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An integrated analysis of technology adoption, demographic moderators, and financial inclusion across generations in Egypt

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Abstract

This study examines the determinants of digital payment adoption across generational cohorts in Egypt, with particular attention to the interaction between digital transformation, technology acceptance constructs, and demographic moderators within Egypt's rapidly evolving fintech ecosystem. Adopting a pragmatic mixed-methods design, the research integrates quantitative and qualitative approaches to capture both behavioural patterns and contextual explanations. Quantitatively, survey data collected from 406 Egyptians aged 18–75 (81.3% male, 18.7% female) were analyzed using structural equation modeling to test an integrated framework combining UTAUT2, the Technology Acceptance Model (PTS), and generational theory. The quantitative findings reveal that Effort Expectancy (β = 0.318) and Generational membership (β = 0.327) are the most influential predictors of digital payment usage. Generational effects significantly moderate adoption pathways, with Generation negatively moderating Facilitating Conditions (β = −0.139) and positively moderating Social Influence (β = 0.131), indicating distinct mechanisms of adoption across age groups. While the sample includes both genders, the analysis focuses primarily on generational dynamics to inform inclusive digital policy. This study provides the first empirical evidence of generational moderation effects in Egyptian fintech adoption and demonstrates that digital payment diffusion requires age-sensitive, culturally grounded, and usability-focused interventions to advance financial inclusion and economic empowerment across all segments of society.

Keywords Digital payments, Fintech adoption, Technology acceptance model, Generational cohorts, Egypt

Introduction

Digital transformation has emerged as a critical driver reshaping how organizations operate, innovate, and engage with customers across global economies. The adoption of technology by organizations for productivity growth, enhanced customer experiences, and innovative goals throughout the economy defines digital transformation's impact on organizational operations. Vial [24] defines digital transformation as the method businesses use to embed digital technologies throughout all operations for generating substantial alterations in operational and strategic processes alongside stakeholder connections. Cloud computing and artificial intelligence, along with big data analytics and Internet of Things (IoT) solutions, have pushed industries towards this paradigm change. Businesses now benefit from automated operational efficiency, which enables them to deliver customized services at scale.

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The financial industry stands as one of the most noticeable sectors affected by digital transformation, as payment systems have urgently adapted to serve customers in the all-digital economy. However, digital transformation represents more than technological modernization; it serves as an organizational strategy that transforms cultural values and customer demands while reshaping industry competitive environments [29]. This broader perspective recognizes that successful transformation requires changes not only in technology infrastructure but also in organizational culture, business models, and strategic market approaches.

Digital payment platforms have transformed the payment ecosystem after replacing traditional cash-based systems, thus becoming essential components of digital transformation programmes. Modern payment methods, including mobile payments, contactless technology, and blockchain-based solutions, have revolutionized the value trading process by providing users with increased speed, security, and expanded accessibility according to Nakamoto and Bitcoin [19]. The contemporary landscape encompasses diverse solutions wherein digital payment systems including Apple Pay and Google Pay have joined peer-to-peer payment networks like Venmo and PayPal to create financial technology solutions that enable business and consumer transactions across international borders without friction.

Real-time payment systems represent, particularly, significant innovations in advancing financial accessibility. The implementation of real-time payment systems, such as the Unified Payments Interface (UPI) in India, is a prime example of how digital infrastructure may be used to propel financial inclusion and economic growth [35]. By enabling instant, interoperable digital transactions, such systems have successfully integrated millions of previously unbanked individuals into formal financial networks.

Nevertheless, this transformation introduces significant challenges, including cybersecurity vulnerabilities, complex regulatory landscapes, and the need for interoperable standards to ensure global scalability [4]. Cybersecurity threats persistently endanger user security and system reliability, while regulatory frameworks often lag behind rapid technological advances. Despite these hurdles, the payment industry continues to play a vital role in economic development by bridging the gap between technological innovation and practical application [21].

Egypt has emerged as an active participant in this global shift, as digital transformation has become a fundamental driver of economic change worldwide. As noted by Vial [24], Egyptian organizations are enhancing operational efficiency, customer engagement, and innovation through advanced technologies such as cloud computing, artificial intelligence, and big data analytics. This shift extends beyond mere technological adoption,it also reshapes cultural and strategic frameworks, aligning with Egypt's [10], which prioritizes digital inclusion and economic modernization.

