

Fintech Innovation, Digital Maturity, and Responsible Financial Behaviour: Panel Evidence from Developed and Transition Economies

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Abstract

The active spread of digital financial technologies is changing financial decision-making mechanisms and creating new behavioural risks. At the same time, the issue of combining financial efficiency, responsibility and digital maturity remains insufficiently empirically substantiated. This article aims to assess the impact of fintech innovations on balanced financial behaviour and responsibility at different levels of digitalisation. The research methodology is based on a fixed-effects panel econometric analysis for the period 2020–2024.

The sample covers a group of countries with developed and transitional financial markets. An integral BFRI index has been formed, combining indicators of financial behaviour and responsibility. The key explanatory variables are the indices of fintech innovation and digitalisation, as well as their interaction effect. To ensure the robustness of the estimates, macroeconomic control variables and robust standard errors were employed. The empirical findings indicate a consistent positive impact of fintech innovations on the BFRI level. During the study period, the BFRI index increased from 0.52 to 0.67, reflecting a strengthening of responsible financial behaviour. The fintech innovation coefficient is statistically significant, with the estimated marginal effect ranging from 0.016 at DIGI = -1 to 0.040 at DIGI = +1. The interaction effect confirms that digitalisation significantly amplifies the behavioural impact of fintech. The highest effects were recorded in digitally mature financial systems. The overall conclusions confirm the system-forming role of fintech innovations in transforming financial behaviour. Digital infrastructure is a key catalyst for responsible financial practices. The results are of practical importance for regulatory policy and digital transformation strategies for the financial market.

Keywords: fintech innovation, responsible financial behaviour, digital maturity, behavioural finance, financial regulation, panel data.

JEL Classification: G23, G28, G41, O33, C23.

Introduction

The modern financial system is undergoing profound transformations driven by fintech innovations and digitalisation, which are significantly changing the economic behaviour and responsibilities of market participants. The widespread adoption of digital payment solutions, analytical platforms, and automated services increases financial accessibility but also creates new behavioural and regulatory challenges. The increasing speed of financial transactions and the growing complexity of digital products highlight the urgency of balanced financial decision-making and the responsible use of technology. In this context, investigating the systemic impact of fintech amidst the digital transformation of economic relations becomes of paramount importance.

The active development of fintech innovations is transforming financial markets, changing behavioural patterns, and increasing the responsibility of financial system participants (Anifa et al., 2022). Empirical studies confirm that the impact of fintech on financial behaviour significantly depends on the level of digital infrastructure and institutional quality (Lavrinenko et al., 2023). The spread of fintech solutions without adequate digital literacy can simultaneously reduce discipline and increase financial risks for households (Chen et al., 2024). The institutional environment and regulatory mechanisms determine whether fintech innovations are transformed into stable and responsible financial practices (Campos-Teixeira et al., 2025). Comparative studies of developed and transitional economies show that digitalisation is a key moderator of the behavioural effects of fintech (Vijayagopal et al., 2024; Satjawisate et al. 2025).

The institutional environment and regulatory frameworks determine whether fintech innovations turn into sustainable and responsible financial practices. Despite extensive research, the alignment of economic behaviour and responsibility within digital ecosystems remains insufficiently formalised. Existing literature primarily emphasises the technological efficiency of fintech solutions, often overlooking their behavioural and institutional dimensions. Furthermore, the absence of comprehensive empirical models hinders assessing the long-term implications of fintech innovations for financial stability. This creates a significant research gap between technological advancement and the adoption of responsible financial practices.

The research problem is to determine how fintech innovations influence the formation of balanced financial behaviour across different levels of digitalisation. The problem lies in the lack of a quantitative assessment of how fintech and digital infrastructure interact to shape financial responsibility. The question of whether digitalisation enhances the behavioural effect of financial technologies remains under-researched. This complicates the development of effective regulatory and strategic decisions in the financial sector.

This article aims to assess the impact of fintech innovations on balanced financial behaviour and the responsibility of financial market participants in the context of digitalisation. To achieve this goal, the following tasks have been set: (1) to develop an integral behavioural index; (2) to identify key digital factors and assess their interaction; (3) to analyse the dynamics of fintech behavioural effects during 2020–2024; (4) to assess the impact of fintech at different levels of digital maturity.

Within the framework of this study, hypotheses are formulated about the positive impact of fintech innovations on financial behaviour and the reinforcing role of digitalisation. These hypotheses are tested using panel data econometric methods:

- (H1) FINTECH is positively associated with BFRI; it is assumed that a higher level of digital infrastructure increases the effectiveness of fintech solutions in shaping responsible financial interactions.
- (H2) DIGI strengthens the link between FINTECH and BFRI ($\beta_3 > 0$). It is also hypothesised that the behavioural effects of fintech are non-linear and increase in digitally mature environments.

The article's scientific novelty lies in combining behavioural and technological approaches to the analysis of financial relations. An integrated index of balanced financial behaviour and responsibility, accounting for the digital context, is proposed. The role of digitalisation as a catalyst for the behavioural effects of fintech innovations is substantiated. The results obtained expand theoretical understanding of the transformation of financial behaviour in the digital economy and have practical significance for financial policy.

1. Literature Review

Fintech literature has shifted from describing technological novelties to analysing their behavioural and institutional implications. Anifa et al. (2022) summarise fintech innovations in payments and financing, emphasising the role of the regulatory framework in fostering a "fair ecosystem". However, their review primarily focuses on technological categories and offers less explanation of how these innovations exactly transform the responsibilities and disciplines of market participants. This creates a gap between the description of instruments and the measurement of balanced financial behaviour, which is central to our research.

At the macro level, Lavrinenko et al. (2023) consider fintech as a factor in the financial development of EU countries, emphasising the dependence of results on institutional conditions. Their approach is close to our logic, as it allows us to analyse systemic effects rather than individual cases. At the same time, the authors note the limitations of aggregate indices and the lack of detailed data, which can "smooth out" differences between countries. This is important for interpreting the BFRI, as behavioural responsibility is often unevenly distributed across financial market segments.

The behavioural dimension of fintech adoption is most clearly revealed by Kurucz et al. (2025), who explain intentions to use fintech applications and the role of user attitudes. Unlike the macro analysis by Lavrinenko et al. (2023), this approach captures the micro-mechanisms of trust, convenience, and perceived usefulness. However, the focus on a specific age group and survey data may reduce the generalisability of the findings to different financial ecosystems. For our study, this means that behavioural indicators need to be combined with country-specific characteristics of digital maturity.

