Artificial Intelligence Applications and Digital Finance Development: The Moderating Role of Human Resources and Digital Infrastructure

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Abstract

The rapid advancement of digital technologies has fundamentally transformed financial systems, particularly in emerging economies, where digital finance plays a critical role in enhancing financial accessibility and efficiency. Among these technologies, artificial intelligence (AI) has emerged as a strategic driver reshaping digital financial services. This study aims to investigate the direct and moderating effects of artificial intelligence applications on the development of digital finance by integrating technological, human, institutional, and innovation perspectives. A sequential mixed-methods design was employed. In the qualitative phase, semi-structured interviews were conducted with 55 experts in banking, finance, and financial technology. The sample size was determined based on theoretical saturation, which was reached when successive interviews yielded no substantially new insights regarding construct dimensions or measurement refinement. Insights from this phase were used to validate constructs and refine the measurement instrument. In the quantitative phase, survey data were collected from 700 digital banking users across 20 commercial banks in Vietnam. Partial Least Squares Structural Equation Modeling (PLS-SEM) was applied to test the proposed hypotheses. The results indicate that the digital policy framework ($\beta = 0.300$) and the digital human resource management ($\beta = 0.279$) exhibit the largest direct effects on digital finance development, based on the relative magnitude of standardized path coefficients. Among these factors, digital policy frameworks and digital human resource management demonstrate the strongest direct impacts. More importantly, the findings confirm the moderating role of artificial intelligence applications. AI significantly strengthens the relationships between digital human resource management and digital finance development, as well as between digital technology infrastructure and digital finance development. These results indicate that AI serves not only as an independent technological driver but also as a strategic catalyst, enhancing the effectiveness of digital infrastructure and human capital. This study contributes to the digital finance and information systems literature by empirically demonstrating that artificial intelligence serves as both a determinant and a moderator of digital finance development. From a practical perspective, the findings suggest that policymakers and banking executives should prioritize AI-enabled human resource strategies and the intelligent use of digital infrastructure to accelerate the development of sustainable digital finance in emerging economies.

Keywords: Artificial Intelligence Applications, Digital Finance Development, Digital Human Resources, Digital Technology Infrastructure, Fintech

1. Introduction

The rapid diffusion of digital technologies has profoundly reshaped financial systems worldwide, driving the expansion of digital finance as a critical component of modern economic development. Digital finance enhances financial accessibility, reduces transaction costs, and improves the efficiency of financial intermediation, particularly in emerging and developing economies. Prior studies emphasize that integrating information and communication technologies (ICT) into financial systems plays a fundamental role in accelerating financial development by enabling digital transactions, expanding financial inclusion, and supporting economic growth [1], [2]. A growing body of empirical research has examined the relationship between ICT and financial development from a macroeconomic perspective. International evidence suggests that ICT diffusion significantly improves financial sector depth and efficiency by facilitating information flows and reducing asymmetries between financial institutions and customers [1], [2]. Similar findings have been reported in China, where ICT development has been shown to promote financial development through enhanced digital connectivity and technological adoption [3]. These studies collectively highlight digital infrastructure as a foundational driver of financial development across diverse economic contexts. In parallel,

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financial development has been widely recognized as a key determinant of economic growth, particularly in emerging economies. Empirical evidence from Africa and Ghana demonstrates that improvements in financial development contribute to economic growth by alleviating financial frictions, enhancing capital allocation, and supporting productive investment [2], [4]. However, the strength and effectiveness of financial development are often contingent upon complementary factors such as institutional quality, technological capability, and human capital. As economies increasingly transition toward digitalization, the traditional finance–growth nexus is being transformed into a more complex digital finance ecosystem.

Recent research has begun to explore the role of human capital and income distribution in shaping financial development outcomes. Studies indicate that financial inclusion and digital financial services can significantly influence human capital accumulation and income inequality, particularly in developing regions [5]. These findings suggest that the sustainability of digital finance development depends not only on technological investments but also on the availability of skilled human resources capable of adopting and managing advanced digital systems. Institutional and governance factors further shape the trajectory of financial development. Cross-country evidence confirms that institutional quality and regulatory effectiveness are crucial for fostering stable and inclusive financial systems [6]. In digital contexts, well-designed policy frameworks are essential for managing technological risks, ensuring data security, and promoting innovation in regulated financial environments. Without appropriate institutional support, the potential benefits of digital finance may remain underutilized.

More recently, Artificial Intelligence (AI) has emerged as a transformative force in financial research and practice. AI applications have been increasingly adopted in areas such as credit scoring, fraud detection, algorithmic trading, and personalized financial services. Scholars argue that AI-driven technologies enhance analytical accuracy and decision-making efficiency, thereby reshaping the foundations of financial systems [7]. Despite its growing importance, the empirical role of AI in the development of digital finance, particularly its interactions with human resources and digital infrastructure, remains underexplored in the existing literature.

Against this backdrop, this study aims to address critical gaps by investigating the role of artificial intelligence applications in the development of digital finance in an emerging economy context. Specifically, the study examines both the direct effects of AI and its moderating role in strengthening the relationships between digital human resource management, digital technology infrastructure, and digital finance development. Using empirical evidence from Vietnam's banking sector, this research contributes to the evolving literature on digital finance by integrating technological, human, and institutional perspectives into a unified analytical framework.

While much of the prior literature examining ICT and financial development is situated at the macroeconomic level, this study adopts a micro-level perspective by focusing on customer perceptions within the banking sector. This approach is consistent with digital finance research that operationalizes institutional and environmental conditions through individual-level perceptual measures, thereby capturing contextual factors as experienced by service users.

2. Literature Empirical Review and Hypothesis Development

2.1. Digital Technology Infrastructure and Digital Finance Development

Digital technology infrastructure is the backbone of digital finance development, enabling secure, efficient, and scalable digital financial services. Prior empirical studies consistently emphasize that ICT infrastructure enhances financial system efficiency by reducing transaction costs, improving connectivity, and facilitating real-time information exchange [8], [9]. In the context of digital transactions and global e-commerce, robust digital infrastructure allows financial institutions to integrate advanced platforms for payments, settlements, and cross-border financial services [9].

Empirical evidence from both developing and developed economies confirms that ICT diffusion plays a crucial role in strengthening financial development outcomes. Studies highlight that digital infrastructure contributes to financial deepening and inclusion by expanding access to financial services and supporting digital payment ecosystems [10], [11]. Moreover, the effectiveness of digital infrastructure is particularly evident in emerging markets, where traditional financial systems often face structural constraints [12]. These findings suggest that digital technology infrastructure remains a fundamental determinant of the development of digital finance. Therefore, H1: Digital technology infrastructure positively influences the development of digital finance, as hypothesized in figure 1.

