
C4	S	VH	S	H	M	VH			S	M	M	N
C5	H	H	M	H	H	H	M	N			S	M
C6	H	H	S	H	M	H	H	VH	S	VH		

Average values are shown in Table 12.

Table 12 Average values

	C1				C2				C3				C4				C5				C6			
	PEG		NEG		PEG		NEG		PEG		NEG		PEG		NEG		PEG		NEG		PEG		NEG	
	μ	n	μ	n	μ	n	μ	n	μ	n	μ	n	μ	n	μ	n	μ	n	μ	n	μ	n	μ	n
C1					0.45	0.28	−0.55	−0.34	0.45	0.28	−0.55	−0.34	0.50	0.31	−0.60	−0.37	0.50	0.31	−0.50	−0.31	0.55	0.34	−0.48	−0.30
C2	0.55	0.34	−0.45	−0.28					0.48	0.30	−0.43	−0.27	0.53	0.33	−0.45	−0.28	0.50	0.31	−0.60	−0.37	0.53	0.33	−0.45	−0.28
C3	0.53	0.33	−0.50	−0.31	0.57	0.35	−0.45	−0.28					0.50	0.31	−0.43	−0.27	0.50	0.31	−0.53	−0.33	0.47	0.29	−0.48	−0.30
C4	0.45	0.28	−0.47	−0.29	0.48	0.30	−0.50	−0.31	0.50	0.31	−0.40	−0.25					0.55	0.34	−0.47	−0.29	0.55	0.34	−0.55	−0.34
C5	0.52	0.32	−0.45	−0.28	0.50	0.31	−0.45	−0.28	0.55	0.34	−0.45	−0.28	0.50	0.31	−0.60	−0.37					0.47	0.29	−0.47	−0.29
C6	0.55	0.34	−0.50	−0.31	0.47	0.29	−0.45	−0.28	0.50	0.31	−0.47	−0.29	0.55	0.34	−0.40	−0.25	0.45	0.28	−0.40	−0.25				

Score function values are indicated in Table 13.

Table 13 Score function values

	C1	C2	C3	C4	C5	C6
C1	0.000	0.197	0.197	0.260	0.191	0.213
C2	0.197	0.000	0.148	0.186	0.260	0.186
C3	0.211	0.209	0.000	0.158	0.211	0.164
C4	0.147	0.182	0.144	0.000	0.205	0.254
C5	0.175	0.165	0.197	0.260	0.000	0.155
C6	0.223	0.147	0.173	0.176	0.119	0.000

Significant values are shown in Table 14.

Table 14 Sj, kj, qj, and wj values

C1	Sj	kj	qj	wj	C2	Sj	kj	qj	Wj
C4	0.260	1.000	1.000	0.265	C5	0.260	1.000	1.000	0.259
C6	0.213	1.213	0.824	0.218	C1	0.197	1.197	0.836	0.217
C2	0.197	1.197	0.689	0.182	C4	0.186	1.186	0.705	0.183
C3	0.197	1.197	0.689	0.182	C6	0.186	1.186	0.705	0.183
C5	0.191	1.191	0.578	0.153	C3	0.148	1.148	0.614	0.159
C3	**Sj**	**kj**	**qj**	**wj**	**C4**	**Sj**	**kj**	**qj**	**Wj**
C1	0.211	1.000	1.000	0.241	C6	0.254	1.000	1.000	0.272
C5	0.211	1.211	1.000	0.241	C5	0.205	1.205	0.830	0.226
C2	0.209	1.209	0.827	0.199	C2	0.182	1.182	0.702	0.191
C6	0.164	1.164	0.711	0.171	C1	0.147	1.147	0.612	0.166
C4	0.158	1.158	0.614	0.148	C3	0.144	1.144	0.535	0.145
C5	**Sj**	**kj**	**qj**	**wj**	**C6**	**Sj**	**kj**	**qj**	**Wj**
C4	0.260	1.000	1.000	0.271	C1	0.223	1.000	1.000	0.265
C3	0.197	1.197	0.836	0.227	C4	0.176	1.176	0.850	0.225
C1	0.175	1.175	0.711	0.193	C3	0.173	1.173	0.725	0.192
C2	0.165	1.165	0.610	0.166	C2	0.147	1.147	0.632	0.168
C6	0.155	1.155	0.528	0.143	C5	0.119	1.119	0.565	0.150

Relation matrix is constructed in Table 15.