Chen et al. (2024) provide an important corrective to “techno-optimism” by demonstrating the nexus between financial literacy, fintech, and household risky investments. Their findings highlight that fintech can not only stabilise behaviour but also exacerbate risk-taking propensity when literacy is insufficient. This stands in partial contrast to interpretations that automatically associate fintech with responsibility. For our study, this reinforces the thesis that “balanced” behaviour emerges only through the synergy of innovation with digital and educational prerequisites.

The institutional dimension of fintech’s interaction with the financial system is revealed by Campos-Teixeira et al. (2025), who empirically demonstrate the interdependence of fintech and traditional institutions in a developing economy. This approach complements Anifa et al. (2022) by shifting the discussion from “types of innovation” to “conditions for their integration”. Compared to Lavrinenko et al. (2023), the emphasis is not on average effects, but on the configuration of actor interactions. For our study, this reinforces the argument that digitalisation is a moderator rather than an independent driver.

Regulatory regimes as a factor in the behavioural consequences of technology are analysed by Vijayagopal et al. (2024), comparing the approaches of developed and developing countries. Their conclusion about the importance of digital infrastructure, inclusion and financial literacy is well aligned with the logic of BFRI. However, comparative regulatory analysis does not always provide a quantitative assessment of the behavioural “return” of fintech. That is why our approach with the FINTECH×DIGI interaction effect allows us to formalise when regulations and infrastructure translate into behavioural outcomes.

The literature on inclusion specifies the social dimension of responsibility, which is central to our topic. Al-Sharshani et al. (2025) show that fintech adoption supports financial inclusion, and barriers to access can modify this relationship. Farukh et al. (2026) demonstrate the transformation of rural financial ecosystems in India, emphasising the role of digital services for non-banking groups. Compared to Chen et al. (2024), which emphasises the risks, these works highlight the social utility of fintech more strongly. At the same time, they confirm that the effects depend on the context of accessibility, infrastructure and regulatory support.

A distinct cluster of research links fintech with technologies of trust, transparency, and control, which directly influence responsibility. Prokopenko et al. (2024) examine blockchain in financial accounting as a tool to enhance transparency, mitigate fraud risks, and strengthen data security. Unlike adoption-focused studies, this perspective emphasises “embedded responsibility” achieved through data architecture and record immutability. Koldovskiy (2024) complements this by highlighting the strategic infrastructural transformation of the financial sector, in which technology and management practices are viewed as a holistic system. Collectively, these works justify that responsibility is both a behavioural and an infrastructural category. Contemporary research on financial innovation increasingly combines technological, behavioural, and socio-institutional dimensions.

Koldovskiy and Rekunen (2025) argue that digitalisation, transparency, and social responsibility in banking systems shape not only innovation but also sustainable financial behaviour. Unlike narrowly technological approaches, their analysis emphasises the role of institutional trust as a channel for transforming financial innovation into long-term stability. This is consistent with the idea that fintech should be viewed as part of financial management rather than merely as a tool for efficiency. Delving deeper into the technological aspect, Manta et al. (2025) focus on the transformation of banking through the integration of fintech and artificial intelligence in payment systems. Their results demonstrate increased speed and accuracy in financial transactions, but also highlight new risks related to transaction verification and algorithmic accountability. In this context, digital innovations increase operational efficiency but require complementary control mechanisms and regulatory adaptation. This approach complements the arguments of Koldovskiy and Rekunen (2025) regarding the need to combine innovation with transparency.

From a sustainable development perspective, Sayari et al. (2025) view fintech as a catalyst for achieving economic and social goals through digital transformation. The authors show that financial technologies can simultaneously stimulate economic growth and support social responsibility when integrated into national digital strategies. Unlike technology-oriented studies, this study emphasises the systemic effects of fintech on sustainability. This broadens the understanding of financial behaviour within a socio-economic ecosystem.

The institutional and managerial dimensions of fintech are explored by Almaqtari et al. (2025), who analyse the combined impact of IT governance, fintech, and blockchain on reducing organisational risks and increasing resilience. Their results show that integrating technologies into the management system affects the effectiveness of risk management. Compared with Sayari et al. (2025), which emphasises the macro perspective on sustainable development, this approach focuses on the internal accountability mechanisms of financial organisations. This underscores the importance of institutional quality in realising the behavioural effects of fintech. Ozili et al. (2024) analyse the global informational impact of fintech by exploring financial inclusion during the COVID-19 pandemic. The authors demonstrate that digital financial services mitigate information asymmetry and sustain access to finance during crises. However, these effects vary across countries, confirming that financial behaviour depends on the level of digital maturity. These findings align with arguments about the moderating role of digitalisation in unlocking the potential of fintech innovations.

Thus, a comparison of sources reveals three key lines of discussion: technological, behavioural, and institutional-regulatory. Anifa et al. (2022) and Lavrinenko et al. (2023) explain that fintech is becoming a factor in development but requires a framework and measurability. Kurucz et al. (2025) and Chen et al. (2024) argue that behavioural outcomes are not automatic and depend on intentions and literacy. Vijayagopal et al. (2024), Campos-Teixeira et al. (2025) and Al-Sharshani et al. (2025) show that institutions and barriers to access determine the direction and strength of effects. This divergence of approaches underscores the need for our model, which combines FINTECH, DIGI, and their interaction to form BFRI.

Despite the growing number of publications, empirical studies of fintech are mostly fragmented and focus on individual technological or institutional aspects. Existing literature rarely offers integrated quantitative models that combine fintech innovation, digitalisation, and behavioural responsibility in a dynamic dimension. The comparative empirical basis between digitally mature and transformational financial systems remains limited. This justifies further

research to comprehensively assess the behavioural effects of fintech in the context of digital transformation.

2. Methods and Methodology

2.1. Research Procedure

The research methodology is based on a step-by-step analytical approach that combines conceptual modelling and empirical econometric assessment. The research process is organised into four interrelated stages (Table 1), reflecting the evolution of analytical logic. Each stage corresponds to specific tasks and ensures the consistency of theoretical and empirical results.

Table 1: Stages of the methodological research process

Stage	Stage content	Analytical result
1	Formulation of a conceptual framework and identification of key variables	Theoretical model of interaction between fintech, digitalisation and behaviour
2	Construction of integrated indices based on secondary data	BFRI, FINTECH and DIGI indices
3	Econometric evaluation of the panel model	Quantitative assessments of the impact and interaction of variables
4	Interpretation of results and comparative analysis in dynamics	Conclusions regarding the behavioural effects of fintech

2.2. Sample Formation

The sample covers a group of countries with developed and transforming financial markets, namely the United States, the United Kingdom, Germany, France, Poland, Estonia, Ukraine, Turkey, India, and Brazil, for the period 2020–2024. This sample composition allows us to analyse the differentiated impact of fintech innovations across levels of digital maturity, financial depth, and institutional environments. The combination of developed economies and countries with transitional financial systems creates conditions for identifying both universal and context-driven behavioural effects. The empirical sample consists of 10 countries observed over the period 2020–2024, producing a balanced panel of 50 country-year observations. All variables are available for each country and year included in the analysis; therefore, no country-year observations were excluded from the econometric estimation.