2.2. Innovation and Fintech Ecosystem and Digital Finance Development

The innovation and FinTech ecosystem has emerged as a powerful driver of digital finance by fostering competition, technological experimentation, and service diversification. Prior literature indicates that FinTech innovations enhance financial efficiency and inclusiveness by introducing digital platforms, mobile applications, and data-driven financial solutions [8], [13], [14]. The interaction between traditional financial institutions and FinTech startups creates a dynamic ecosystem that accelerates the adoption of digital finance. Empirical studies further demonstrate that FinTech-driven innovation contributes to financial development by lowering entry barriers and expanding access to underserved populations [15]. In addition, FinTech ecosystems encourage continuous innovation through partnerships, regulatory sandboxes, and open banking initiatives, thereby enhancing the resilience and adaptability of digital financial systems [16], [17]. These empirical insights underscore the importance of innovation ecosystems in sustaining long-term growth in digital finance. Therefore, H2: Innovation and the FinTech ecosystem positively influence the development of digital finance, as hypothesized in figure 1.

2.3. Digital Economic Development and Digital Finance Development

Digital economic development reflects the extent to which economic activities are supported and transformed by digital technologies [18]. A growing body of empirical research suggests that digitalized economies generate strong demand for digital financial services, including online payments, digital credit, and e-commerce financing [19], [20]. Digital finance, in turn, enables digital economic activities by facilitating seamless transactions and financial integration. Evidence from developing countries confirms that ICT diffusion and financial development jointly contribute to economic growth by supporting digital trade and consumption [21]. Moreover, digital economic development creates a favorable environment for financial innovation by increasing user readiness and acceptance of digital financial services [21]. Constructs such as digital economic development and digital policy framework are conceptualized as perceived contextual conditions rather than objective national indicators. This operationalization follows prior information systems and digital transformation studies, where individual perceptions are used to capture environmental and institutional influences on technology adoption and service evaluation. These studies collectively suggest a mutually reinforcing relationship between digital economic development and digital finance. Therefore, H3: Digital economic development positively influences the development of digital finance, as hypothesized in figure 1.

2.4. Digital Policy Framework and Digital Finance Development

Institutional and policy frameworks play a decisive role in shaping the trajectory of digital finance development. Prior empirical research emphasizes that effective regulatory systems reduce uncertainty, enhance trust, and support innovation in financial markets [22], [23]. In digital contexts, policies related to data protection, cybersecurity, and digital governance are particularly critical. Empirical studies demonstrate that well-designed digital policies promote financial development by encouraging responsible innovation and mitigating technological risks [24], [25]. Conversely, weak regulatory environments may exacerbate digital inequalities and hinder the sustainable growth of digital finance [26]. These findings underscore the need for comprehensive digital policy frameworks to ensure balanced and inclusive digital finance development. Therefore, H4: Digital policy framework positively influences the development of digital finance, as hypothesized in figure 1.

2.5. Digital Human Resource Management and Digital Finance Development

Digital human resource management (DHRM) refers to the strategic development and utilization of human capital with digital competencies. Empirical literature underscores that skilled human resources are indispensable for implementing and managing advanced digital financial systems [25], [27]. Digital finance transformation requires employees who possess not only technical skills but also analytical and adaptive capabilities. Studies focusing on human capital development suggest that ICT-enabled skill formation significantly enhances productivity and organizational performance [5], [28]. Furthermore, research indicates that the success of digital transformation initiatives is strongly contingent upon effective human resource strategies that align technological investments with workforce capabilities [29]. These empirical insights support the argument that DHRM is a critical driver of the development of digital finance. Therefore, H5: Digital human resource management positively influences the development of digital finance.

2.6. Artificial Intelligence Applications and Digital Finance Development

Artificial intelligence has emerged as a transformative technology in financial systems, enabling advanced data analytics, automation, and intelligent decision-making. Empirical studies show that AI applications significantly improve the efficiency, accuracy, and personalization of financial services [30], [31]. In digital finance, AI is widely applied in credit scoring, fraud detection, risk management, and customer service automation [32], [33]. Recent literature further highlights that AI-driven financial technologies enhance financial inclusion by reducing information asymmetries and expanding access to credit [34]. Moreover, AI contributes to strategic decision-making in financial institutions by enabling predictive analytics and real-time risk assessment [35]. These empirical findings indicate that AI applications play a direct and significant role in advancing the development of digital finance. Therefore, H6: Artificial intelligence applications positively influence the development of digital finance, hypothesized in figure 1.

2.7. The Moderating Role of Artificial Intelligence Applications

Beyond its direct impact, AI is increasingly viewed as a strategic enabler that enhances the effectiveness of other digital resources. Empirical research suggests that AI strengthens the contribution of human capital by enabling human–AI collaboration in knowledge-intensive tasks [28], [36]. In digital finance contexts, AI-supported human resources are better equipped to manage complex financial data and deliver innovative services [37]. Similarly, prior studies indicate that the value generated from digital infrastructure is significantly amplified when combined with intelligent analytics and AI-driven systems [38], [39], [40]. Without AI, digital infrastructure may remain underutilized, limiting its impact on financial development. These insights suggest that AI plays a critical moderating role by transforming digital infrastructure and human resources into strategic assets [41], [42]. Accordingly, this study proposes that AI applications positively moderate the relationships between digital human resource management, digital technology infrastructure, and digital finance development [43]. Therefore, H7: Artificial intelligence applications positively moderate the relationship between digital human resource management and the development of digital finance. H8: Artificial intelligence applications positively moderate the relationship between digital technology infrastructure and the development of digital finance, as hypothesized in figure 1.