Table 15 Relation matrix

	C1	C2	C3	C4	C5	C6
C1		0.182	0.182	0.265	0.153	0.218
C2	0.217		0.159	0.183	0.259	0.183
C3	0.241	0.199		0.148	0.241	0.171
C4	0.166	0.191	0.145		0.226	0.272
C5	0.193	0.166	0.227	0.271		0.143
C6	0.265	0.168	0.192	0.225	0.150	

Table 16 includes stable matrix.

Table 16 Stable matrix

	C1	C2	C3	C4	C5	C6
C1	0.177	0.177	0.177	0.177	0.177	0.177
C2	0.154	0.154	0.154	0.154	0.154	0.154
C3	0.152	0.152	0.152	0.152	0.152	0.152
C4	0.181	0.181	0.181	0.181	0.181	0.181
C5	0.169	0.169	0.169	0.169	0.169	0.169
C6	0.166	0.166	0.166	0.166	0.166	0.166

Impact relation map is defined in Fig. 6. It shows the connection map for the criteria: Transitioning to the cloud (criterion 1), Simplicity and modularity (criterion 2), Automation (criterion 3), Artificial intelligence (ai) and machine learning (mL) (criterion 4), Platform upgrade (criterion 5), Digitalization of processes (criterion 6).

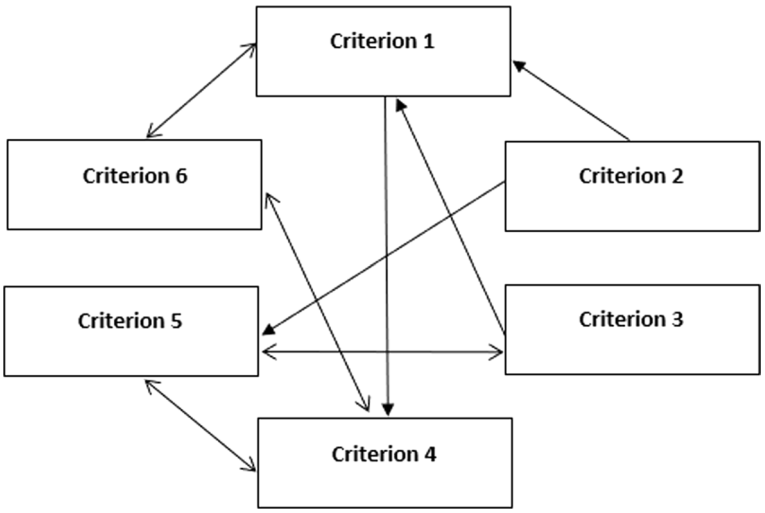

Fig. 6 Impact-relation map for the criteria

Table 17 includes the comparative weighting results.

Table 17 Comparative weighting priorities for the criteria

	Bipolar IFSs	Bipolar PFSs	Bipolar q-ROFSs
C1	2	2	2
C2	5	5	5
C3	6	6	6
C4	1	1	1
C5	3	3	3
C6	4	4	4

Artificial intelligence (ai) and machine learning is the most significant factor for the open innovation-based fintech potential. Transitioning to the cloud and platform upgrade are other important criteria. The second stage of the analysis includes evaluating the emerging economies with the determinants of open innovation-based fintech potential. Emerging seven (E7) economies are taken into consideration in the analysis process that are Russia (E1), Brazil (E2), India (E3), China (E4), Turkey (E5), Indonesia (E6) and Mexico (E7). Table 18 demonstrates the evaluations.

Table 19 gives information about the average values.

Score functions are shown in Table 20.

Table 21 represents normalized matrix.

Weighted matrix is indicated in Table 22.

Concordance and discordance interval matrixes are defined in Table 23.

The concordance, discordance, and aggregated index matrixes are constructed in Table 24.

Net superior, inferior, and overall values are calculated in Table 25 for ranking the economies.

Ranking results for all sets are shown in Table 26.

