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ORIGINAL RESEARCH PAPER

The Impact of Green Finance and Fintech on Bank Resilience: The Moderating Role of Digital Transformation

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P A P E R I N F O

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A B S T R A C T

Growing environmental pressures, financial uncertainty, and rapid technological developments have increased the importance of bank resilience. This study examines the associations of green finance and FinTech with bank resilience and investigates whether digital transformation moderates these relationships. Using fixed-effects panel regression based on 128 bank-year observations from banks listed on the Tehran Stock Exchange over the 2017–2024 period, bank resilience is measured using a composite financial resilience index constructed from debt-to-assets, debt-to-equity, and equity ratios. Green finance and FinTech are measured using localized checklist-based indicators, while digital transformation is measured as the proportion of digital technology-related intangible assets to total intangible assets. The results indicate that green finance and FinTech are positively and statistically significantly associated with bank resilience. Furthermore, the interaction terms between digital transformation and green finance and between digital transformation and FinTech are positive and statistically significant, indicating that these associations are stronger at higher levels of digital transformation. The findings contribute to the literature by providing bank-level longitudinal evidence from an emerging-market context and by distinguishing the role of FinTech as a technology-enabled financial capability from digital transformation as a broader organizational capability that moderates its association with bank resilience and the association of green finance with resilience. The findings should be interpreted as statistical associations rather than definitive causal effects.



1. Introduction

Climate-related challenges, economic uncertainty, and rapid technological developments have increased the need for resilient banking systems. The complexity of the contemporary business environment can threaten the survival of banks, making the ability to adapt to rapid changes increasingly important. Banks require resilience capacities to respond appropriately to unexpected events and to overcome difficult conditions. Organizational resilience refers to the ability to anticipate opportunities, adapt to and continuously respond to changes, recover after a crisis, and remain stable in a turbulent environment. A resilient system not only withstands crises but can also return to its previous state in a relatively short period through flexibility and adaptability. Ignoring resilience capacity may gradually weaken a bank's