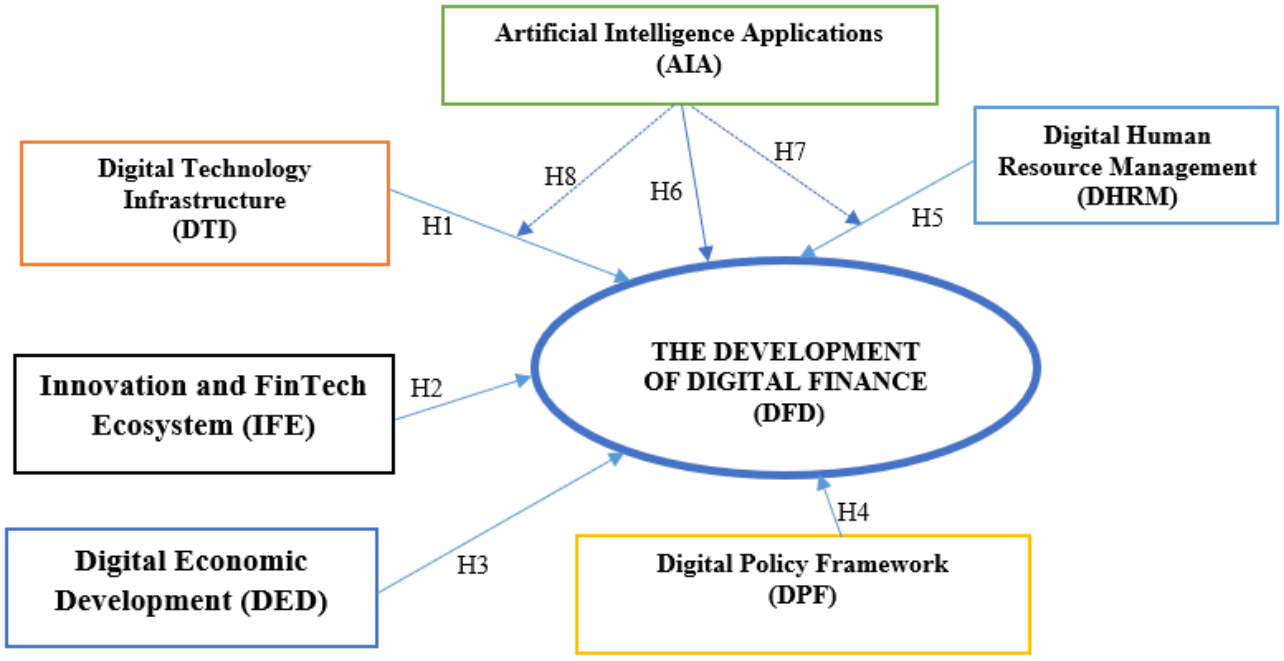

Figure 1. A study model for factors influencing the development of digital finance

Figure 1 presents the proposed research model, which illustrates the key determinants influencing the development of digital finance. The model highlights digital technology infrastructure, innovation, and FinTech ecosystem, digital economic development, digital policy framework, and digital human resource management as direct antecedents. Artificial intelligence applications play a central role, exerting both direct effects and moderating the relationships

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among digital infrastructure, human resources, and the development of digital finance. Artificial intelligence applications enhance human resource effectiveness by supporting data-driven decision-making, automating routine analytical tasks, and enabling human–AI collaboration. For example, AI-assisted credit analytics allows employees to process complex datasets more efficiently, improving service quality and responsiveness. Similarly, AI amplifies the value of digital technology infrastructure by transforming raw digital capabilities into actionable insights through predictive analytics and intelligent automation. Despite extensive research on ICT, infrastructure, and financial development, empirical findings remain mixed, particularly regarding the magnitude and mechanisms of technological effects. Moreover, while AI has been widely examined as a technological innovation, its role as a moderating mechanism within digital finance ecosystems remains underexplored. This gap is particularly evident in emerging economies, where AI may function as a complementary capability, enhancing the value of human capital and digital infrastructure.

3. Methodology and Data

3.1. Research Design

This study employs a mixed-methods research design to comprehensively examine the factors influencing the development of digital finance and the moderating role of artificial intelligence applications. The research design integrates qualitative and quantitative approaches to ensure both theoretical rigor and empirical robustness. Such an approach is particularly appropriate for studies investigating complex digital transformation phenomena that involve technological, human, and institutional dimensions. The qualitative phase was conducted to refine research constructs and ensure content validity of the measurement scales. Subsequently, a large-scale quantitative survey was employed to empirically test the proposed research model and hypotheses. This sequential exploratory design allows qualitative insights to inform quantitative measurement and analysis, thereby enhancing the reliability and validity of the findings.

3.2. Qualitative Phase and Instrument Development

In the qualitative phase, in-depth discussions were conducted with 55 experts specializing in finance, banking, financial technology, and digital transformation. These experts included senior bank managers, FinTech practitioners, policymakers, and academic scholars with extensive experience in digital finance. The objective of this phase was to validate the relevance of the research constructs, refine measurement items, and ensure contextual suitability for the Vietnamese digital banking environment. The expert discussions focused on identifying key dimensions of digital finance development, artificial intelligence applications, and related digital factors. Based on the qualitative findings and prior empirical studies, an initial questionnaire was developed. The questionnaire items were then refined in response to expert feedback to ensure clarity, relevance, and alignment with the research objectives. This process contributed to establishing strong content and face validity of the measurement instrument. Semi-structured interviews were conducted using a predefined protocol focusing on construct relevance, dimensionality, and measurement clarity. Interviews were audio-recorded, transcribed, and analyzed using thematic content analysis. Open coding was first applied to identify emerging themes, followed by axial coding to refine construct dimensions. This iterative process informed the refinement and validation of measurement items.

3.3. Quantitative Data Collection and Sampling

The quantitative phase involved a cross-sectional survey targeting customers who actively use digital banking services in Vietnam. Data were collected both online and offline to maximize coverage and reduce sampling bias. The survey was administered to customers of 20 commercial banks operating in Vietnam, encompassing both state-owned and private institutions. The study focused on five major cities, which represent the most developed digital finance markets in the country. A total of 700 valid responses were obtained; 685 were used for empirical analysis. This sample size exceeds the minimum requirements for Partial Least Squares Structural Equation Modeling (PLS-SEM), ensuring adequate statistical power and robust results. Respondents were required to have prior experience with digital banking services such as mobile banking, internet banking, or digital payment platforms. This criterion ensured that participants possessed sufficient familiarity with digital finance practices to provide reliable responses. A stratified convenience sampling strategy was adopted across 20 commercial banks and five major cities in Vietnam. Respondents were screened to ensure prior experience with digital banking services. To mitigate non-response bias, follow-up reminders and response completeness checks were implemented.

3.4. Measurement of Variables

All constructs in the research model were measured using multi-item scales adapted and refined from prior empirical studies. The questionnaire employed a five-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree"). The use of reflective measurement models was deemed appropriate given the nature of the constructs and the research objectives. The key constructs measured include digital technology infrastructure, the FinTech ecosystem and innovation, digital economic development, a digital policy framework, digital human resource management, artificial intelligence applications, and digital finance development. Measurement items were carefully worded to capture respondents' perceptions of digital finance practices and technological adoption within the banking sector.