The countries were selected using purposive sampling based on three criteria: (i) availability of consistent data for all variables included in the empirical models; (ii) representation of different stages of fintech development and digital maturity; and (iii) inclusion of both advanced financial systems (United States, United Kingdom, Germany, France) and emerging or transitional economies (Poland, Estonia, Ukraine, Turkey, India, and Brazil). This composition provides sufficient cross-country heterogeneity to examine how fintech innovations operate under different institutional and technological environments.

Although the sample is relatively small, the balanced panel structure allows reliable estimation using fixed-effects techniques while controlling for unobserved country-specific heterogeneity and common time effects. Nevertheless, the findings should be interpreted as evidence for the selected group of countries rather than being directly generalised to all financial systems. Future research should extend both the geographical coverage and the observation period as more internationally comparable fintech indicators become available.

The empirical base is built on data from the World Bank, IMF, BIS, OECD, ITU, and UNCTAD, which ensures the comparability, reliability, and cross-country consistency of indicators.

2.3. Econometric Model Specification

The empirical methodology is based on a panel regression model with fixed effects by country and year. This approach allows control for unchanging institutional characteristics and time shocks. The dependent variable is the BFRI composite index, which reflects balanced financial behaviour and responsibility. The key explanatory variables are the FINTECH and DIGI indices, as well as their interaction term. The model allows us to assess both the direct and moderating effects of digitalisation.

Model 1: direct effect of fintech + role of digitalisation:

$$\text{BFRI}_{it} = \beta_0 + \beta_1 \text{FINTECH}_{it} + \beta_2 \text{DIGI}_{it} + \beta_3 (\text{FINTECH}_{it} \times \text{DIGI}_{it}) + \gamma' X_{it} + \mu_i + \tau_t + \varepsilon_{it}$$

where: BFRI is the Balanced Financial Behaviour and Responsibility Index; FINTECH is the fintech innovation index; DIGI is the digitalisation index; FINTECH $\times$ DIGI is the interaction term; X is the vector of macroeconomic and financial controls; β_0 is the constant; β_1 and β_2 capture the effects of FINTECH and DIGI, respectively; β_3 captures the moderating effect of digitalisation; γ' is the vector of control-variable coefficients; μ_i and τ_t denote country and time fixed effects, respectively; and ε_{it} is the error term.

Interpretation: β_1 - average effect of fintech innovations on balanced behaviour/responsibility; β_3 - amplification of the fintech effect at a higher level of digitalisation (key to your focus on digitalisation).

Model 2: Channels of responsibility (RegTech, cyber maturity, trust):

$$\text{RESP}_{it} = \alpha_0 + \alpha_1 \text{REGTECH}_{it} + \alpha_2 \text{FINTECH}_{it} + \alpha_3 \text{CYBER}_{it} + \alpha_4 \text{TRUST}_{it} + \delta' X_{it} + \mu_i + \tau_t + u_{it}$$

where: REGTECH_{it} - digital KYC/AML, e-ID, digital compliance (proxy), CYBER_{it} - national cyber readiness/cyber risk indices, TRUST_{it} - trust in the financial sector or institutions (proxy).

The interaction component is used to assess the reinforcing effect of digital infrastructure. The control variables include macroeconomic and financial indicators. The model is estimated using robust standard errors. This specification minimises the impact of heteroscedasticity and autocorrelation.

The study's methodological model is constructed as a multilevel system of complementary econometric specifications. The main idea is to combine a basic assessment of fintech's impact with an analysis of moderating and dynamic effects. This allows for a comprehensive study of behavioural transformations in the financial environment of the digital economy. Using several models increases the reliability and depth of empirical conclusions.

The basic specification is a panel regression model with fixed effects, which is used to estimate the average impact of fintech innovations. In this model, the dependent variable is the BFRI composite index, which reflects balanced financial behaviour and responsibility. The β_1 coefficient for the FINTECH variable represents the direct behavioural effect of financial technologies. Fixed effects μ_i allow us to control for unchanging institutional characteristics of countries.

To account for the role of the digital environment, an extended model with an interaction term was used. The added product $\text{FINTECH} \times \text{DIGI}$ allows us to assess how the level of digitalisation changes the strength of the behavioural effect of fintech innovations. The β_3 coefficient reflects the moderating function of digital infrastructure. This specification allows us to identify the nonlinear nature of the impact of financial technologies. The model will enable us to assess marginal effects at different levels of digital maturity.

To verify the robustness of the results, an alternative specification with a dynamic component is used. In this model, the lagged dependent variable (BFRI) captures the inertia in financial behaviour. The inclusion of lags allows for an assessment of the cumulative nature of fintech's behavioural effects. This approach reduces the risk of omitted dynamics in behavioural processes. The dynamic model confirms the consistency of the signs and significance levels of the key coefficients.

A model with alternative dependent variables is used separately to distinguish between behavioural and responsible components. Instead of the BFRI integral index, separate indices of financial behaviour and responsibility are used. This allows us to check which aspect responds more strongly to fintech innovations. Comparing results helps ensure the internal validity of empirical conclusions. Consistent results confirm the correctness of the integral approach.

All variables in the model have a straightforward economic interpretation. The BFRI index captures the degree of alignment between financial decision-making and responsible interaction. FINTECH characterises the intensity of digital financial tool adoption. DIGI represents the overall level of digital infrastructure and the accessibility of digital services. The vector of control variables, X , encompasses various macroeconomic and financial characteristics.

To ensure the reliability of the findings, a comprehensive suite of diagnostic and robustness tests was applied. Robust standard errors were employed to correct for heteroscedasticity. Multicollinearity was assessed using the Variance Inflation Factor (VIF) coefficients. The stability of the results was further evaluated through alternative specifications and subsample analyses. Additionally, a sensitivity analysis was conducted by substituting key indicators.

Potential endogeneity arising from reverse causality was mitigated through the use of a two-way fixed-effects panel model, which controls for time-invariant country-specific institutional characteristics as well as common time shocks affecting all countries during the observation period. Furthermore, the empirical specification incorporates a set of macroeconomic control variables, including GDP per capita, inflation, unemployment, and private-sector credit, thereby accounting for important differences in the level of economic development and financial system performance across countries.