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competitiveness and adversely affect its organizational life cycle and survival [1-4]. In this context, green finance has emerged as a modern paradigm in finance and encompasses a broad range of sustainability-related issues [5]. In today's competitive environment, business organizations seek to enhance their value through various activities while maintaining greater environmental balance. Accordingly, green finance has been introduced as a new approach within banking policies and business activities [6]. Green finance can be defined as a financial initiative, process, product, or service designed to protect the natural environment. It is generally understood as a process through which firms obtain financing based on environmental conditions, while risk assessment is conducted to meet sustainable environmental standards and avoid environmental risks. The integration of environmental considerations into banking activities requires financial institutions to assess the potential environmental risks of financed projects and incorporate these considerations into resource-allocation decisions. Green banking practices can involve the development of environmental risk assessment systems, the allocation of financial resources to green projects, and the provision of sustainable financial products. Such practices underscore the importance of considering environmental risk management as part of banks' broader financing and decision-making strategies [5]. Unlike traditional financing approaches, green finance focuses on environmental benefits and supporting environmentally friendly industries, thereby combining environmental protection with financial and economic interests. It covers a broad range of users, including consumers, producers, investors, creditors, governments, and society. Green finance also provides a platform for sustainable development within the financial system and includes instruments such as green housing and automobile loans, investment in clean energy, green deposits, and green credit cards. The development of green finance has consequently become increasingly relevant to the banking sector. Green finance can serve as an important mechanism through which banks support environmentally sustainable economic activities. By allocating financial resources to green projects, developing sustainable financial products, and incorporating environmental criteria into lending and investment decisions, banks can contribute to environmental protection and sustainable development. These practices also highlight the importance of integrating environmental considerations into banks' strategic and financial decision-making processes [5]. Green financing can facilitate investment in clean energy and environmentally responsible business activities by directing financial resources toward projects that support sustainable development. Banks can contribute to this process through financing green startups, supporting renewable energy initiatives, and developing financial instruments such as green bonds [6]. The role of financial markets in supporting environmental objectives is also highlighted in research on energy policy, which notes that environmental and fiscal policies in the energy sector may be implemented through capital markets. As stated in Energy Programs of American Parties (Republicans and Democrats) and Global Oil Market, "the Democratic Party believes in enforcing their environmental and fiscal policies in the energy sector through the capital market." This perspective provides contextual support for considering the role of financial mechanisms and capital allocation in advancing environmentally oriented economic activities [7]. The extent to which these activities are incorporated into banking strategies may reflect the role of green finance in shaping banks' engagement with environmental and economic sustainability [6]. Governments and regulators around the world are seeking to reduce pollution and greenhouse-gas emissions and to encourage firms to disclose risks and returns associated with environmental sustainability. Therefore, the development of green finance is expected to continue as financial systems increasingly incorporate environmental considerations into financing activities [8-9]. From a banking resilience perspective, green finance may influence financial stability through its potential implications for credit risk and the allocation of financial resources. Greater use of green loans can reduce exposure to climate-related risks associated with environmentally intensive or "brown" activities and may therefore contribute to lower credit risk and greater financial stability. However, this relationship is not necessarily uniform across different types of banks. Evidence from China indicates that the implementation of green credit policies may reduce credit risk among major state-controlled banks while increasing credit risk among city and regional commercial banks. Thus, although green finance can potentially strengthen bank resilience through improved risk allocation and reduced exposure to climate-related risks, its consequences may depend on the institutional and organizational characteristics of financial institutions [10]. Accordingly, the expected positive relationship between green finance and bank resilience represents an empirical question rather than an assumption that green finance is universally beneficial. Alongside these developments, financial technology (FinTech) has emerged as an important technological force in the financial sector. FinTech refers to innovative financial services enabled by contemporary information technologies, including artificial intelligence, blockchain, cloud computing, and big data. These technologies enable the financial sector to provide more timely and efficient services and improve the quality of conventional financial services [11]. FinTech can also improve access to essential financial services such as savings, credit, and insurance, particularly where these services may be difficult to obtain through traditional banking channels. In addition, FinTech can improve operational efficiency by optimizing payment processes, improving record-keeping, and facilitating cash-flow management. These capabilities may strengthen banks' ability to maintain effective operations and respond to changing financial conditions [12, 13]. The importance of technology-enabled information processing is also reflected in research showing that smart technologies can provide real-time information and trends, thereby improving operational efficiency and performance. As stated by Razavi and Motavali [14], "Tracking data using smart technologies can help with drilling efficiency and well performance by providing real-time information and trends" .Although this evidence originates from the oil industry, it highlights the broader operational value of timely information, which may also be relevant to the use of FinTech in banking. [13]. The potential contribution of FinTech to bank resilience can therefore arise from improvements in operational efficiency, service delivery, information processing, and competitiveness. However, technological development may also introduce new vulnerabilities. Greater technological complexity and increased dependence on digital systems can expose financial institutions to cybersecurity threats and other technology-related risks, potentially creating systemic risks to financial stability and integrity [14]. FinTech should therefore not be viewed as inherently beneficial to bank resilience. Its relationship with resilience may depend on how effectively banks manage the risks and organizational changes associated with technological adoption. This provides a theoretical basis for examining whether greater FinTech adoption is associated with stronger bank resilience after controlling for other bank-specific characteristics. At the same time, rapid advances in digital transformation have contributed to the emergence of the digital economy and its integration with the industrial economy, creating new opportunities for sustainable development. To support sustainable development and organizational resilience, digital transformation has become one of the main priorities of banks. Digital transformation should, however, be distinguished from FinTech. FinTech primarily concerns technology-enabled financial products, services, and business models, whereas digital transformation represents a broader organizational and strategic process involving the deliberate and continuous integration of digital technologies into business models, processes, resources, and organizational practice. In banking, digital transformation extends beyond the adoption of individual financial technologies and encompasses areas such as strategy, organization, information technology, supply chains, and organizational culture [15]. Thus, FinTech can be considered a specific manifestation of technology-driven innovation in financial services, while digital transformation represents a broader organizational capability through which banks integrate digital technologies into their overall operations. This distinction is particularly important when considering the potential moderating role of digital transformation. Digital transformation can provide the organizational infrastructure, data capabilities, processes, and technological resources required to integrate FinTech solutions and green-finance activities more effectively. In the context of green finance, advanced digital technologies such as big data analytics, artificial intelligence, blockchain, and cloud computing may improve information processing, traceability, transparency, and monitoring of green investments [16]. These capabilities can facilitate the identification and management of environmental and credit risks associated with green financing. Similarly, when banks have stronger digital transformation capabilities, they may be better positioned to integrate FinTech applications into their operations, manage large volumes of digital information, improve service delivery, and respond to technological risks. Consequently, digital transformation may strengthen the potential contribution of both green finance and FinTech to bank resilience. Nevertheless, digital transformation may also involve substantial implementation costs, organizational restructuring, employee adaptation, and technological integration challenges. These costs may place pressure on banks during the transformation process, particularly when digital investments are not immediately translated into operational or financial benefits. Therefore, the moderating role of digital transformation should not be interpreted as necessarily positive in all circumstances. Rather, the empirical question is whether the organizational capabilities created through digital transformation are sufficiently strong to enhance the resilience-related benefits associated with green finance and FinTech. Despite the growing importance of these developments, the relationships among green finance, FinTech, digital transformation, and bank resilience remain insufficiently examined simultaneously, particularly in emerging and institutionally constrained financial environments. Existing research has increasingly considered the interaction between environmental finance and technological development, but less attention has been given to how these factors relate specifically to the financial resilience of banks. This gap is particularly relevant because resilience concerns not only sustainable development or organizational performance but also the capacity of banks to absorb financial pressures, maintain stability, and continue operating under adverse conditions. A relevant recent study is Zaid et al., which examined the relationship between green finance and sustainable performance and investigated the moderating roles of FinTech adoption and digital transformation using survey data collected from 152 employees of Saudi banks. The present study extends this line of research in several respects. First, rather than relying on perceptual responses obtained through an employee survey, it uses financial information and corporate disclosures of banks listed on the Tehran Stock Exchange, thereby providing evidence based on bank-level financial and disclosed information. Second, the study employs a longitudinal panel structure covering multiple banks and years, allowing both cross-sectional and temporal variation to be considered. Third, instead of using sustainable performance as the dependent variable, the present study focuses specifically on bank financial resilience and measures it through a composite financial resilience index based on capital-structure-related

indicators. This shifts the analytical focus from broader sustainability outcomes toward the ability of banks to withstand financial pressures and maintain financial stability. Finally, while Zaid et al. examined digital transformation as a moderator within the relationship between green finance, FinTech adoption, and sustainable performance, the present study directly examines whether digital transformation strengthens the relationships of green finance and FinTech with bank resilience. These differences allow the present study to extend the existing literature to an emerging-market banking context and to provide evidence based on longitudinal bank-level observations rather than cross-sectional survey perceptions [17-19]. In the Iranian context, examining these relationships is particularly relevant given the importance of strengthening banks' capacity to respond to unexpected events and maintain their operations under difficult conditions [1, 2]. Accordingly, this study examines the associations of green finance and FinTech with bank resilience and investigates whether digital transformation moderates these relationships. The study focuses on banks listed on the Tehran Stock Exchange and provides empirical evidence based on 128 bank-year observations over the 2017–2024 period. By examining green finance and FinTech together, distinguishing FinTech from the broader concept of digital transformation, and considering digital transformation as a moderating factor, the study seeks to provide a more focused understanding of the technological and environmental factors associated with bank resilience in an emerging banking environment. The scientific contribution of this study lies primarily in integrating environmental financing, financial technology, and organizational digital transformation within a bank-resilience framework. In particular, it extends the literature by examining whether digital transformation changes the strength of the associations between green finance, FinTech, and bank resilience using longitudinal evidence from Iranian banks. This perspective provides a more specific understanding of how environmental and technological developments may jointly relate to the financial capacity of banks to withstand adverse conditions. Based on the above arguments, the following hypotheses are proposed:

H1: Green finance is positively and significantly associated with bank resilience.