3.5. Data Analysis Technique

Partial Least Squares Structural Equation Modeling (PLS-SEM) was employed to analyze the data and test the proposed hypotheses. PLS-SEM is particularly suitable for predictive research models involving multiple latent constructs and moderating effects. It is also appropriate for studies with complex models and non-normal data distributions. The analysis followed a two-stage approach: measurement model assessment and structural model evaluation. In the first stage, internal consistency reliability, convergent validity, and discriminant validity were assessed using established criteria. In the second stage, the structural relationships among constructs were examined using path coefficients, t-statistics, and p-values obtained via bootstrapping. The moderating effects of artificial intelligence applications were tested by incorporating interaction terms into the structural model. Bootstrapping with a large number of subsamples was applied to assess the statistical significance of the moderating relationships. This approach is widely recommended for evaluating moderation effects within the PLS-SEM framework [44].

3.6. Reliability and Validity Assessment

To ensure the robustness of the measurement model, multiple reliability and validity indicators were examined. Internal consistency reliability was evaluated using Cronbach's alpha and composite reliability measures. Convergent validity was assessed through Average Variance Extracted (AVE), while discriminant validity was examined by comparing construct correlations. These assessment procedures align with established methodological guidelines for PLS-SEM research, ensuring that the constructs accurately capture the underlying theoretical concepts and that the empirical results are reliable and valid [44]. The measurement model demonstrates strong reliability and validity. All constructs exhibit Cronbach's alpha and composite reliability values exceeding recommended thresholds, while average variance extracted values are above 0.50. These results confirm internal consistency, convergent validity, and the suitability of the measurement scales for subsequent structural model analysis. By employing a mixed-methods approach and advanced PLS-SEM techniques, this study provides a rigorous methodological framework for examining the development of digital finance in emerging economies. The integration of qualitative expert insights with large-scale quantitative analysis strengthens the credibility of the findings and contributes methodological value to the digital finance and information systems literature. The use of PLS-SEM further enables the simultaneous examination of direct and moderating effects, providing a comprehensive understanding of the role of artificial intelligence in the development of digital finance [44].

4. Empirical Results

4.1. Demographic Characteristics of 685 Valued Respondents

The demographic profile of the 685 respondents indicates that the sample is well-suited to represent customers who actively use digital banking services in major cities in Vietnam. Regarding gender, female respondents constitute a higher proportion of the sample (58.1%), whereas male respondents account for 41.9%. This distribution reflects the increasing participation of women in digital financial services, including mobile banking, digital payments, and personal finance management applications. The result suggests that digital finance has become more inclusive and accessible, attracting a diverse user base across genders rather than being dominated by a single group. In terms of marital status, the majority of respondents are married (61.3%), whereas single individuals constitute 38.7% of the sample. This structure implies that digital banking services are particularly relevant to individuals with family responsibilities, who typically have more complex financial needs related to household expenditures, savings, transfers,

and long-term financial planning. As a result, digital finance platforms play an important role in supporting this group's daily financial management.

With respect to age, the largest proportion of respondents falls within the 35-under-45 age group (52.6%), followed by those aged 25-under-35 (23.1%). Younger users aged 22 to 25 account for only 8.5%, while respondents aged 45 and above account for 15.9%. This age distribution indicates that digital finance adoption is most prevalent among mature working-age individuals who combine stable income levels with sufficient digital literacy. The findings also suggest that digital financial services are no longer limited to younger generations but have gained widespread acceptance among middle-aged users. Concerning average monthly income, a substantial share of respondents report relatively high income levels. Specifically, 37.2% earn more than 25 million VND per month, and 35.6% earn between 20 and 25 million VND. This implies that the sample largely consists of middle- to high-income individuals, who are more likely to adopt and frequently use advanced digital banking and financial services. Finally, regarding the length of service, most respondents have long-term experience with banking services. Those with 10-15 years of experience account for 36.8%, whereas those with more than 15 years account for 35.6%. This indicates that most participants have extensive experience with banking systems, thereby enhancing the demographic distribution. Digital finance usage spans multiple age and income groups, with the largest representation among working-age individuals.

Table 1. Testing of Cronbach's alpha and composite reliability

Factors	Code	Items	Mean	Std. Deviation	Cronbach's alpha	Composite reliability	Average variance extracted
1. Artificial Intelligence Applications	AIA	4	3.125	0.925	0.871	0.909	0.715
2. Digital Economic Development	DED	4	3.154	0.943	0.941	0.958	0.849
3. Development of Digital Finance	DFD	3	3.232	0.956	0.836	0.901	0.752
4. Digital Human Resource Management	DHRM	4	3.326	0.965	0.916	0.941	0.800
5. Digital Policy Framework	DPF	3	3.311	0.927	0.891	0.932	0.822
6. Digital Technology Infrastructure	DTI	4	3.375	0.955	0.936	0.953	0.834
7. Innovation and FinTech Ecosystem	IFE	4	3.235	0.925	0.879	0.903	0.703

Table 1 presents the results of reliability and convergent validity testing for the measurement scales. All constructs exhibit Cronbach's alpha values above the recommended threshold of 0.70, indicating strong internal consistency. Composite reliability values range from 0.901 to 0.958, further confirming the robustness of the measurement model. In addition, the Average Variance Extracted (AVE) values for all constructs exceed 0.50, demonstrating adequate convergent validity. Finally, these results confirm that the measurement scales are reliable and suitable for subsequent structural model analysis. Table 1 provides a comprehensive assessment of the reliability and convergent validity of the measurement scales used in this study, demonstrating that all constructs meet the recommended methodological standards. The Cronbach's alpha values range from 0.836 to 0.941, exceeding the commonly accepted threshold of 0.70, which confirms strong internal consistency among the observed items within each construct. This indicates that the measurement items reliably capture the underlying theoretical concepts. In addition, composite reliability values ranging from 0.901 to 0.958 further reinforce the robustness of the measurement model. These high values suggest that the constructs exhibit substantial shared variance among their indicators, making them particularly suitable for structural equation modeling. The consistency between Cronbach's alpha and composite reliability results strengthens confidence in the overall reliability of the scales.

The AVE values for all constructs are well above the recommended minimum of 0.50, ranging from 0.703 to 0.849. This confirms adequate convergent validity, indicating that each construct accounts for a substantial proportion of the variance in its corresponding indicators. Notably, constructs such as Digital Economic Development, Digital Policy Framework, and Digital Technology Infrastructure demonstrate particularly high AVE values, reflecting strong explanatory power and well-developed measurement items. Furthermore, the mean values of the constructs fall within a moderate-to-high range, suggesting that respondents generally perceive a positive level of digital finance development, digital infrastructure, policy support, human resource readiness, and the application of artificial intelligence in the banking context. The relatively consistent standard deviation values indicate reasonable variability

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in responses, which is desirable for capturing diverse perceptions among respondents. Overall, the results presented in table 1 confirm that the measurement model is both reliable and valid, providing a solid foundation for subsequent structural model analysis and hypothesis testing. Mean values across constructs fall within a moderate range, indicating neither extreme agreement nor disagreement among respondents.