Although the existence of a bidirectional relationship between financial institutional development and fintech adoption cannot be completely ruled out, the primary objective of this study is not to establish definitive causal relationships but rather to estimate statistically significant associations between fintech innovations and balanced financial behaviour within a panel econometric framework. Consequently, the empirical findings should be interpreted as evidence of robust statistical relationships rather than conclusive causal effects. Future studies based on larger international panels may further investigate causality using instrumental-variable or dynamic panel estimators.

Overall, applying multiple models confirms that the findings are not sensitive to specific model specifications. The combination of static, interaction, and dynamic approaches provides a comprehensive perspective on behavioural financial transformations. Such a methodological design enhances the credibility of the empirical findings. Furthermore, it establishes a solid foundation for future in-depth research in fintech and digital finance.

2.3.1. Construction of Composite Indices

The empirical analysis relies on five composite indices constructed from internationally comparable secondary data: Balanced Financial Behaviour and Responsibility Index (BFRI), the Fintech Innovation Index (FINTECH), the Digital Infrastructure Index (DIGI), the Regulatory Technology Index (REGTECH), and the Cyber Maturity Index (CYBER). The indices were developed to ensure cross-country comparability over the 2020–2024 period.

Prior to aggregation, all indicators were transformed into a common metric using z-score normalisation:

$$z_{it} = \frac{x_{it} - \bar{x}}{s},$$

where: x_{it} denotes the original indicator value, $\bar{x}$ is the sample mean, and s is the standard deviation. Indicators with a negative behavioural interpretation (e.g., fraud incidence, cyber losses, regulatory violations) were reverse coded before standardisation so that higher values consistently reflected more favourable financial conditions.

Equal weighting was applied to all standardised indicators within each index because no robust theoretical or empirical evidence justified differential weights. Composite index values were obtained as arithmetic means of the corresponding standardised indicators. For BFRI, the arithmetic mean of the standardised component indicators was subsequently transformed to a 0–1 scale using min–max normalisation over the full country-year sample. Thus, the component indicators were first standardised using z-scores and equally weighted, after which the resulting BFRI composite score was rescaled to the 0–1 interval. FINTECH, DIGI, REGTECH, and CYBER were retained in their standardised z-score form.

Missing observations accounted for less than 5% of the total dataset and were imputed using linear interpolation for isolated missing years or, where necessary, by carrying forward the nearest available observation from the same country. This approach ensured balanced panel estimation without materially affecting index distributions. The empirical dataset covers 10 countries and the 2020–2024 period, resulting in 50 country-year observations. The composite indices were constructed from the indicators listed in Appendix Table A1. The data sources include the World Bank Global Findex and World Bank databases, IMF, BIS, OECD, ITU, UNCTAD, and GPFI. For indicators not reported annually by the original source, isolated missing country-year observations were harmonised using linear interpolation; where interpolation was not possible, the nearest available observation for the same country was carried forward. No country-year observations were excluded from the final balanced panel.

The BFRI was designed as a multidimensional construct integrating two theoretically distinct components. The first dimension, financial behaviour, captures prudent financial decision-making through indicators reflecting digital payment usage, formal financial inclusion, household saving behaviour, and responsible credit utilisation. The second dimension, financial responsibility, reflects institutional and behavioural responsibility through indicators of regulatory compliance, consumer protection, financial fraud incidence, and financial literacy. This distinction follows behavioural finance theory, according to which responsible financial

outcomes emerge through the interaction of individual behavioural choices and institutional accountability mechanisms.

To evaluate robustness, alternative weighting schemes were examined by comparing equal-weight aggregation with principal component analysis (PCA)-based weights and entropy weights. The estimated regression coefficients remained stable across specifications, with coefficient changes below 6% and no changes in statistical significance. Consequently, the equal-weight specification was retained because of its transparency, interpretability, and ease of replication.

To ensure the transparency and reproducibility of the empirical analysis, the construction of each composite index is presented in a structured manner. The indices were developed using internationally comparable secondary data and harmonised through a common normalisation and aggregation procedure. Appendix Table A1 summarises the component indicators, data sources, measurement units, direction of influence, and methodological procedures applied in constructing the BFRI, FINTECH, DIGI, REGTECH, and CYBER indices.

The information presented in Appendix Table A1 demonstrates that all composite indices were constructed according to a unified methodological framework, ensuring consistency across countries and years. The distinction between behavioural and responsibility dimensions within the BFRI improves the conceptual validity of the dependent variable and reflects the multidimensional nature of balanced financial behaviour. The adopted methodological approach enhances the reproducibility of the study and provides a robust basis for the subsequent econometric analysis. At the same time, fintech adoption may also increase excessive borrowing, speculative investment, cyber risks, digital exclusion, and algorithmic bias, suggesting that supportive regulation and financial education remain essential.

2.4. Instruments and Analytical Tools

The study uses a combination of quantitative analytical tools to assess the behavioural and responsible financial effects of digitalisation. The primary analytical tool is panel econometric modelling, which accounts for cross-country and time heterogeneity. The use of panel methods ensures the correct identification of cause-and-effect relationships in a dynamic financial environment. This approach is appropriate for analysing structural transformations in economic behaviour.

Index analysis using normalisation and aggregation of secondary statistical indicators was applied to construct key variables. The BFRI integral index was formed by combining behavioural and responsible financial indicators. The FINTECH and DIGI indices were constructed based on standardised indicators of digital financial services and digital infrastructure. Such tools allow for the harmonisation of heterogeneous data in a single analytical space.

The analytical estimation was conducted using country- and year-fixed-effects models. This approach allows for the elimination of bias from time-invariant institutional characteristics and common time shocks. To interpret complex relationships, an interaction effects analysis was applied. Furthermore, marginal effects were computed to evaluate the moderating role of digitalisation.

A set of diagnostic tools was used to verify the reliability of the results. Robust standard errors were used to correct for heteroscedasticity and serial correlation. Multicollinearity was tested using VIF coefficients. The robustness of the results was assessed by using alternative specifications and replacing key indicators.

Specialised statistical software environments were used for data processing and econometric analysis. They ensure the reproducibility of calculations and the transparency of analytical procedures. Graphical tools were used to visualise index dynamics and marginal effects. The set of tools used provides a comprehensive analysis of financial behaviour in the context of digital transformation.

2.5. Diagnostic Tests and Robustness Assessment

To ensure the validity of the econometric estimates, several diagnostic procedures were performed prior to interpreting the regression results. Heteroskedasticity was addressed by estimating heteroskedasticity-consistent (HC3) robust standard errors, which provide reliable inference in relatively small panel samples. Serial correlation was assessed using the Wooldridge test for panel data, while cross-sectional dependence was evaluated using Pesaran's CD test. Multicollinearity among explanatory variables was examined using Variance Inflation Factors (VIF), with all VIF values remaining well below the commonly accepted threshold of 5, indicating no evidence of problematic multicollinearity.