Table 18 Linguistic evaluations of economies

	C1		C2		C3		C4		C5		C6	
	PEG	**NEG**	**PEG**	**NEG**	**PEG**	**NEG**	**PEG**	**NEG**	**PEG**	**NEG**	**PEG**	**NEG**
Decision maker 1												
E1	P	G	B	F	G	W	B	G	W	G	W	W
E2	F	F	B	G	B	G	P	F	B	F	B	W
E3	B	W	B	F	P	F	P	G	B	F	W	G
E4	G	F	G	W	G	G	B	G	G	G	B	G
E5	B	G	G	W	B	G	G	G	G	G	G	W
E6	G	F	G	G	P	G	B	F	P	G	G	W
E7	P	P	B	G	P	G	B	W	B	G	B	W
Decision maker 2												
E1	B	P	B	F	G	W	B	F	W	G	W	P
E2	G	P	G	G	P	G	B	P	B	F	B	W
E3	P	F	B	F	P	F	P	G	B	F	W	G
E4	G	W	W	W	G	F	B	P	G	G	B	F
E5	B	P	B	W	B	W	G	G	G	G	G	W
E6	W	F	G	G	P	G	B	F	P	F	B	P
E7	B	P	P	G	B	P	G	W	B	P	G	W
Decision maker 3												
E1	B	P	W	F	G	W	B	G	W	G	W	W
E2	B	F	W	F	B	G	W	F	B	W	B	G
E3	B	W	B	F	W	W	P	G	B	W	W	G
E4	G	F	G	W	G	G	B	G	G	F	B	G
E5	B	G	G	W	G	G	B	G	W	G	G	W
E6	G	P	G	G	P	G	B	F	P	G	G	F
E7	G	P	B	P	P	G	B	W	B	G	G	G

Table 19 Average values for the economies

	C1				C2				C3				C4				C5				C6			
	PEG		NEG		PEG		NEG		PEG		NEG		PEG		NEG		PEG		NEG		PEG		NEG	
	μ	n	μ	n	μ	n	μ	n	μ	n	μ	n	μ	n	μ	n	μ	n	μ	n	μ	n	μ	n
E1	0.55	0.34	−0.52	−0.32	0.53	0.33	−0.50	−0.31	0.55	0.34	−0.60	−0.37	0.60	0.37	−0.47	−0.29	0.40	0.25	−0.45	−0.28	0.40	0.25	−0.58	−0.36
E2	0.55	0.34	−0.52	−0.32	0.52	0.32	−0.47	−0.29	0.55	0.34	−0.45	−0.28	0.48	0.30	−0.52	−0.32	0.60	0.37	−0.53	−0.33	0.60	0.37	−0.55	−0.34
E3	0.55	0.34	−0.57	−0.35	0.60	0.37	−0.50	−0.31	0.43	0.27	−0.53	−0.33	0.45	0.28	−0.45	−0.28	0.60	0.37	−0.53	−0.33	0.40	0.25	−0.45	−0.28
E4	0.55	0.34	−0.53	−0.33	0.50	0.31	−0.60	−0.37	0.55	0.34	−0.47	−0.29	0.60	0.37	−0.48	−0.30	0.55	0.34	−0.47	−0.29	0.60	0.37	−0.47	−0.29
E5	0.60	0.37	−0.48	−0.30	0.57	0.35	−0.60	−0.37	0.58	0.36	−0.50	−0.31	0.57	0.35	−0.45	−0.28	0.50	0.31	−0.45	−0.28	0.55	0.34	−0.60	−0.37
E6	0.50	0.31	−0.52	−0.32	0.55	0.34	−0.45	−0.28	0.45	0.28	−0.45	−0.28	0.60	0.37	−0.50	−0.31	0.45	0.28	−0.47	−0.29	0.57	0.35	−0.55	−0.34
E7	0.53	0.33	−0.55	−0.34	0.55	0.34	−0.48	−0.30	0.50	0.31	−0.48	−0.30	0.58	0.36	−0.60	−0.37	0.60	0.37	−0.48	−0.30	0.57	0.35	−0.55	−0.34

Table 20 Score function values of the economies

	C1	C2	C3	C4	C5	C6
E1	0.232	0.211	0.292	0.243	0.119	0.201
E2	0.232	0.183	0.197	0.192	0.281	0.292
E3	0.266	0.260	0.178	0.139	0.281	0.119
E4	0.243	0.260	0.205	0.251	0.205	0.243
E5	0.251	0.304	0.247	0.209	0.165	0.292
E6	0.201	0.197	0.139	0.260	0.147	0.266
E7	0.243	0.213	0.182	0.317	0.251	0.266

Table 21 Normalized matrix

	C1	C2	C3	C4	C5	C6
E1	0.367	0.338	0.524	0.389	0.208	0.307
E2	0.367	0.293	0.353	0.307	0.492	0.448
E3	0.421	0.417	0.319	0.223	0.492	0.182
E4	0.384	0.417	0.367	0.402	0.359	0.372
E5	0.397	0.486	0.443	0.334	0.289	0.448
E6	0.317	0.315	0.250	0.417	0.258	0.408
E7	0.384	0.341	0.326	0.507	0.440	0.408