Table 2. Factors affecting the development of digital finance

Factors	Original sample	Sample mean	Standard deviation	T statistics	P values
AIA → DFD	0.085	0.090	0.029	2.881	0.004
AIA x DHRM → DFD	0.090	0.088	0.031	2.941	0.003
AIA x DTI → DFD	0.119	0.114	0.031	3.888	0.000
DED → DFD	0.158	0.157	0.030	5.229	0.000
DHRM → DFD	0.279	0.280	0.038	7.354	0.000
DPF → DFD	0.300	0.300	0.037	8.114	0.000
DTI → DFD	0.057	0.061	0.027	2.094	0.036
IFE → DFD	0.166	0.169	0.047	3.506	0.000

Note: *** with 1%.

Table 2 reports the results of the structural model analysis, identifying the factors influencing the development of digital finance. The findings indicate that all hypothesized relationships are statistically significant, as evidenced by t-statistics exceeding the critical value of 1.96 and p-values < 0.05. This confirms that the proposed research model provides a reliable explanation of the development of digital finance. Among the direct effects, the Digital Policy Framework (DPF) shows the strongest impact on digital finance development, with a path coefficient of 0.300. This result highlights the pivotal role of supportive regulations, clear legal frameworks, and effective governance mechanisms in facilitating the adoption and expansion of digital financial services. Digital Human Resource Management (DHRM) follows closely, exhibiting a substantial positive effect ($\beta = 0.279$). This finding underscores the importance of digital skills, employee competencies, and strategic human resource practices in successfully implementing digital finance initiatives.

The innovation and FinTech ecosystem (IFE) and Digital Economic Development (DED) also demonstrate significant positive effects on the development of digital finance, indicating that a dynamic innovation environment and a digitally driven economy contribute meaningfully to the growth of digital financial services. These factors support increased demand for digital finance and foster collaboration between traditional financial institutions and technology-driven firms. Digital Technology Infrastructure (DTI), although showing a smaller effect size, remains statistically significant, suggesting that technological foundations are necessary conditions but must be complemented by other strategic factors to generate stronger outcomes. Importantly, Artificial Intelligence Applications (AIAs) exhibit both direct positive effects and significant moderating effects. The interaction terms reveal that AI strengthens the influence of digital human resource management and digital technology infrastructure on the development of digital finance. This indicates that AI acts as a catalyst, enhancing the effectiveness of both human capital and technological resources. Overall, the results in Table 2 demonstrate that the development of digital finance is driven by a synergistic combination of policy, human resources, innovation, infrastructure, and artificial intelligence.

This result extends existing AI and digital transformation theories by positioning AI not merely as an innovation tool but as a capability amplifier. The moderation effects indicate that AI strengthens the productivity of human capital by augmenting analytical capacity, automating routine cognitive tasks, and enabling data-driven decision-making. Simultaneously, AI enhances the value of digital infrastructure by converting raw digital resources into predictive insights, intelligent automation, and adaptive financial services. Theoretically, this supports the complementarity perspective of technology, suggesting that AI generates value primarily through interaction effects rather than standalone deployment. AI does not replace human or infrastructural resources but reconfigures and enhances their functional impact. This contributes to socio-technical systems theory by empirically demonstrating how intelligent

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technologies reshape the interplay between human expertise and digital systems. Taken together, the findings suggest that the development of digital finance is best understood as a multidimensional configuration of capabilities rather than a technology adoption process. Sustainable digital transformation requires alignment among: Institutional conditions (DPF), Human capital capabilities (DHRM), Ecosystem dynamics (IFE), Economic digitalization (DED), Technological foundations (DTI), and Intelligent Augmentation Mechanisms (AIA).

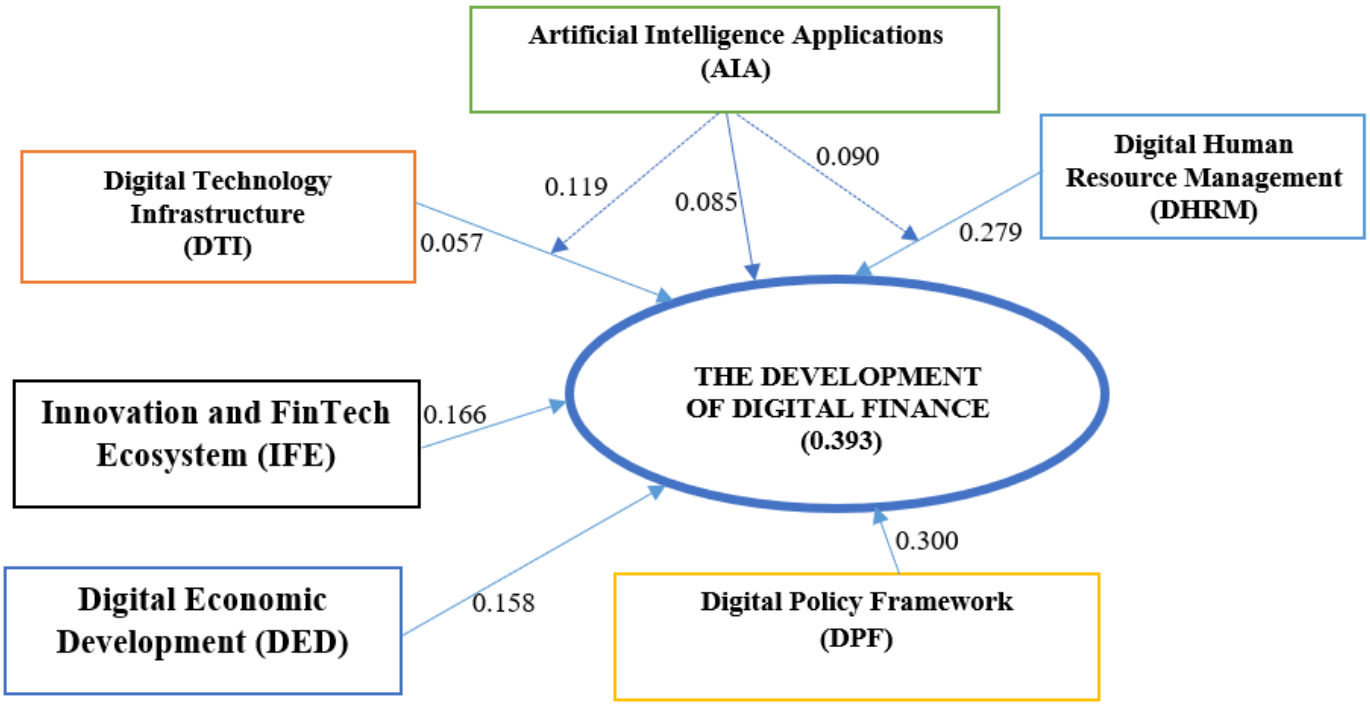

Figure 2. Testing results for factors affecting the development of digital finance

Figure 2 illustrates the results of the PLS-SEM structural model analysis of factors affecting the development of digital finance. The model shows that all hypothesized paths are statistically significant, with the digital policy framework and digital human resource management exerting the strongest direct effects on digital finance development. Artificial intelligence applications not only have a direct positive impact but also significantly moderate the relationships between digital technology infrastructure, digital human resource management, and digital finance development. The model accounts for a substantial proportion of the variance in digital finance development, confirming its strong explanatory power.