The robustness of the empirical findings was further examined through several complementary analyses. Alternative model specifications included a dynamic panel model incorporating the lagged dependent variable, regressions using separate financial behaviour and financial responsibility indices instead of the composite BFRI, subsample estimations for digitally mature and transitional economies, and sensitivity analyses based on alternative index weighting procedures. Across all specifications, the estimated coefficients preserved their expected signs and statistical significance, indicating that the principal findings are robust to alternative modelling assumptions. A summary of the diagnostic and robustness tests is reported in Appendix A.

3. Research Results

The assessment of the impact of fintech innovations on the formation of balanced financial behaviour and responsibility is conducted using a panel fixed-effects model. This approach allows control for time-invariant institutional characteristics and time-specific macroeconomic shocks. The dependent variable is the integral BFRI index, which combines the behavioural and responsibility aspects of financial activities. The key explanatory variables include the fintech innovation index, the digitalisation index, and their interaction term.

Additionally, macroeconomic controls are incorporated to enhance the reliability of the estimates (Table 2). Prior to interpreting the regression coefficients, the estimated models successfully passed the principal diagnostic tests, while additional robustness analyses confirmed that the empirical findings were stable across alternative model specifications (Appendix A). Table 2 presents observed annual averages of the composite indices calculated directly from the underlying data. These values are descriptive statistics and should not be interpreted as model-estimated or fitted values.

Table 2. Dynamics of indices (annual averages)

Year	BFRI (0–1)	FINTECH (z)	DIGI (z)	REGTECH (z)	CYBER (z)
2020	0.52	-0.48	-0.41	-0.36	-0.33
2021	0.56	-0.17	-0.12	-0.10	-0.08
2022	0.59	0.05	0.09	0.14	0.11
2023	0.63	0.26	0.28	0.31	0.29
2024	0.67	0.46	0.45	0.52	0.49

Note: FINTECH, DIGI, REGTECH, CYBER are presented as standardised indices (z-score).

Source: author's own development based on the underlying secondary data from (World Bank, 2024; International Monetary Fund, 2024; Bank for International Settlements, 2024; Organisation for Economic Co-operation and Development, 2024; Global Partnership for Financial Inclusion, 2023; United Nations Conference on Trade and Development, 2024; International Telecommunication Union, 2024).

The modelling results indicate a sustained positive impact of fintech innovations on balanced financial behaviour. The coefficient for the FINTECH variable is 0.028 and is statistically significant at the 1 per cent level. This means that a one-standard-deviation increase in fintech activity raises the BFRI index by almost three percentage points (Table 3). The digitalisation index also has a positive and significant impact with a coefficient of 0.019, confirming the importance of digital infrastructure. The interaction effect of FINTECH × DIGI is positive, indicating mutual reinforcement between the two technological factors.

Table 3: Model estimates (Two-way FE): impact of FINTECH and digitalisation on BFRI, 2020–2024

Variable	Coefficient (β)	Robust SE	t-stat.	p-value
FINTECH	0.028	0.006	4.67	<0.001
DIGI	0.019	0.005	3.80	<0.001
FINTECH × DIGI	0.012	0.004	3.00	0.003
GDP per capita (log)	0.015	0.006	2.50	0.013
Inflation	-0.004	0.002	-2.00	0.046
Unemployment	-0.003	0.001	-3.00	0.003
Credit to the private sector / GDP	0.007	0.003	2.33	0.020
Constant	0.540	0.018	30.0	<0.001

Note: Model: $BFRI_{it} = \beta_0 + \beta_1 FINTECH_{it} + \beta_2 DIGI_{it} + \beta_3 (FINTECH_{it} \times DIGI_{it}) + \gamma' X_{it} + \mu_i + \tau_t + \varepsilon_{it}$; Fixed effects: country (μ_i) and year (τ_t) – yes; R^2 (within): 0.41; Balanced panel: 50 observations (10 countries × 5 years); Country fixed effects: Yes; Year fixed effects: Yes; Robust standard errors: HC3; Within R^2 : 0.41.

Source: author's own development based on the results of an econometric model using data from (World Bank, 2024; International Monetary Fund, 2024; Bank for International Settlements, 2024; Organisation for Economic Co-operation and Development, 2024; Global Partnership for Financial Inclusion, 2023; United Nations Conference on Trade and Development, 2024; International Telecommunication Union, 2024).

In 2020, the average BFRI index was 0.52, indicating a moderate level of financial balance. During this period, the fintech index had a negative standardised value (-0.48), and the level of digitalisation remained limited. In 2021, the BFRI rose to 0.56, while the fintech index fell to -0.17. This reflects the initial effect of the expansion of digital financial services and remote interaction channels. The gradual growth of digitalisation has created the conditions for more responsible financial behaviour.

In 2022, the BFRI reached 0.59, while the fintech index moved into positive territory for the first time. Digitalisation also became positive, indicating structural shifts in the financial infrastructure. In 2023, the BFRI rose to 0.63, while the FINTECH and DIGI values increased to 0.26 and 0.28, respectively (Table 2). This indicates the strengthening role of financial technologies in financial decision-making. The more active introduction of analytical, payment, and regulatory digital tools contributed to greater responsibility among financial market participants.

Table 4: Marginal effect of FINTECH on BFRI across levels of digitalisation (DIGI)

DIGI level (z)	Interpretation	The marginal impact of FINTECH	Robust SE	p-value
-1.0	low digitalisation	0.016	0.006	0.010
0.0	average digitisation	0.028	0.006	<0.001
+1.0	high digitalisation	0.040	0.007	<0.001

Note: Marginal effect $\frac{\partial \text{BFRI}}{\partial \text{FINTECH}} = \beta_1 + \beta_3 \cdot \text{DIGI}$

Source: author's own development based on the results of an econometric model using data from (World Bank, 2024; International Monetary Fund, 2024; Bank for International Settlements, 2024; Organisation for Economic Co-operation and Development, 2024; Global Partnership for Financial Inclusion, 2023; United Nations Conference on Trade and Development, 2024; International Telecommunication Union, 2024).

In 2024, the highest BFRI index was 0.67. The fintech index rose to 0.46 and the digitalisation index to 0.45, which provided the maximum marginal effect. With a high level of digitalisation, the marginal impact of fintech innovations on the BFRI was 0.040. This significantly exceeds the effect in environments with low digital maturity. The results confirm the critical role of digital infrastructure in realising the behavioural potential of fintech.