H2: FinTech is positively and significantly associated with bank resilience.

H3: Digital transformation positively moderates the relationship between green finance and bank resilience.

H4: Digital transformation positively moderates the relationship between FinTech and bank resilience.

2. Method

2.1. Methodology

2.1. Research Design and Sample Selection

This study is applied in terms of its objective and adopts an ex post facto (causal–comparative) research design. It relies on historical financial information and corporate disclosures to examine the relationships among green finance, FinTech, digital transformation, and bank resilience. Panel-data analysis is employed to account for both the cross-sectional and temporal dimensions of the observations . The statistical population consists of banks listed on the Tehran Stock Exchange (TSE) during the 2017–2024 period. The sample was selected using a systematic elimination method. Accordingly, banks were included in the final sample if they met the following criteria: (1) continuous operation throughout the study period; (2) availability of reliable financial information and annual reports through Codal and other reputable financial databases; (3) no change in fiscal year-end, with the fiscal year ending on March 20 (29 Esfand); and (4) listing on the TSE prior to 2017. These criteria were applied to ensure the comparability, consistency, and reliability of the information used in the empirical analysis .Based on these criteria, 128 bank-year observations met the required conditions, corresponding to 16 banks with complete observations throughout the eight-year study period. The final sample includes Eghtesad Novin Bank, Parsian Bank, Pasargad Bank, Tejarat Bank, Dey Bank, Sarmayeh Bank, Sina Bank, Bank Saderat Iran, Shahr Bank, Post Bank of Iran, Khavarmianeh Bank, Karafarin Bank, Gardeshgari Bank, Saman Bank, Bank Mellat, and Resalat Bank .The panel regression models are estimated using a two-way fixed-effects specification that incorporates both bank-specific and year-specific effects. Bank fixed effects account for unobserved heterogeneity across banks, while year fixed effects control for common time-specific shocks affecting the banking sector. The covariance estimator used in the original estimation is the ordinary covariance estimator. Bank age is measured as the elapsed time between each bank's establishment date and the end of the corresponding fiscal year, expressed in years, including fractional years. The estimation sample and residual degrees of freedom are determined separately for each model based on the number of observations and independently estimated parameters.

2.2. Data Collection and Analysis

Data were collected through library research, review of scientific literature, and content analysis of banks' annual reports, financial statements, board of directors' reports, explanatory notes, and corporate disclosures. The theoretical foundations of the study were obtained from relevant academic studies, while the empirical data required for measuring the research variables were extracted from publicly available financial and corporate information. Content analysis was used to identify the disclosures required for the measurement of green finance and FinTech. Information related to digital transformation was extracted from the explanatory notes to the financial statements based on the specified measurement criteria. Financial data required for the calculation of the resilience index and control variables were obtained from the financial statements and other authoritative sources related to listed companies. Microsoft Excel was used for data classification, coding, checklist preparation, and calculation of the research indices. Eviews was used to conduct the descriptive and econometric analyses. The empirical analysis was performed using panel-data techniques. Prior to estimating the regression models, the stationarity of the variables was examined. Subsequently, the appropriate panel-data specification was determined using the F-Limer (Chow) and Hausman tests. Finally, the proposed hypotheses were evaluated using the estimated regression models and the statistical significance of the relevant coefficients. It should be noted that the continuous variables were not mean-centered before constructing the interaction terms.

2.3. Research Models

To examine the proposed relationships, four regression models were specified. The first two models examine the associations of green finance and FinTech with bank resilience, respectively, while the third and fourth models examine the moderating role of digital transformation in the relationships between green finance and bank resilience and between FinTech and bank resilience, respectively.

The baseline models are specified as follows:

1- $Model\ 1: BR = \beta_0 + \beta_1\, GF_{it} + \beta_2\, Control_{it} + \varepsilon_{it}$

2- $Model\ 2: BR = \beta_0 + \beta_1\, FinTech_{it} + \beta_2\, Control_{it} + \varepsilon_{it}$

3- $Model\ 3: BR = \beta_0 + \beta_1 DT_{it} + \beta_2 (DT_{it} * GF_{it}) + \beta_3\, Control_{it} + \varepsilon_{it}$

4- $Model\ 4: BR = \beta_0 + \beta_1\, DT_{it} + \beta_2\, (DT_{it} * FinTech_{it}) + \beta_3\, Control_{it} + \varepsilon_{it}$

where BR denotes bank resilience; GF denotes green finance; FinTech denotes financial technology; DT denotes digital transformation; and Control represents the set of control variables including firm age, Short-term Liability Share, cash holdings, liquidity, and efficiency, i denotes Banks listed on the Tehran Stock Exchange after systematic elimination of ineligible banks, t denotes Eight-year period 2017 to 2024, e denotes Unobserved factors affecting bank resilience.