4.2. Result Discussion

This study provides comprehensive empirical evidence on the factors influencing the development of digital finance by examining standardized path coefficients and their statistical significance. The results confirm that the development of digital finance is driven by a combination of technological, human, institutional, and innovation-related factors, with artificial intelligence applications playing a central and multifaceted role.

(1) The findings show that the digital policy framework (DPF) has the strongest direct effect on digital finance development ($\beta = 0.300$, $p < 0.001$) (In table 2). This result underscores the decisive role of regulatory clarity, governance mechanisms, and policy support in shaping digital financial systems. In line with methodological recommendations for interpreting PLS-SEM results [15], the magnitude and significance of this coefficient indicate that policy-related factors provide a foundational environment that enables the flourishing of digital finance. Prior studies emphasize that effective digital regulations reduce uncertainty, enhance institutional trust, and support innovation within financial markets [52], [53]. In emerging economies with highly regulated financial systems, a well-designed digital policy framework is a critical prerequisite for the sustainable development of digital finance. The findings reinforce the central role of the Digital Policy Framework (DPF) as the most influential direct determinant of digital finance development. While prior studies have acknowledged the importance of regulatory and institutional

quality, this study refines existing theory by demonstrating that, in digitally transforming financial systems, policy support functions not merely as a background condition but as a strategic enabler of technological value creation. In emerging economies, where financial innovation operates within tightly regulated environments, regulatory clarity and adaptive governance structures reduce uncertainty, legitimize technological experimentation, and foster trust in AI-enabled financial services. This extends institutional and digital governance theories by highlighting that digital policy frameworks actively shape the effectiveness of innovation and technology adoption rather than passively constraining them.

(2) The second strongest determinant is digital human resource management (DHRM), which exhibits a substantial positive impact on digital finance development ($\beta = 0.279$, $p < 0.001$) (In table 2). This finding highlights the importance of skilled human capital in driving digital transformation within financial institutions. Consistent with PLS-SEM best practices [23], the high standardized coefficient suggests that investments in digital skills, training, and talent management significantly enhance banks' ability to deploy and manage digital financial services. This result aligns with existing evidence that the quality of human capital plays a crucial role in mediating the benefits of technological adoption [51]. In the context of digital finance, competent human resources are essential for managing complex systems, interpreting data, and ensuring effective customer engagement. The significant impact of Digital Human Resource Management (DHRM) on human capital and digital transformation research is evident. Existing literature often treats technological investment as the primary driver of digitalization, with human resources playing a supportive role. However, our results indicate that digitally competent human capital constitutes a core mechanism of transformation, directly influencing digital finance outcomes. This finding supports and extends the resource-based view (RBV), suggesting that intangible organizational capabilities, particularly digital skills, adaptive competencies, and strategic talent management, represent critical sources of competitive advantage in digital finance ecosystems. Importantly, DHRM emerges not only as an operational factor but as a strategic capability that mediates the translation of digital technologies into financial service innovation.

(3) Innovation and FinTech ecosystem (IFE) also demonstrates a significant positive effect on digital finance development ($\beta = 0.166$, $p < 0.001$) (In table 2). This result confirms that collaboration between traditional financial institutions and FinTech firms accelerates digital innovation and diversification of services. The presence of a dynamic FinTech ecosystem fosters competition, improves service efficiency, and enhances customer experience. Previous empirical studies highlight that FinTech-driven innovation contributes to financial inclusion and the expansion of digital services, particularly in developing and emerging markets [27], [45], [47]. The moderate effect size observed in this study suggests that while innovation ecosystems are important, their impact is maximized when supported by favorable policies and capable human resources. The positive effects of the innovation and FinTech ecosystem (IFE) provide further theoretical insight into ecosystem and open innovation perspectives. The findings suggest that the development of digital finance is embedded within a broader network of inter-organizational relationships, in which collaboration between banks and FinTech firms accelerates experimentation, service diversification, and customer-centric innovation. This reinforces ecosystem theory by demonstrating that innovation capacity is distributed across actors rather than concentrated within individual institutions. The results imply that digital finance transformation is inherently co-evolutionary, requiring coordinated adaptation among incumbents, startups, and regulators.

(4) Similarly, Digital Economic Development (DED) exerts a significant positive influence on digital finance development ($\beta = 0.158$, $p < 0.001$) (In table 2). This finding indicates that the broader digitalization of economic activities stimulates demand for digital financial services. As digital commerce, online transactions, and platform-based economic activities expand, financial institutions are compelled to offer more advanced and accessible digital finance solutions. This result is consistent with prior evidence showing that digital economic growth and financial development are mutually reinforcing processes [31], [48], [50]. In this regard, digital finance functions not only as a facilitator but also as a beneficiary of digital economic development. The significant role of DED highlights the reciprocal relationship between macro-level digitalization and micro-level financial behavior. The study contributes to digital economy theory by empirically demonstrating that the development of digital finance is demand- and supply-driven. As digital transactions, platform economies, and e-commerce expand, financial institutions must develop more sophisticated digital financial services. This suggests a mutual reinforcement mechanism in which digital economic activities stimulate the adoption of digital finance, which in turn supports further digital economic growth.

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(5) The results further reveal that Digital Technology Infrastructure (DTI) has a positive but relatively modest effect on digital finance development (β = 0.057, p = 0.036) (In table 2). Although statistically significant, the smaller magnitude of this coefficient suggests that infrastructure alone is insufficient to drive substantial digital finance outcomes. This finding is consistent with earlier research indicating that ICT infrastructure represents a necessary but not sufficient condition for financial development [35], [52]. In mature or rapidly developing digital environments, infrastructure may have reached a baseline level, reducing its marginal contribution unless complemented by advanced applications and skilled human capital. Although the path from digital technology infrastructure to digital finance development is statistically significant (β = 0.057), its relatively small magnitude suggests limited practical impact when considered independently. Although DTI exhibits a statistically significant but relatively small direct effect, this finding offers an important theoretical nuance. Rather than contradicting prior ICT–finance literature, the result suggests a threshold or baseline effect: once infrastructure reaches a sufficient level of maturity, its marginal contribution diminishes unless complemented by higher-order capabilities. This aligns with RBV and dynamic capability theory, indicating that infrastructure alone is insufficient to generate sustained value without intelligent mechanisms for its utilization.