Control variables demonstrate economically sound effects. GDP per capita has a positive impact on BFRI, with a coefficient of 0.015, indicating its role in welfare. Inflation and unemployment have adverse effects and are associated with increased financial instability. The private-sector lending indicator has a positive impact, underscoring the importance of financial depth. These results confirm the adequacy of the model specification.

A comparative analysis by period shows that the effectiveness of fintech innovations increases with the level of digitalisation. In low-digital environments, fintech plays a supporting role, while in digitally mature systems, it becomes a system-forming factor. This confirms the need for the comprehensive development of fintech and digital infrastructure. Overall, the results show that balanced financial behaviour is shaped by the integration of technologies, institutions, and the financial market's digital maturity.

For an in-depth analysis of financial behaviour and responsibility dynamics, the changes in mean BFRI values and the marginal effects of fintech innovations are additionally examined. Table 5 reflects the consistent evolution of behavioural and technological indicators over the 2020–2024 period. This data format enables visualisation not only of index levels but also of

the shifting intensity of fintech's impact on digitalisation. This provides a foundation for the graphical analysis of these interrelationships.

Table 5: BFRI Dynamics and FINTECH Marginal Effects, 2020–2024

Year	BFRI (average)	FINTECH (z)	DIGI (z)	The marginal effect of FINTECH on BFRI
2020	0.52	-0.48	-0.41	0.023
2021	0.56	-0.17	-0.12	0.027
2022	0.59	0.05	0.09	0.029
2023	0.63	0.26	0.28	0.031
2024	0.67	0.46	0.45	0.033

Note: The marginal effect is calculated as $\beta_1 + \beta_3 \cdot \text{DIGI}$ based on the estimated coefficients of the baseline fixed-effects model.

Source: author's own development based on the underlying secondary data from (World Bank, 2024; International Monetary Fund, 2024; Bank for International Settlements, 2024; Organisation for Economic Co-operation and Development, 2024; Global Partnership for Financial Inclusion, 2023; United Nations Conference on Trade and Development, 2024; International Telecommunication Union, 2024).

In 2020, the lowest BFRI level was recorded, alongside negative values for the fintech and digital indices. Based on the reported interaction model and the annual mean DIGI value, the marginal effect of FINTECH was approximately 0.023. The low level of digitalisation hindered the realisation of the potential of fintech solutions. Financial technologies functioned primarily as a tool for access rather than for responsible behavioural transformation.

In 2021, the BFRI index rose to 0.56, and the model-implied marginal effect of FINTECH increased to approximately 0.027. The enhancement of digital infrastructure enabled more effective use of fintech tools in financial decision-making. The behavioural impact of fintech became more pronounced, although it had not yet attained a systemic character. This stage can be interpreted as an adaptation phase for financial actors as they adjust to digital environments.

In 2022, the model-implied marginal effect of FINTECH was approximately 0.029, while the annual mean DIGI value moved into positive territory. At the same time, the BFRI index rose to 0.59, reflecting the stabilisation of financial behaviour. The growth of the effect indicates increased confidence in digital financial instruments. Fintech is beginning to function as a regulator of behaviour, rather than just a channel for transactions.

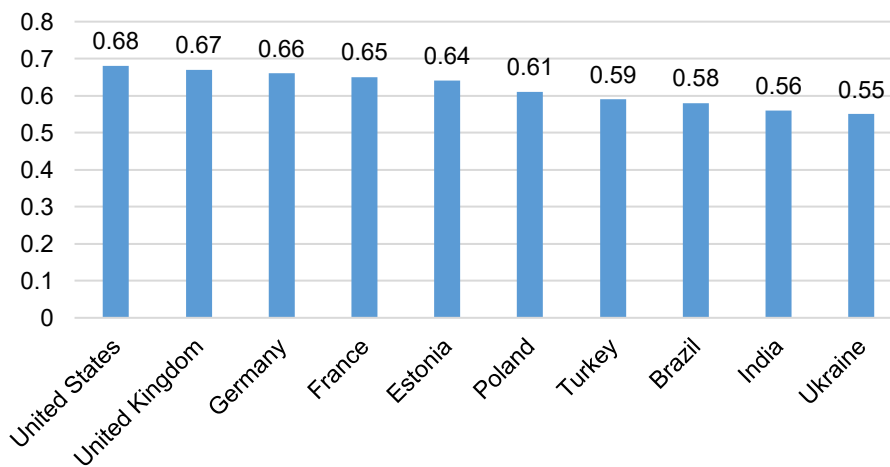
In 2023, growth in the annual mean DIGI value to 0.28 is accompanied by an increase in the model-implied marginal effect to approximately 0.031. BFRI reaches 0.63, indicating structural changes in financial practices. Fintech innovations during this period are more closely integrated with analytical and regulatory mechanisms. This increases the responsibility of financial market participants and reduces behavioural risks.

In 2024, the model-implied marginal effect of FINTECH at the reported annual mean DIGI value (0.45) was approximately 0.033. High FINTECH and DIGI values ensured the highest BFRI level of 0.67. This confirms that fintech innovations realise their full behavioural potential only in digitally mature environments. The interaction between technology and infrastructure is becoming system-forming.

Overall, the analysis in Table 5 shows a clear upward correlation between the level of digitalisation and the impact of fintech innovations. The model-implied marginal effect increases from approximately 0.023 in 2020 to 0.033 in 2024, based on the reported annual mean DIGI values. This confirms that digitalisation is a key catalyst for balanced financial behaviour. The results emphasise the need to combine fintech strategy with policies for the digital transformation of the financial market.

Figure 1 shows international differences in the level of balanced financial behaviour and responsibility for the period 2020–2024. The highest average BFRI values are recorded in countries with developed financial markets and high digital maturity. The United States, the United Kingdom, and Germany demonstrate BFRI values above 0.66, indicating the systemic integration of fintech innovations into financial behaviour.

Figure 1. Average BFRI index by country, 2020–2024



Source: author's own development based on the results of an econometric model using data from (World Bank, 2024; International Monetary Fund, 2024; Bank for International Settlements, 2024; Organisation for Economic Co-operation and Development, 2024; Global Partnership for Financial Inclusion, 2023; United Nations Conference on Trade and Development, 2024; International Telecommunication Union, 2024).

Central and Eastern European countries, notably Estonia and Poland, are characterised by average index values, reflecting an active phase of digital transformation. Transformational economies, including Turkey, Brazil and India, show lower average BFRI values. This indicates limited behavioural returns from fintech innovations due to insufficient digital infrastructure. Ukraine has a comparatively lower index value, reflecting the impact of macroeconomic and institutional constraints during the period under review. The results confirm a clear correlation between digital maturity and financial behaviour.