2.4. Operational Definitions and Measurement of Variables

2.4.1. Green Finance

Green finance is measured following the approach adopted by Sun et al. [20]. The seven dimensions of green finance—green loans and credit facilities, green financing initiatives, green insurance, investment in green funds or green projects, green bonds, sustainable participation and investment, and the protection of green rights and interests—were derived from the framework proposed by Sun et al. and subsequently localized to reflect the green-finance instruments and practices available in the Iranian banking context. This localization was undertaken to ensure that the measurement framework was applicable to the institutional and financial conditions of Iranian banks. Given the limitations of financial disclosure in the Iranian banking context, a binary scoring procedure was used to measure the seven dimensions. In particular, the amounts related to green financing are not reported separately and consistently in most banks' annual reports. In cases where such information is disclosed, the reported amounts may be presented in different currencies, including Iranian rials, US dollars, and euros. Moreover, green-finance amounts are generally not reported in an integrated and comparable manner within the financial statements. Therefore, using the disclosed monetary amounts as a quantitative measure would not provide a sufficiently consistent basis for comparison across banks and years. Accordingly, the relevant information was assessed using a binary scoring approach. For each bank-year observation, a score of 1 was assigned when evidence of the relevant green-finance dimension was identified in the bank's financial statements or annual reports, and a score of 0 was assigned when no evidence was identified. The scores for the seven dimensions were then summed to obtain the final green finance score for each bank-year observation, ranging from 0 to 7. A higher score indicates a greater presence and disclosure of green-finance practices across the identified dimensions.

2.4.2. FinTech

FinTech is measured using a localized checklist developed based on the Peking

University Digital Financial Inclusion Index and adapted to the specific context of virtual banking services provided by Iranian banks. The localization process involved translating the general dimensions of digital financial services into observable banking services and technological features applicable to Iranian banks. The resulting checklist comprises seven dimensions and 32 items: (1) infrastructure and accessibility, including 24-hour service availability, system stability and continuity, appropriate transaction speed, and compatibility with Android, iOS, and web-based platforms; (2) diversity of virtual banking services, including bill payment and mobile recharge, remote account opening, online loan applications, account authorization services, and investment and fund-purchase services; (3) security and privacy, including biometric or one-time-password login, two-factor authentication, real-time transaction notifications, and immediate account blocking; (4) user experience, including a simple and understandable user interface, appropriate graphic design, quick access to frequently used services, user-interface personalization, and in-app visual guidance and tutorials; (5) innovation and emerging technologies, including the use of artificial intelligence, QR-code money transfers, transfers to contacts using telephone numbers, and dedicated platforms for neobanking services; (6) customer support and services, including 24-hour online support, rapid response, multiple communication channels such as chat, telephone, and ticketing, ticket-based support, branch information, and customer clubs; and (7) transparency and information disclosure, including clear disclosure of fees, advanced financial reporting, financial management tools, and notification of changes in services. A binary scoring procedure is applied to each of the 32 items. A score of 1 is assigned when the relevant service or technological feature is disclosed or demonstrably available for the bank during the relevant year, while a score of 0 is assigned when no evidence of its availability or disclosure is identified. The scores across the 32 items are then summed for each bank-year observation to obtain the final FinTech score, ranging from 0 to 32. Accordingly, higher scores indicate a greater breadth of FinTech-enabled virtual banking services and technological capabilities [21].

2.4.3. Digital Transformation

The digital transformation variable is measured following the methodology employed by Liu and Wang [22]. Digital transformation is assessed using information disclosed in the explanatory notes to financial statements. Specifically, intangible assets associated with digital transformation—such as computer software, enterprise software systems, intelligent platforms, and similar digital technologies—are identified, and the proportion of their monetary value relative to the firm's total intangible assets is calculated.

2.4.4. Bank Resilience

Bank resilience is measured using a composite financial resilience index constructed from three financial ratios: the debt-to-assets ratio, the debt-to-equity ratio, and the equity ratio. These indicators were selected based on the capital structure perspective of financial resilience, according to which a bank's ability to withstand financial pressures is associated with its reliance on liabilities and the capital buffer available to absorb potential losses. The debt-to-assets ratio measures the proportion of a bank's assets financed by liabilities. A higher ratio indicates greater reliance on external obligations and is therefore interpreted as reflecting lower financial resilience. The debt-to-equity ratio measures liabilities relative to shareholders' equity. A higher ratio indicates greater financial leverage relative to the equity base and is likewise interpreted as reflecting lower financial resilience. In contrast, the equity ratio measures the proportion of total assets financed by shareholders' equity. A higher ratio indicates a larger equity buffer available to absorb potential losses and is therefore interpreted as reflecting greater financial resilience. Although these ratios are mathematically and conceptually related because they represent different aspects of a bank's capital structure, they capture complementary dimensions of capital-based financial resilience. Specifically, they reflect the extent of reliance on liabilities relative to total assets, liabilities relative to shareholders' equity, and the proportion of assets financed by equity. Accordingly, the three indicators are combined to provide a broader representation of capital-structure-based financial resilience than any single ratio could provide. The resulting index is not intended to capture all dimensions of organizational resilience.