The financial sector, in particular, is undergoing profound transformation, propelled by both governmental initiatives and private-sector innovation [20]. Payment systems lie at the heart of this evolution, functioning as essential infrastructure for broader economic digitization. Egypt's ongoing efforts to upgrade digital infrastructure, promote financial inclusion, and reduce dependence on cash transactions underscore its commitment to digital transformation [30]. These coordinated actions reflect a comprehensive national strategy to establish Egypt as a competitive force in the global digital economy.

Modern digital changes have substantially advanced the payment system infrastructure within Egypt. The Central Bank of Egypt (CBE) leads the development of both the Instant Payment Network (IPN) and Meeza digital system, which push payment methods from traditional cash-centric systems to modern accessible digital platforms [18]. These projects allow participants to conduct real-time transactions through their mobile wallets, thus driving financial inclusion for both urban and rural areas [13].

The Egyptian fintech ecosystem has experienced remarkable growth in recent years. Fintech solutions Fawry and Paymob, together with mobile wallets like Vodafone Cash, have experienced rising popularity throughout the last several years. The payment solutions offer various streamlined transaction types for e-commerce, peer-to-peer transfers, and bill payments [34]. These platforms have collectively enhanced the accessibility and convenience of digital financial services for Egyptian consumers. However, the progression of fintech solutions faces limitations from digital illiteracy in rural area coupled with concerns about cybersecurity safety. The percentage of Egyptians showing trust in digital banking institutions stands at only 28 per cent [33]. This low confidence level represents a significant barrier to achieving widespread adoption of digital payment solutions and highlights the need for enhanced consumer education and security measures.

Despite these challenges, Egypt's payment landscape continues to evolve, driven by robust regulatory support and a growing tech-savvy population. This trajectory positions Egypt as a regional leader in the digital economy of the Middle East and North Africa [1]. The synergy between governmental initiatives, private-sector innovation, and rising digital literacy fosters a conducive environment for sustained advancement [22]. Nevertheless, digital payment systems in Egypt confront significant

barriers that impede financial inclusion across age groups and geographic regions. Platform developers such as Fawry and Telda face multifaceted obstacles, including low digital literacy among older adults, inadequate rural internet connectivity—affecting approximately 57% of the population—and cultural hesitance towards non-cash payment methods [15, 16]. Security concerns further inhibit adoption, with about 55% of senior citizens expressing fraud-related apprehensions [25]. Compounding these issues are persistent gender gaps in technology access: smartphone ownership stands at 35% for women compared to 55% for men [7]. Together, these age- and gender-based digital divides intensify the challenges of achieving widespread and equitable digital payment adoption.

While gender disparities in digital access are well-documented, this study focuses primarily on generational divides as a critical yet understudied dimension of digital inclusion in Egypt. Generational membership—shaped by differing exposures to technological, economic, and social transformations—may exert a more profound influence on adoption behaviour than gender alone, particularly in a society undergoing rapid digital transition. By examining how adoption pathways differ across Generation Z, Millennials, Generation X, and Baby Boomers, this research aims to provide actionable insights for designing age-sensitive digital policies that can bridge the adoption gap.

Modern technology implementation faces challenges from multiple barriers, which establish disjointed adoption patterns requiring special intervention methods to unite different age groups, geographical areas, and cultural beliefs in order to achieve digital transformation fairness [18]. Addressing these multifaceted obstacles necessitates comprehensive strategies that account for demographic diversity, infrastructure limitations, and cultural contexts. Only through such targeted approaches can Egypt realize equitable digital financial inclusion across its entire population, ensuring that the benefits of digital transformation reach all segments of society regardless of age, gender, geographic location, or socio-economic status.

While Egypt's digital transformation operates at a national and organizational level, this study focuses on individual adoption behaviour as a micro-foundation of that macro-level change, examining how generational and perceptual factors shape uptake.

Accordingly, this study seeks to answer the following research questions: What are the key determinants of digital payment adoption across generational cohorts in Egypt?

How does generational membership moderate the relationships between technology acceptance constructs and adoption behaviour? What role do perceived trust and security (extended PTS constructs) play in shaping adoption across different age groups?

By integrating UTAUT2, PTS, and generational theory within a mixed-methods framework, this study offers a nuanced understanding of adoption dynamics in Egypt's evolving fintech landscape, with implications for policy, practice, and future research on inclusive digital finance.