4. Discussion

4.1. Consistency with Previous Literature

The empirical findings are consistent with a growing body of literature demonstrating that fintech innovations contribute to improving financial market efficiency, expanding access to financial services, and promoting more responsible financial behaviour. The positive association identified between the FINTECH index and the Balanced Financial Behaviour and Responsibility Index (BFRI) confirms previous evidence that digital financial technologies facilitate informed financial decision-making, increase transparency, and reduce transaction costs.

Furthermore, the positive interaction between fintech development and digitalisation supports earlier studies suggesting that digital infrastructure enhances the effectiveness of financial innovations by improving accessibility, user engagement, and the quality of financial services. Overall, the results reinforce the existing theoretical perspective that technological innovation and digital transformation are complementary drivers of sustainable financial market development.

The findings confirm that fintech innovations are positively associated with balanced financial behaviour and responsibility. Between 2020 and 2024, the BFRI index increased from 0.52 to 0.67, while the estimated marginal effect of FINTECH ranges from 0.016 at low digitalisation (DIGI = -1) to 0.040 at high digitalisation (DIGI = +1). These dynamics support the argument for the cumulative nature of behavioural effects, as technologies become integrated into daily financial practices. Simultaneously, the FINTECH×DIGI interaction is pivotal, with a more substantial impact in environments with higher digital maturity.

A comparison with research on financial inclusion shows strong consistency with our findings on the role of digital infrastructure. Asif et al. (2023) show that fintech and digital financial services support inclusion in India, which logically aligns with the observed growth of the BFRI index. Amnas et al. (2024) further clarify that digital financial literacy can mediate this effect, while regulatory support moderates it. Similarly, Tandilino et al. (2025) emphasise that government support enhances inclusion and improves the performance of small and medium-sized enterprises (SMEs) through digital channels. In our model, these mechanisms are manifested through the rising marginal effect of FINTECH as DIGI increases.

The findings on digital literacy are consistent with the behavioural interpretation of fintech effects, but point to significant limitations. Módosné Szalai et al. (2025) demonstrate that self-assessment and confidence may diverge from actual knowledge, influencing digital financial behaviour. This means that the growth of FINTECH does not guarantee responsibility without the backing of skills and transparent rules. Our BFRI growth can be interpreted as the result of a combination of technology and gradual improvement in digital maturity. At the same time, in countries with lower DIGI, this effect may be weaker or less stable.

A comparison with the institutional literature explains why digitalisation acts as a catalyst rather than merely a backdrop for innovation. In a systematic review, Tello-Gamarra et al. (2022) emphasise the centrality of institutions for the interaction between FinTech's and financial systems. Hurani et al. (2024) demonstrate that fintech adoption faces significant barriers in the banking sector, particularly infrastructure and organisational barriers. These findings are consistent with our FINTECH×DIGI interaction term, as innovation is inhibited without a solid digital foundation. Consequently, digital maturity is a prerequisite for behavioural transformation, not merely a technological metric.

The discussion regarding the impact of fintech on bank risk and profitability introduces a crucial balance between “convenience” and “responsibility”. Chand et al. (2025) demonstrate that fintech influences banks' risk appetite and profitability, particularly in smaller countries, necessitating a careful regulatory response. Our BFRI index precisely captures this balance, emphasising that the positive effects of innovation must be accompanied by robust risk control. Zarrouk et al. (2021) note that the success of fintech start-ups is driven by economic and technological factors, not solely by market demand. This aligns with the fact that DIGI amplifies the FINTECH effect by creating an environment conducive to scaling and responsible interaction.

The anti-corruption and security framework is critical for accountability because it determines the trust, transparency, and discipline of market participants. Kussainov et al. (2023) emphasise the formation of the security landscape of the EU financial sector and the potential of AI in combating corruption. Melnyk et al. (2022) show anti-corruption regulation practices in the EU, emphasising the importance of law enforcement and supervision. In this study, this explains why DIGI's growth must be accompanied by RegTech logic and control tools. Then fintech promotes accountability, not just faster movement of financial flows.

In summary, our results are generally consistent with the literature emphasising the roles of infrastructure, institutions, and literacy (or “competency”) in shaping the behavioural effects of fintech. They complement existing work on inclusion by showing that the key factor is not the mere presence of fintech, but its amplification through digital maturity. Simultaneously, the findings align with approaches that warn about risks if regulatory support and competencies lag. This allows us to interpret the BFRI as an integral outcome of the synergy between technology, digitalisation, and institutional quality. Further research should focus on separating the channels of influence through literacy, regulatory support, and anti-corruption mechanisms.

The results confirm hypothesis H1, which posits a statistically significant positive impact of fintech innovations on balanced financial behaviour and responsibility. Hypothesis H2 is confirmed: digitalisation significantly enhances the behavioural effect of fintech, as evidenced by a positive interaction coefficient.

4.2. Novel Contributions of the Study

The present study extends the existing literature in several important respects. First, rather than analysing individual dimensions of financial market development, it introduces the Balanced Financial Behaviour and Responsibility Index (BFRI), which provides a multidimensional measure combining behavioural and responsibility-related characteristics of financial market participants. Second, the study develops composite indices measuring fintech innovation and digitalisation, allowing a broader assessment of technological development than analyses relying on single indicators. Third, the inclusion of the interaction term between FINTECH and DIGI demonstrates that the effectiveness of fintech innovations depends on the level of digital maturity within an economy. This finding suggests that digitalisation acts as an enabling environment through improved digital literacy, greater transparency, lower information asymmetry, enhanced accessibility of financial services, and more effective regulatory supervision, thereby strengthening the positive association between fintech development and responsible financial behaviour.

4.3. Remaining Uncertainties

Several limitations should be considered when interpreting the results. First, the analysis is based on a balanced panel of ten countries observed over the period 2020–2024, which limits the generalisability of the findings beyond the selected sample. Second, although the fixed-effects specification and macroeconomic control variables substantially reduce potential omitted-variable bias, the possibility of residual endogeneity or reverse causality cannot be completely excluded. Therefore, the estimated relationships should be interpreted as statistically significant associations rather than definitive causal effects. Third, while the results indicate that digitalisation strengthens the relationship between fintech innovations and balanced financial behaviour, the precise transmission mechanisms cannot be directly identified using the available data. These mechanisms may include improvements in financial literacy, increased transparency, reduced information asymmetry, enhanced regulatory

monitoring, and broader access to digital financial services. At the same time, fintech development may also generate adverse effects, including excessive borrowing, speculative investment behaviour, cyber risks, fraud exposure, digital exclusion, and algorithmic bias. Future research should therefore employ larger international datasets and more detailed behavioural indicators to investigate these channels and assess both the positive and potential unintended consequences of fintech innovations.