The index was constructed separately for each bank-year observation over the study period. First, the three financial ratios were calculated for each bank in each year. Second, the debt-to-assets ratio and the debt-to-equity ratio were multiplied by −1 to align their direction with that of the equity ratio, because higher values of the two debt-related ratios indicate lower resilience, whereas a higher equity ratio indicates greater resilience. The equity ratio was retained in its original direction. Third, the directionally aligned ratios were standardized using the Z-score method. For each ratio, the mean and standard deviation were used to calculate its standardized value. Finally, the three standardized values were combined using an equally weighted arithmetic mean, with no differential weights assigned to the component indicators. The composite bank resilience index is calculated as the arithmetic mean of the standardized and directionally aligned indicators:

$$\text{Bank Resilience} = (Z_1 + Z_2 + Z_3) / 3$$

where Z_1, Z_2, and Z_3 represent the standardized and directionally aligned values of the debt-to-assets ratio, debt-to-equity ratio, and equity ratio, respectively. Higher values of the resulting index indicate a stronger level of capital-based financial resilience. This approach ensures that the composite index simultaneously reflects the bank's reliance on liabilities and the strength of its equity buffer while avoiding the use of different measurement scales across the component indicators. The methodological approach was developed with inspiration from the approach adopted by Hardiyanti [23], while the selection of the specific financial ratios was guided by their relevance to the assessment of financial resilience.

2.4.5. Control Variables

The regression models include several control variables that may influence bank resilience, including firm age, Short-term Liability Share, liquidity, cash holdings, and efficiency. These variables are incorporated to reduce the possibility that the estimated relationships between the main explanatory variables and bank resilience are driven by other firm-specific characteristics. It is noteworthy that Short-term Liability Share, which is included as one of the control variables in the regression models, is measured as the ratio of current liabilities to total liabilities. This measure captures the maturity structure of a bank's liabilities and reflects the proportion of total obligations that are due in the short term. It therefore provides information about the bank's short-term liability structure, which is conceptually distinct from the components used to construct the bank resilience index. Specifically, the resilience index is constructed from the debt-to-assets ratio, the debt-to-equity ratio, and the equity ratio, which capture the overall relationship between liabilities, assets, and shareholders' equity. In contrast, Short-term Liability Share in this study is defined as current liabilities relative to total liabilities and therefore focuses on the composition and maturity structure of liabilities rather than the overall level of indebtedness relative to assets or equity. Accordingly, the control variable does not mechanically reproduce any of the ratios used to construct the dependent variable. Including Short-term Liability Share as a control variable therefore allows the analysis to account for differences in banks' short-term liability structures when examining the associations between the main explanatory variables and bank resilience. Nevertheless, given the conceptual relationship between liability structure and financial resilience, the coefficient of Short-term Liability Share is interpreted as the partial association between Short-term Liability Share and bank resilience, conditional on the other variables in the model.

3. Results and Discussion

3.1. Descriptive Statistics

Table 1 reports the descriptive statistics of the study variables. The sample consists of 128 bank-year observations. The mean values indicate substantial variation across the sampled banks in FinTech, green finance, digital transformation, and the control variables. It should be noted that, prior to conducting the descriptive statistics and subsequent statistical analyses, the variables were normalized and weighted to improve measurement consistency and comparability. Accordingly, the reported ranges and values may differ from the original unprocessed data.

Table 1. Descriptive Statistics of the Study Variables

Variables	Observations	Minimum	Maximum	Mean	Median	Standard Deviation	Kurtosis
Resilience	128	0.76	2.37	1.56	1.56	0.32	2.65
FinTech	128	7	27	15.80	16	4.76	2.46
Green financing	128	0	1	0.44	0.45	0.26	2.73
Digital transformation	128	-0.28	1.01	0.25	0.24	0.31	2.43
Financial leverage	128	0.60	1.22	0.91	0.91	0.12	2.70
Liquidity	128	1	10.38	4.24	4.05	2.26	2.46
Efficiency	128	-0.04	0.15	0.04	0.04	0.03	2.82
Cash	128	-4.04	4.07	0.01	0.02	1.62	2.69
Company age	128	1.32	72	24.32	23.34	14.53	2.93

Source: Refs [10-12]

Table 2 presents the Jarque–Bera statistics and corresponding p-values. The results do not indicate significant departures from normality at the 5% level for the examined variables.

Table 2. Jarque–Bera Normality Test Results

Variables	Jarque–Bera Statistic	Probability
Resilience	0.63	0.72
FinTech	2.00	0.36
Green financing	2.14	0.34
Digital transformation	2.12	0.34
Financial leverage	0.46	0.79
Liquidity	5.25	0.07
Efficiency	2.86	0.23
Cash	0.48	0.78
Company age	5.76	0.05

Source:Research Findings

Table 3 reports the Pearson correlation coefficients. The correlations among the explanatory variables are generally moderate, indicating no apparent severe multicollinearity problem. Although the Pearson correlation coefficient between FinTech and bank resilience is negative (−0.32), the regression coefficient of FinTech in Table 7 is positive. This difference can be explained by the relationships between FinTech and the control variables included in the regression model. Specifically, both efficiency and bank age are positively correlated with bank resilience, while FinTech is also positively correlated with these two control variables. Therefore, the negative bivariate correlation between FinTech and bank resilience does not necessarily imply a negative association after accounting for the relevant control variables. Once efficiency and bank age, together with the other control variables, are incorporated into the regression model, the coefficient of FinTech becomes positive and statistically significant (β=0.0139, p=0.0429). This result suggests that the positive association between FinTech and bank resilience becomes evident after accounting for the observed characteristics of the banks included in the model.

Table 3. Pearson Correlation Matrix of the Study Variables

Variables	Resilience	Cash	Liquidity	Financial leverage	Green financing	FinTech	Efficiency	Digital transformation	Company age
Resilience	1	0.38	0.06	-0.35	0.28	-0.32	0.50	0.22	0.24
Cash	-	1	0.00	-0.17	0.05	0.18	0.33	0.27	0.02
Liquidity	-	-	1	-0.09	0.07	0.03	0.11	0.13	0.14
Financial leverage	-	-	-	1	-0.21	-0.06	-0.26	-0.08	-0.54
Green financing	-	-	-	-	1	0.07	0.33	-0.17	0.36
FinTech	-	-	-	-	-	1	0.09	0.03	0.07
Efficiency	-	-	-	-	-	-	1	0.29	0.26
Digital transformation	-	-	-	-	-	-	-	1	-0.19
Company age	-	-	-	-	-	-	-	-	1

Source: Research Findings

3.2. Panel Data Tests and Model Selection

Table 4 presents the results of the Levin–Lin–Chu (LLC) panel unit-root test. The reported p-values are below 0.05 for all variables, leading to rejection of the null hypothesis of a unit root. Accordingly, the variables are considered stationary over the study period. The LLC test is applied given the relatively short time dimension of the panel, with eight annual observations for each bank.