Literature review

The imperative for digital transformation

The global business environment has undergone substantial transformation driven by rapid technological advancement, including artificial intelligence (AI), cloud computing, big data analytics, and the Internet of Things (IoT). Organizations must adapt to these shifts to maintain competitive advantage. Research indicates that companies successfully executing digital transformation achieve significantly stronger financial performance [17]. Furthermore, contemporary customer expectations for personalized, seamless services have accelerated digital initiatives, a trend reinforced during the COVID-19 pandemic when 77% of executives reported accelerating their digital transformation plans [9].

Key components of digital transformation

Successful digital transformation involves multiple interconnected components. Process optimization, often achieved through automation and agile methodologies, streamlines operations and reduces inefficiencies [29]. Equally critical is cultural transformation, which requires leadership to foster innovation, collaboration, and continuous learning. Finally, customer-centric innovation involves leveraging digital tools to enhance user experience and engagement, a principle central to fintech adoption [5].

Benefits of digital transformation

Digital transformation generates numerous benefits that optimize business operations, enhance customer connections, and drive revenue expansion. Operational efficiency improves as automated systems perform repetitive tasks while data analytics facilitates superior decision-making. Research from IDC demonstrates that enterprises embracing digital initiatives can reduce operational expenses by 30% by 2025. Digital transformation enhances customer engagement through personalized, seamless interactions. Netflix's recommendation algorithm employs machine learning to power 80% of content viewing decisions, demonstrating how digital instruments enhance customer experience [14]. Technological advancement enables organizations to pioneer innovative business models generating new revenue streams.

Tesla's over-the-air software updates and feature releases exemplify how digital transformation facilitates innovative business model discovery [24]. Organizational agility becomes enhanced through digital transformation, enabling businesses to respond rapidly to market fluctuations. Target and other retailers utilized their digital infrastructures to transition sales online as physical stores closed during the 2020 pandemic [11], demonstrating how organizations implementing these benefits establish advantageous positions during market disruptions in dynamic business scenarios.

Fintech adoption in Egypt and the MENA context

Within the broader digital transformation landscape, financial technology (fintech) adoption presents unique challenges and opportunities in emerging economies. In Egypt, fintech growth is propelled by national initiatives such as the Central Bank of Egypt's Meeza digital system and the Instant Payment Network (IPN), alongside private-sector platforms like Fawry and Paymob [6, 18]. These systems aim to reduce cash dependency and advance financial inclusion, a key pillar of Egypt's [10]. However, adoption remains uneven. Significant barriers include low digital literacy in rural areas, cybersecurity concerns—with only 28% of Egyptians expressing trust in digital banking —and pronounced generational divides. Older cohorts report higher fraud anxiety and lower usage rates, whereas younger, digitally native Egyptians demonstrate greater adoption willingness [15, 25]. Gender disparities further complicate this picture,women's smartphone ownership stands at 35%, compared to 55% for men [7], limiting their access to digital payment platforms.

Previous studies in Egypt have examined mobile payment adoption using TAM and UTAUT2 (e.g. [2, 12]), yet few have integrated generational theory to explain how adoption mechanisms differ across age groups. This study addresses that gap by investigating how generational membership moderates technology acceptance pathways within Egypt's evolving fintech ecosystem. Therefore, the suggested hypotheses and models are as follows, see Fig. 1:

Research model

Research hypothesis H1: Digital transformation has a positive significant effect on User Behaviour.

H2: Generation moderates the relationship between Digital transformation and User Behaviour.

H3: Perceived Trust and Security (PTS) moderates the relationship between Digital transformation and User Behaviour.

The PTS construct extends TAM to include trust and security perceptions, moderating the relationship between digital infrastructure and user behaviour.

The study's conceptual framework establishes a clear causal relationship where Digital Transformation serves