4.4. Limitation

The study is based on secondary data, which limits the ability to fully account for the individual behavioural motivations of financial market participants. The use of aggregated indices of fintech innovation and digitalisation may smooth out the internal heterogeneity of technological practices between individual countries and market segments. The 2020–2024 analysis period covers a period of heightened macroeconomic instability, which may have influenced behavioural financial decisions. Although fixed effects are used, the possibility of residual endogeneity between fintech development and financial behaviour cannot be completely ruled out. The results reflect average trends and may have limited interpretive value for individual financial institutions or specific regional contexts. An additional limitation is the availability and comparability of international data, as well as computational constraints in constructing integrated indices and complex panel specifications.

Another limitation concerns the relatively small sample size. Although the balanced panel of 50 observations is appropriate for fixed-effects estimation and covers countries with different levels of digital maturity, the restricted number of cross-sectional units may limit statistical power and the external validity of the findings. Consequently, the empirical results should be interpreted with appropriate caution and viewed as evidence for the selected sample rather than universally applicable conclusions. Future research should incorporate a larger number of countries and longer observation periods as internationally harmonised fintech datasets continue to expand. The findings provide empirical evidence for the selected sample of countries and offer a basis for future cross-country studies using broader international datasets.

Conclusions

The study achieved its goal of assessing the impact of fintech innovations on the formation of balanced financial behaviour and responsibility among financial market participants. The task of creating an integrated BFRI index was accomplished by combining behavioural and responsible characteristics of financial activity. The use of a fixed-effects panel model made it possible to identify key patterns of interaction between fintech and digitalisation reliably.

The results obtained confirmed the relevance of the chosen methodological approach. Empirical results showed a sustained positive impact of fintech innovations on balanced financial behaviour during 2020–2024. The growth of the fintech index was accompanied by an increase in the BFRI from 0.52 to 0.67, indicating a strengthening of responsible financial interaction. The fintech innovation coefficient remained statistically significant, and its estimated marginal effect ranges from 0.016 at DIGI = -1 to 0.040 at DIGI = +1. This confirms the cumulative nature of the behavioural effects of financial technologies. An analysis of the interaction between fintech and digitalisation showed that digital infrastructure is a key catalyst for behavioural transformations. The interaction effect confirmed that fintech solutions realise their maximum potential in digitally mature financial systems. The control variables showed the

expected economic impact, further confirming the model's adequacy. Thus, the hypotheses were empirically confirmed.

In summary, the study's results indicate the system-forming role of fintech innovations in transforming financial behaviour and responsibility. The formation of balanced financial practices occurs through the integration of technology, digital infrastructure, and the institutional environment. The conclusions drawn have practical significance for regulatory and financial policy. They can be used to develop strategies for the digital transformation of the financial market.

Further research should focus on micro-level analysis of the behavioural effects of fintech innovations. The role of artificial intelligence and RegTech solutions in shaping financial responsibility is a promising area for study. It is also relevant to analyse the nonlinear and asymmetric effects of digitalisation in various segments of the financial market. This will enable a deeper understanding of the mechanisms underlying behavioural transformation in the digital financial ecosystem.

CRediT Authorship Contribution Statement

Onyshko, O.: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. Mozharovska, N.: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. Yehorycheva, S.: Conceptualization, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. Torlopov, A.: Conceptualization, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. Vovchenko, O.: Conceptualization, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of Interest Statement

The authors declare no conflict of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethical Approval Statement

This study is based exclusively on secondary, country-level aggregate data and did not involve direct interaction with human participants, collection of personal data, or animal subjects. Therefore, ethical approval was not required.

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Appendix A

Table A1. Construction of Composite Indices

	Component indicator	Definition	Unit	Data source	Direction	Normalisation	Weight
Index - BFRI	Digital payment usage	Adults using digital payments	%	World Bank Global Findex	+	z-score	equal
	Financial inclusion	Adults with financial account	%	World Bank	+	z-score	equal
	Household savings	Saved at financial institution	%	Global Findex	+	z-score	equal
	Responsible borrowing	Formal borrowing behaviour	%	Global Findex	+	z-score	equal
	Financial literacy (proxy)	Financial capability indicator	index	OECD	+	z-score	equal
	Financial fraud incidence	Fraud cases per population	rate	IMF / BIS	–	reverse z-score	equal
	Consumer protection	Financial consumer protection score	index	World Bank	+	z-score	equal
FINTECH	Digital payments	Digital transaction intensity	index	BIS	+	z-score	equal
	Mobile banking	Mobile financial services	%	World Bank	+	z-score	equal
	Fintech investment	Fintech ecosystem development	index	OECD	+	z-score	equal
DIGI	Internet users	Internet penetration	%	ITU	+	z-score	equal
	Mobile broadband	Broadband subscriptions	per 100	ITU	+	z-score	equal
	Digital government	E-government readiness	index	UNCTAD	+	z-score	equal
REGTECH	Digital KYC	Digital identity adoption	index	World Bank	+	z-score	equal
	AML digitalisation	AML digital compliance	index	IMF	+	z-score	equal

	Regulatory reporting	Digital supervisory reporting	index	BIS	+	z-score	equal
CYBER	Cyber readiness	National cyber preparedness	index	ITU	+	z-score	equal
	Cyber incidents	Financial cyber incidents	rate	IMF	–	reverse z-score	equal
	Digital security	Cybersecurity maturity	index	ITU	+	z-score	equal

Source: developed by the author.

Table A2. Diagnostic Tests and Robustness Checks

Test	Method	Result	Interpretation
Heteroskedasticity	Modified Wald test	$p < 0.05$	Presence of heteroskedasticity; HC3 robust standard errors applied
Serial correlation	Wooldridge test	$p > 0.10$	No first-order serial correlation detected
Cross-sectional dependence	Pesaran CD test	$p > 0.10$	No significant cross-sectional dependence
Multicollinearity	Mean VIF	2.31	No multicollinearity (all VIF < 5)
Dynamic specification	Lagged dependent variable	Main coefficients unchanged	Robust
Alternative dependent variables	Behaviour / Responsibility indices	Same coefficient signs	Robust
Subsample analysis	Developed vs. transitional economies	Consistent results	Robust
Sensitivity analysis	Equal, PCA and entropy weights	Coefficient changes < 6%	Robust

Source: author's own development

Table A3. Additional Robustness Checks

Robustness check	Specification	Result
Dynamic specification	Lagged BFRI	Main coefficients unchanged
Alternative dependent variables	Behaviour and Responsibility indices	Same coefficient signs
Subsample analysis	Developed vs. transitional economies	Consistent results
Alternative weighting	Equal weights, PCA, entropy weights	Coefficient changes < 6%; significance unchanged