Table 4. Levin–Lin–Chu Panel Unit-Root Test Results

Description	Calculated statistics	Prob.	Result
Resilience	-3.8130	0.0001	Stationary
Cash	-10.7000	0.0000	Stationary
Liquidity	-36.2700	0.0000	Stationary
Financial leverage	-9.9690	0.0000	Stationary
Green financing	-2.2850	0.0111	Stationary
FinTech	-6.4300	0.0000	Stationary
Efficiency	-7.1610	0.0000	Stationary
Digital transformation	-12.6820	0.0000	Stationary
Company age	-8.4950	0.0000	Stationary

Source:Research Findings

Table 5 reports the F-Limer (Chow) and Hausman tests used to determine the appropriate panel-data specification. The F-Limer test rejects the pooled-effects specification, indicating the presence of statistically significant bank-specific effects. The Hausman test subsequently indicates that the fixed-effects specification is preferred to the random-effects specification. Accordingly, the four regression models are estimated using a fixed-effects specification.

Table 5. F-Limer and Hausman Test Results for Panel-Data Model Selection

Hypotheses	F-Limer Statistic	Prob.	Hausman Test	Prob.	Method
Hypothesis 1	6.4610	0.0000	16.4830	0.0116	Fixed Effects
Hypothesis 2	6.5660	0.0000	16.6750	0.0010	Fixed Effects
Hypothesis 3	7.4370	0.0000	17.3660	0.0152	Fixed Effects
Hypothesis 4	7.5940	0.0000	18.0550	0.0117	Fixed Effects

Source:Research Findings

3.3. Regression Results

3.3.1. Direct Associations of Green Finance and FinTech with Bank Resilience

The results reported in Table 6 indicate that green finance is positively and statistically significantly associated with bank resilience (β=0.225, p=0.0433). Thus, H1 is supported. Among the control variables, efficiency is also statistically significant, whereas the other control variables do not exhibit statistically significant associations with bank resilience.

Table 6. Fixed-Effects Regression Results for the Association between Green Finance and Bank Resilience

Variable	Coefficient	Standard Error	t-Statistic	Prob.	F-Statistic	Prob.
Green financing	0.2250	0.1102	2.0470	0.0433	9.0970	0.0000
Firm Age	-0.0046	0.0104	-0.4460	0.6559	-	-
Efficiency	2.6620	0.8560	3.1070	0.0025	-	-
Financial Leverage	-0.0801	0.3240	-0.2460	0.8056	-	-
Liquidity	-0.0040	0.0086	-0.4740	0.6362	-	-
Cash Holdings	0.0076	0.0137	0.5520	0.5819	-	-
Constant (Intercept)	1.5370	0.4302	3.5740	0.0005	-	-
	R-squared		Adjusted R-squared		Durbin–Watson Stat	
	0.7201		0.6409		1.7660	

Source: Research Findings

Similarly, Table 7 shows that FinTech is positively and statistically significantly associated with bank resilience (β=0.0139, p=0.0429). Therefore, H2 is supported. As in the green finance model, efficiency is statistically significant, while the other control variables are not statistically significant. Overall, these findings indicate that both green finance and FinTech are positively associated with bank resilience after accounting for the control variables included in the models.

Table 7. Fixed-Effects Regression Results for the Association between FinTech and Bank Resilience

Variable	Estimated Coefficient	Standard Error	t-Statistic	Prob.	F-Statistic	Prob.
FinTech	0.0139	0.0068	2.0500	0.0429	9.0900	0.0000
Firm Age	0.0005	0.0104	0.0510	0.9580	-	-
Efficiency	2.6840	0.8560	3.1330	0.0023	-	-
Financial Leverage	0.0164	0.3200	0.0510	0.9590	-	-
Liquidity	-0.0039	0.0086	-0.4640	0.6430	-	-
Cash Holdings	0.0044	0.0136	0.3260	0.7440	-	-
Constant (Intercept)	1.2010	0.4460	2.6880	0.0084	-	-
	R-squared		Adjusted R-squared		Durbin–Watson Stat	
	0.7200		0.6410		1.8310	

Source: Research Findings

3.3.2. Moderating Role of Digital Transformation

The results presented in Table 8 show that the interaction term between digital transformation and green finance is positive and statistically significant (β=0.603, p=0.0081). This finding indicates that the positive association between green finance and bank resilience becomes stronger at higher levels of digital transformation, supporting H3.