(6) Regarding Artificial Intelligence Applications (AIA), the results show a significant direct effect on digital finance development (β = 0.085, p = 0.004) (In table 2). While the effect size is moderate, the statistical significance confirms that AI directly enhances digital financial services. AI-driven tools improve operational efficiency, risk management, and customer personalization, thereby strengthening digital finance performance. This finding aligns with recent methodological and empirical discussions emphasizing the growing role of intelligent technologies in reshaping financial systems [49], [53].

(7) More importantly, this study provides strong evidence for the moderating role of artificial intelligence applications, which represents a key theoretical contribution. The interaction between AI and digital human resource management (AIA × DHRM) has a significant positive effect on digital finance development (β = 0.090, p = 0.003) (In table 2). This result indicates that AI enhances the effectiveness of human capital by enabling data-driven decision-making, intelligent task allocation, and human–AI collaboration. Consistent with prior research, AI does not replace human expertise but augments it, allowing skilled employees to deliver higher-value digital financial services [15], [45], [51]. Similarly, the interaction between AI and digital technology infrastructure (AIA × DTI) shows a strong and significant moderating effect (β = 0.119, p < 0.001) [52], [53]. This finding suggests that AI transforms digital infrastructure from a passive technological resource into an active strategic asset. Without AI-driven analytics and automation, digital infrastructure may remain underutilized, thereby limiting its contribution to the development of digital finance. This result supports existing arguments that intelligent technologies are essential for unlocking the full potential of digital infrastructure investments. Simple slope plots were generated to visualize the moderation effects (In figure 2).

Inclusion, the findings demonstrate that digital finance development is not driven by isolated factors but by the synergistic interaction among policies, human resources, innovation ecosystems, infrastructure, and artificial intelligence. From a methodological perspective, the use of standardized beta coefficients and significance testing in PLS-SEM provides robust evidence supporting the proposed research model [53]. From a practical standpoint, the results suggest that policymakers and banking executives should prioritize AI-enabled strategies that integrate human capital development with intelligent use of digital infrastructure. Finally, this study advances the digital finance literature by empirically confirming that artificial intelligence plays a dual role as both a direct driver and a strategic moderator. By strengthening the effects of human resources and digital infrastructure, AI emerges as a critical catalyst for sustainable digital finance development in emerging economies.

5. Conclusions and Policy Recommendations

5.1. Conclusions

This study investigates the factors influencing the development of digital finance with a particular focus on the role of artificial intelligence applications in an emerging economy context. By integrating technological, human, institutional, and innovation perspectives into a unified research framework, the study provides robust empirical evidence on how the development of digital finance is shaped by both direct effects and interaction mechanisms. Using a mixed-methods

approach and PLS-SEM analysis based on a large sample of digital banking users, the findings offer meaningful theoretical and practical insights. The results confirm that the development of digital finance is driven by multiple interrelated factors rather than by technology alone. Digital policy framework and digital human resource management emerge as the most influential direct determinants, highlighting the critical importance of regulatory support and skilled human capital in facilitating digital financial transformation. Innovation and FinTech ecosystems, along with digital economic development, also play significant roles by stimulating demand for digital financial services and fostering collaboration between traditional financial institutions and technology-oriented firms. Although digital technology infrastructure has a smaller direct effect, it remains a necessary foundational element for the development of digital finance. Most importantly, the study demonstrates the central role of artificial intelligence applications. AI not only has a direct positive impact on the development of digital finance but also serves as a strategic moderator, strengthening the effects of digital human resource management and digital technology infrastructure. These findings suggest that artificial intelligence enhances the effectiveness of both human and technological resources by enabling intelligent decision-making, automation, and advanced data analytics. As a result, AI transforms existing digital capabilities into higher-value financial outcomes. Overall, this study contributes to the growing literature on digital finance by empirically validating the dual role of artificial intelligence as both a driver and a catalyst of digital finance development. The findings underscore that sustainable growth in digital finance requires an integrated strategy that aligns policy frameworks, human capital development, innovation ecosystems, digital infrastructure, and intelligent technologies. Such an approach is particularly relevant for emerging economies seeking to accelerate digital transformation in the financial sector while ensuring long-term stability and inclusiveness. This study provides three key contributions. Empirically, it identifies the dominant drivers of the development of digital finance. Theoretically, it clarifies AI's dual role. Practically, it offers policy and managerial implications.

5.2. Policy Recommendations

Based on the standardized beta coefficients and statistical significance of the empirical results, this study proposes policy recommendations to promote the development of digital finance. The recommendations are structured according to the relative strength of the estimated effects, ensuring that policy actions focus on the most influential drivers first.

(1) Strengthening the digital policy framework should be the top priority, as this factor exhibits the highest standardized effect on digital finance development ($\beta = 0.300$, $p < 0.001$) (In table 2). Policymakers should continue to refine legal and regulatory frameworks governing digital banking, data protection, cybersecurity, and the governance of artificial intelligence. Clear and consistent regulations reduce uncertainty for financial institutions, encourage innovation, and build user trust in digital financial services. In particular, regulatory sandboxes and adaptive policy mechanisms should be expanded to support experimentation with AI-driven financial solutions while maintaining systemic stability. The strong impact of the digital policy framework implies that policymakers play a decisive role in shaping the development of digital finance. In practice, governments and financial regulators should prioritize establishing clear, transparent, and adaptable regulatory frameworks for digital banking, FinTech, and artificial intelligence. Regulatory uncertainty often discourages financial institutions from investing in advanced digital solutions. Therefore, policies related to data protection, cybersecurity, AI ethics, and consumer rights should be continually updated to keep pace with technological progress. The implementation of regulatory sandboxes is particularly important, as it allows banks and FinTech firms to test innovative digital financial products under controlled conditions. In addition, harmonizing digital finance regulations across institutions can reduce compliance costs and promote interoperability. A strong, coherent digital policy framework will not only enhance user trust but also create a stable environment that encourages long-term investment in digital finance.