Table 22 Weighted matrix

	C1	C2	C3	C4	C5	C6
E1	0.065	0.052	0.080	0.070	0.035	0.051
E2	0.065	0.045	0.054	0.056	0.083	0.074
E3	0.074	0.064	0.049	0.040	0.083	0.030
E4	0.068	0.064	0.056	0.073	0.061	0.062
E5	0.070	0.075	0.068	0.060	0.049	0.074
E6	0.056	0.048	0.038	0.075	0.044	0.068
E7	0.068	0.052	0.050	0.092	0.075	0.068

Table 23 Concordance and discordance interval matrixes

	Concordance matrix							Discordance matrix						
	E1	E2	E3	E4	E5	E6	E7	E1	E2	E3	E4	E5	E6	E7
E1	0.000	0.664	0.500	0.153	0.334	0.483	0.153	0.000	1.000	0.622	1.000	1.000	0.398	1.000
E2	0.513	0.000	0.670	0.336	0.336	0.666	0.489	0.544	0.000	0.429	0.841	0.863	0.503	1.000
E3	0.500	0.500	0.000	0.500	0.346	0.653	0.500	0.650	1.000	0.000	1.000	1.000	0.949	1.000
E4	0.847	0.664	0.654	0.000	0.350	0.653	0.483	0.938	1.000	0.696	0.000	0.933	0.332	1.000
E5	0.666	0.831	0.654	0.650	0.000	0.819	0.650	0.529	1.000	0.777	0.980	0.000	0.507	1.000
E6	0.517	0.334	0.347	0.347	0.181	0.000	0.166	1.000	1.000	1.000	1.000	1.000	0.000	1.000
E7	0.847	0.511	0.500	0.694	0.350	1.000	0.000	0.770	0.243	0.225	0.610	0.710	0.000	0.000

Table 24 Concordance, discordance and aggregated index matrixes

	Concordance matrix							Discordance matrix							Aggregated matrix						
	E1	E2	E3	E4	E5	E6	E7	E1	E2	E3	E4	E5	E6	E7	E1	E2	E3	E4	E5	E6	E7
E1	0	1	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0
E2	0	0	1	0	0	1	0	1	1	1	0	0	1	0	0	0	1	0	0	1	0
E3	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
E4	1	1	1	0	0	1	0	0	0	1	1	0	1	0	0	0	1	0	0	1	0
E5	1	1	1	1	0	1	1	1	0	1	0	1	1	0	1	0	1	0	0	1	0
E6	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
E7	1	0	0	1	0	1	0	1	1	1	1	1	1	1	1	0	0	1	0	1	0

Table 25 Net superior, inferior, and overall values of the economies

	Net superior values	Net inferior values	Overall values
E1	− 1.599	0.588	− 2.187
E2	− 0.496	− 1.062	0.566
E3	− 0.328	1.850	− 2.178
E4	0.972	− 0.532	1.504
E5	2.371	− 0.713	3.084
E6	− 2.382	3.311	− 5.693
E7	1.461	− 3.443	4.903

Table 26 Comparative overall ranking results for the economies

Economies	Bipolar q-ROF multi SWARA-ELECTRE	Bipolar PF multi SWARA-ELECTRE	Bipolar IF multi SWARA-ELECTRE
E1	6	7	6
E2	4	4	4
E3	5	5	5
E4	3	3	3
E5	2	2	2
E6	7	6	7
E7	1	1	1

Abbreviations

M-SWARA Multi stepwise weight assessment ratio analysis
q-ROFSs Q-rung orthopair fuzzy set
ELECTRE Elimination and choice translating reality
AI Artificial intelligence
ML Machine learning

Author contributions

The problem is proposed by AM. The solving method is proposed by HD and SY. The method is applied by HD and SY. The writing of manuscript is done by AM. All authors read and approved the final manuscript.

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Availability of data and materials

In this study the data is not available.

Declarations

Ethics approval and consent to participate
This manuscript does not require ethical approval and content to participate since it does not contain any human participate, human data or human tissue.

Competing interests
There was no conflict or competing interest for the authors in establishing this manuscript. This manuscript has not been published or presented elsewhere in part or in entirety and is not under consideration by another journal. We have read and understood your journal's policies, and we believe that neither the manuscript nor the study violates any of these. There are no conflicts of interest to declare.

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