Table 8. Fixed-Effects Regression Results for the Moderating Role of Digital Transformation in the Green Finance–Bank Resilience Relationship

Variable	Estimated Coefficient	Standard Error	t-Statistic	Prob.	F-Statistic	Prob.
Digital transformation	-0.4160	0.1360	-3.0550	0.0029	9.4610	0.0000
Digital transformation*Green financing	0.6030	0.2230	2.7010	0.0081	-	-
Firm Age	0.0043	0.0104	0.4160	0.6778	-	-
Efficiency	3.1310	0.8460	3.7000	0.0004	-	-
Financial Leverage	-0.1030	0.3350	-0.3080	0.7586	-	-
Liquidity	0.00005	0.0084	0.0067	0.9900	-	-
Cash Holdings	0.0116	0.0135	0.8620	0.3904	-	-
Constant (Intercept)	1.4460	0.4190	3.4400	0.0008	-	-
	R-squared		Adjusted R-squared		Durbin–Watson Stat	
	0.7368		0.6580		1.869	

Source: Research Findings

Likewise, Table 9 reports a positive and statistically significant interaction between digital transformation and FinTech (β=0.0295, p=0.0107). This result indicates that the positive association between FinTech and bank resilience is stronger at higher levels of digital transformation, supporting H4. Taken together, the results of the two moderation models suggest that digital transformation strengthens the positive associations of both green finance and FinTech with bank resilience.

Table 9. Fixed-Effects Regression Results for the Moderating Role of Digital Transformation in the FinTech–Bank Resilience Relationship

Variable	Estimated Coefficient	Standard Error	t-Statistic	Prob.	F-Statistic	Prob.
Digital transformation	-0.6210	0.1950	-3.1760	0.0020	9.3970	0.0000
Digital transformation*FinTech	0.0295	0.0113	2.6020	0.0107	-	-
Firm Age	0.0064	0.0107	0.6020	0.5480	-	-
Efficiency	2.9670	0.8460	3.5070	0.0007	-	-
Financial Leverage	-0.0020	0.3270	-0.0062	0.9900	-	-
Liquidity	-0.0030	0.0084	-0.3680	0.7130	-	-
Cash Holdings	0.0050	0.0133	0.3870	0.6990	-	-
Constant (Intercept)	1.3230	0.4210	3.1420	0.0022	-	-
	R-squared		Adjusted R-squared		Durbin–Watson Stat	
	0.7350		0.6570		1.8350	

Source: Research Findings

3.4. Discussion

The results provide evidence of statistically significant positive associations between green finance, FinTech, and bank resilience. Regarding green finance, the estimated coefficient is positive and statistically significant (β=0.225, p=0.0433). This finding suggests that, conditional on the control variables and fixed effects included in the model, banks with greater engagement in green-finance practices tend to exhibit higher levels of financial resilience. From a theoretical perspective, green finance may be associated with resilience because incorporating environmental considerations into financing decisions can potentially improve the identification and management of environmental and longer-term financial risks. Green-finance activities may also be associated with a more diversified allocation of financial resources toward environmentally oriented projects and industries. These mechanisms, however, are not directly tested in the present study and should therefore be regarded as plausible explanations rather than established causal channels. The positive association observed in the Iranian banking context may also reflect the growing relevance of environmental considerations in financial activities and the increasing need for banks to allocate resources efficiently under economic and financial constraints. In an environment characterized by financial uncertainty and institutional constraints, banks that disclose or adopt a broader range of green-finance practices may differ in their financial and organizational capacity from banks with more limited engagement in such activities. The finding is broadly consistent with Cao and Tao [19] and Zhang [20], although differences in samples, measures, and research settings should be considered when comparing the results. For FinTech, the estimated coefficient is also positive and statistically significant (β = 0.0139, p = 0.0429). Thus, after accounting for the control variables and bank-specific fixed effects, greater FinTech engagement is positively associated with bank resilience. From a theoretical perspective, FinTech may be associated with resilience through greater operational flexibility, more efficient delivery of financial services, and improved processing of financial information. In the Iranian banking system, the expansion of virtual banking services and technology-enabled financial channels may be particularly relevant because they allow banks to provide services through digital platforms and potentially reduce reliance on traditional service-delivery processes. Improved information processing, service accessibility, and operational efficiency may therefore represent possible explanations for the observed association. However, these mechanisms were not directly measured or tested and should not be interpreted as demonstrated causal effects. The positive FinTech coefficient should also be considered alongside the negative Pearson correlation reported in Table 3. The bivariate correlation between FinTech and bank resilience is negative (−0.32), whereas the conditional regression coefficient is positive (β=0.0139). This difference does not necessarily represent an inconsistency because the Pearson coefficient reflects the unconditional linear association between the two variables, whereas the regression coefficient reflects their partial association after accounting for the other variables in the model. In particular, FinTech is positively correlated with efficiency and bank age, while both efficiency and age are positively associated with bank resilience. Controlling for these and other relevant characteristics can therefore alter the estimated association between FinTech and resilience. The positive regression coefficient should consequently be interpreted as a conditional statistical association rather than as evidence of a causal effect. The moderation results provide further insight into these relationships. The interaction between green finance and digital transformation is positive and statistically significant (β=0.603, p=0.0081). This indicates that the positive association between green finance and bank resilience becomes stronger at higher levels of digital transformation. From a theoretical perspective, digital capabilities may enable banks to process information related to green projects more efficiently, monitor financing activities, improve the availability and transparency of information, and potentially support environmental-risk assessment. In the Iranian banking context, where green-finance information may not always be disclosed in a standardized monetary form, stronger digital capabilities may also facilitate the collection, organization, and monitoring of information related to green-finance activities. These are plausible mechanisms that may help explain the observed interaction, but they were not directly examined in this study. Similarly, the interaction between FinTech and digital transformation is positive and statistically significant (β=0.0295, p=0.0107). This finding indicates that the positive association between FinTech and bank resilience is stronger at higher levels of digital transformation. Theoretically, this pattern may reflect the complementary nature of FinTech services and broader digital capabilities. Digital transformation may provide the organizational and technological infrastructure required to integrate technology-enabled financial services more effectively with existing banking processes. In the Iranian banking context, where banks differ in the extent and maturity of their digital infrastructure, this complementarity may help explain why the association between FinTech and resilience varies across different levels of digital transformation. Again, this interpretation represents a plausible explanation rather than a directly tested mechanism. The result is broadly consistent with the argument advanced by Zaid et al. and Liu and Yu [21] regarding the role of digital capabilities in supporting financial innovation and sustainability. An additional finding requiring careful interpretation is the negative direct coefficient of digital transformation in the moderation models. This coefficient should not be interpreted as evidence that digital transformation generally has a negative relationship with bank resilience. In an interaction model, the coefficient of digital transformation represents its conditional association with bank resilience when the corresponding focal variable is equal to zero. Its negative sign may partly reflect the costs and organizational adjustments associated with digital transformation, including technology investment, restructuring of existing processes, employee adaptation, and the challenges of integrating new digital systems with established banking infrastructures. Such considerations may be particularly relevant in the Iranian banking environment, where technological transformation can require substantial investment and organizational adjustment. Importantly, the positive interaction coefficients provide a different dimension of the relationship. They indicate that the association of green finance and FinTech with bank resilience becomes more favorable as digital transformation increases. Therefore, the negative direct coefficient and positive interaction coefficient are not necessarily contradictory: they represent different conditional aspects of the moderation models. Taken together, the results may suggest that digital transformation involves adjustment and implementation challenges when considered independently, while its presence alongside green finance and FinTech is associated with stronger relationships between these practices and bank resilience. This interpretation should nevertheless be treated cautiously because the underlying mechanisms were not directly tested and the study does not establish causality [22-28].