(2) Investing in digital human resource management is essential, given its strong positive impact ($\beta = 0.279$, $p < 0.001$) (In table 2). Governments and financial regulators should collaborate with banks and educational institutions to develop digital skills training programs focusing on data analytics, AI applications, and digital risk management. Incentive mechanisms should be introduced to attract and retain high-quality digital talent in the financial sector, ensuring that technological investments are effectively translated into improved digital finance outcomes. The significant effect of digital human resource management highlights that people remain at the core of digital finance transformation. For practitioners, this implies that banks should move beyond traditional HR practices and adopt strategic approaches to developing digital talent. Financial institutions should invest in continuous training programs focusing on data

analytics, artificial intelligence applications, cybersecurity, and digital risk management. Recruitment strategies should prioritize digital competencies and adaptability rather than solely relying on conventional banking experience. Moreover, performance evaluation and incentive systems should be aligned with digital innovation goals to encourage employees to actively engage in digital finance initiatives. From a managerial perspective, fostering a culture of continuous learning and innovation is essential. By strengthening digital human resource management, banks can ensure that technological investments are effectively utilized and translated into improved digital finance services and customer experiences.

(3) Promoting innovation and the FinTech ecosystem should be prioritized ($\beta = 0.166$, $p < 0.001$) (In table 2). Policymakers should foster closer collaboration between traditional banks and FinTech firms through open banking initiatives, innovation hubs, and public–private partnerships. Supporting startup ecosystems and improving access to funding for FinTech enterprises will further accelerate digital finance innovation and diversification of services. The positive role of the innovation and FinTech ecosystem suggests that collaboration is critical for advancing digital finance. In practice, banks should actively engage with FinTech startups through partnerships, joint ventures, and open banking platforms. Such collaboration allows traditional financial institutions to leverage innovative technologies and agile business models developed by FinTech firms. Policymakers can support this process by establishing innovation hubs, incubators, and funding mechanisms that facilitate knowledge sharing and experimentation. Encouraging interoperability between banking systems and FinTech platforms can further enhance service diversity and accessibility. For practitioners, participating in a vibrant FinTech ecosystem enables faster innovation cycles and improves competitiveness in the digital finance market. Ultimately, a well-developed innovation ecosystem helps financial institutions respond more effectively to changing customer needs and technological advancements.

(4) Supporting digital economic development remains important ($\beta = 0.158$, $p < 0.001$) (In table 2). Policies that encourage e-commerce, digital platforms, and cashless payments will indirectly stimulate demand for digital financial services, creating a virtuous cycle between the digital economy and digital finance. The findings indicate that the development of digital finance is closely linked to the broader digital economy. From a practical standpoint, governments should promote digital economic activities such as e-commerce, digital platforms, and cashless payment systems to stimulate demand for digital financial services. Investments in digital entrepreneurship and digital literacy programs can further enhance user readiness and acceptance of digital finance. For financial institutions, aligning digital finance products with digital economic activities, such as providing tailored payment solutions for online businesses or financing digital startups, can create new growth opportunities. The integration of digital finance into the digital economy supports a virtuous cycle in which increased digital transactions drive financial innovation, and improved financial services further accelerate digital economic development.

(5) Although digital technology infrastructure has a smaller direct effect ($\beta = 0.057$, $p < 0.05$) (In table 2), it should not be neglected. Infrastructure investments should be strategically integrated with the adoption of artificial intelligence, as AI significantly enhances the effectiveness of both infrastructure and human resources. Therefore, policymakers should prioritize AI-enabled strategies that integrate infrastructure development with intelligent analytics and automation to maximize the development of digital finance. Although digital technology infrastructure has a relatively smaller direct effect, it remains a fundamental prerequisite for digital finance. In practice, banks and policymakers should ensure sustained investment in secure, scalable, and interoperable digital infrastructure, including core banking systems, cloud computing, and network connectivity. However, infrastructure investments should be strategic rather than purely quantitative. Financial institutions should focus on upgrading systems that support real-time processing, data integration, and system flexibility. Importantly, infrastructure development should be integrated with advanced applications such as artificial intelligence and data analytics to maximize its value. Without intelligent utilization, infrastructure may remain underexploited. Therefore, practitioners should adopt a holistic approach that combines infrastructure development with innovation and capability building.

(6) Artificial Intelligence Applications (AIA): The results emphasize that artificial intelligence is both a direct driver and a catalyst for digital finance development. In practice, banks should prioritize the adoption of AI applications across credit assessment, fraud detection, customer service, and personalized financial products. AI enables more accurate decision-making, operational efficiency, and enhanced customer experience. However, successful AI implementation requires more than investment in technology; it demands organizational readiness and ethical

governance. Financial institutions should establish clear AI governance frameworks to address data privacy, transparency, and algorithmic bias. From a strategic perspective, integrating AI with human expertise and digital infrastructure enables banks to realize greater value from existing resources. Consequently, AI should be positioned as a core component of long-term digital finance strategies rather than as a standalone technological tool. Finally, these prioritized policy recommendations emphasize that the development of digital finance requires a coordinated approach, with regulatory readiness, human capital, innovation, and artificial intelligence at the core of sustainable implementation.

Limitations and future research: Despite its theoretical and empirical contributions, this study has several limitations that offer opportunities for future research. (1) The data were collected using a cross-sectional design, which limits the ability to capture dynamic changes in digital finance development and artificial intelligence adoption over time. Future studies could employ longitudinal data to examine causal relationships and the long-term impacts of AI on digital finance transformation. (2) The sample focuses on customers of commercial banks in major cities, which may not fully represent rural areas or less digitally developed regions. Subsequent research could extend the analysis to include diverse geographic contexts or compare urban and rural populations to provide a more comprehensive understanding of digital finance adoption. (3) Although this study incorporates key technological, human, and institutional factors, other relevant variables such as organizational culture, customer trust, or ethical concerns related to AI were not explicitly examined. Future research could integrate these factors to enrich the analytical framework. (4) Comparative studies across countries or regions would help assess the generalizability of the findings and explore how different institutional environments influence the role of artificial intelligence in digital finance development.

6. Declarations

6.1. Author Contributions

Conceptualization: T.T.P. and H.C.T.; Methodology: H.C.T.; Software: T.T.P.; Validation: T.T.P. and H.C.T.; Formal Analysis: T.T.P. and H.C.T.; Investigation: T.T.P.; Resources: H.C.T.; Data Curation: H.C.T.; Writing Original Draft Preparation: T.T.P. and H.C.T.; Writing Review and Editing: T.T.P. and H.C.T.; Visualization: T.T.P.; All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available from the corresponding author upon request.

6.3. Funding

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6.4. Institutional Review Board Statement

Not applicable.

6.5. Informed Consent Statement

Not applicable.

6.6. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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