3.5. Practical Implications

The findings suggest that banks may benefit from considering green finance, FinTech, and digital transformation as interconnected components of their

strategic and operational activities. The positive associations of green finance and FinTech with bank resilience, together with the positive interaction effects of digital transformation, indicate that developing these capabilities in coordination may be more relevant than treating them as completely independent initiatives. From a managerial perspective, banks may consider strengthening digital systems that support green-project monitoring, environmental-risk information processing, and technology-enabled financial services. Such systems may potentially improve the availability and organization of information and facilitate more effective monitoring and resource allocation. However, because these mechanisms were not directly tested, such recommendations should be viewed as strategic implications rather than prescriptions derived from proven causal effects. The negative direct association of digital transformation also suggests that digital investments should be accompanied by appropriate organizational planning. Managers may need to consider implementation costs, process restructuring, employee adaptation, and the integration of new technologies with existing systems. Policymakers may likewise consider supporting standardized green-finance disclosure frameworks, digital infrastructure, and financial innovation. These measures may potentially improve the institutional environment for the coordinated development of green finance, FinTech, and digital transformation.

3.6. Limitations and Future Research

This study has several limitations. First, the sample is restricted to banks listed on the Tehran Stock Exchange, which limits the generalizability of the findings to other countries and financial sectors. Second, several variables are measured using information disclosed in annual reports and financial statements, which may introduce measurement limitations and disclosure-related bias. Third, bank resilience is captured through a composite financial index and therefore does not encompass all operational, market-based, or organizational dimensions of resilience. In addition, although fixed-effects panel regression controls for time-invariant bank-specific characteristics, it does not fully eliminate potential endogeneity or reverse causality. For example, banks with stronger resilience may have greater capacity to invest in FinTech, green finance, or digital transformation. Accordingly, the findings should be interpreted as statistical associations rather than definitive causal effects. Future studies could employ alternative identification strategies, lagged specifications, or other appropriate econometric approaches to examine whether the observed relationships remain robust after addressing potential endogeneity. Future research could also extend the analysis to other countries and financial institutions, employ alternative market- and risk-based measures of resilience, and examine nonlinear or dynamic relationships among green finance, FinTech, and digital transformation. Further studies could investigate whether these associations vary according to bank size, ownership structure, regulatory environment, or level of digital maturity. Future research could also directly examine the mechanisms proposed in this study, such as environmental-risk management, information transparency, monitoring capacity, and resource-allocation efficiency.

4. Conclusions

Overall, the results indicate that green finance (β=0.225, p=0.0433) and FinTech (β=0.0139, p=0.0429) are positively and statistically significantly associated with bank resilience. The moderation results further show that the interaction between green finance and digital transformation is positive and statistically significant (β=0.603, p=0.0081), while the interaction between FinTech and digital transformation is also positive and statistically significant (β=0.0295, p=0.0107). These results indicate that the positive associations of green finance and FinTech with bank resilience become stronger at higher levels of digital transformation. The findings also highlight an important distinction between the direct and moderating roles of digital transformation. Although its direct coefficient is negative in the moderation models, the positive interaction terms indicate that its relationship with bank resilience depends on the level of green finance or FinTech. A possible interpretation is that digital transformation may involve short-term organizational and implementation challenges while simultaneously providing capabilities that enhance the potential association of green finance and FinTech with resilience. However, these mechanisms were not directly tested and should therefore be regarded as possible explanations rather than established causal pathways. Overall, the study contributes empirical evidence on the statistical associations among green finance, FinTech, digital transformation, and bank resilience in an emerging banking environment. The findings do not establish definitive causal effects; rather, they indicate that green finance and FinTech are positively associated with resilience and that these associations vary positively with the level of digital transformation. This evidence highlights the potential importance of considering sustainability-oriented financial practices, financial innovation, and digital capabilities within an integrated framework when examining bank resilience.

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Author Contributions

M. R. Radfar was responsible for conceptualization, hypothesis development, data validation, writing – review & editing, supervision, and project administration. F. Rouzbehani was responsible for data curation and analysis, as well as writing the original draft. Methodology was developed collaboratively by both authors. Both authors reviewed and approved the final version of the manuscript.

Conflict of Interest

The authors, while observing publication ethics in the referencing, declare the absence of interest of conflict.

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