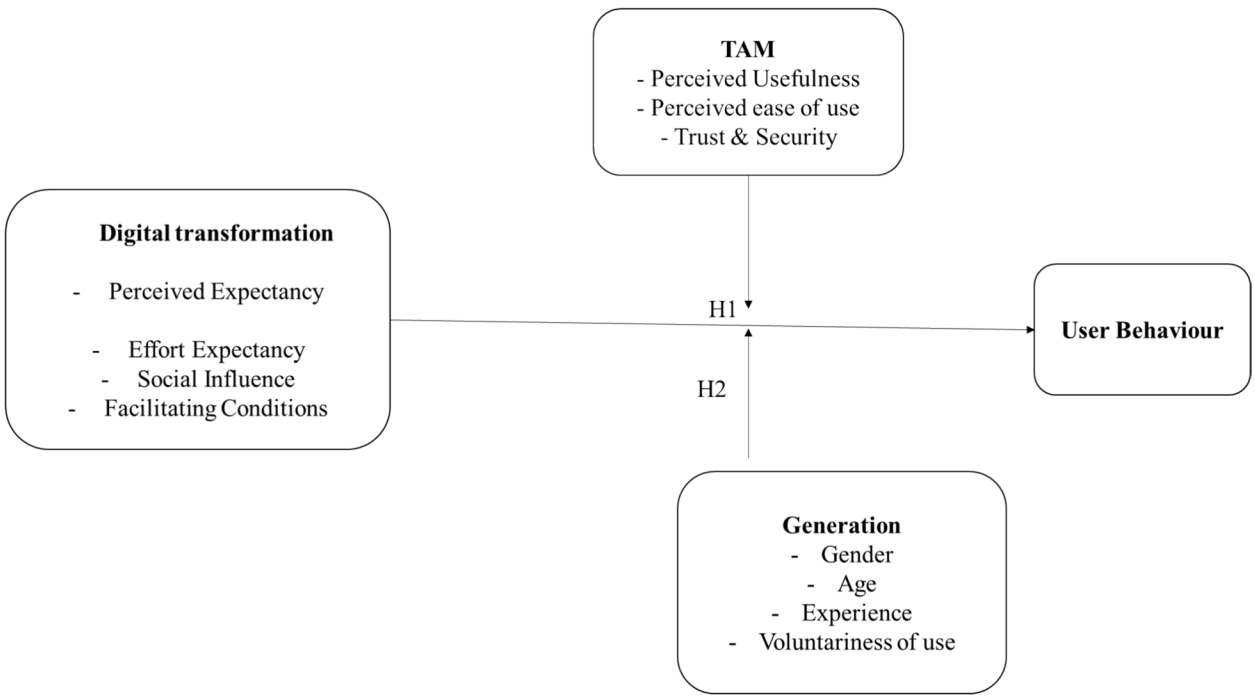

Fig. 1 Conceptual framework. Source Developed by the researchers

as the independent variable, defined as the integration of digital payment technologies such as mobile wallets and contactless payments in Egypt, primarily driven by Central Bank of Egypt (CBE) initiatives like Meeza and Fawry that are fundamentally transforming the national payment ecosystem. User Behaviour functions as the dependent variable, operationalized as the actual adoption and usage patterns of digital payments including frequency and comfort levels, representing the measurable outcome that reflects the real-world success of Perceptions of digital payment adoption as captured through the structured questionnaire. The PTS operates as a mediating variable, encompassing users' perceived usefulness and ease of use of digital payment technologies, which explains the psychological mechanisms through which digital transformation initiatives influence user behaviour outcomes. This mediating role is theoretically justified by PTS's established validity as a framework for understanding technology adoption processes since Davis's [8] seminal work, providing the explanatory bridge between macro-level digital transformation efforts and individual-level behavioural responses. The framework thus captures both the structural changes occurring in Egypt's financial infrastructure and the cognitive processes that determine whether these technological advances translate into actual user adoption and sustained usage patterns among the target population of Egyptian women.

Qualitative analysis: thematic and sentiment findings

To complement the quantitative results, a qualitative analysis was conducted using semi-structured interviews with three purposefully selected Egyptian women representing distinct generational and geographic backgrounds. Transcripts were analyzed through thematic and sentiment analysis in Atlas.ti to identify recurring themes and emotional tones.

Sentiment analysis results

The sentiment classification of 36 coded responses revealed a predominantly positive outlook towards digital payment adoption, though significant concerns persist.

Sentiment classification of the 36 coded responses showed a generally positive outlook towards digital payment adoption, though notable concerns remained. Of the total responses, 69.4% (25 responses) were positive, while 30.6% (11 responses) were negative, see Table 1. This distribution suggests that while digital payments are largely perceived as beneficial, a significant portion of users—nearly one-third—expressed reservations related to usability, trust, and infrastructure.

Positive responses centred around four key themes. First, convenience and time-saving were emphasized, especially by younger participants, with one 24-year-old urban respondent noting, "Paying with my phone takes seconds. I don't need to carry cash or wait for change." Second, several women described digital wallets as enhancing financial autonomy and household management, as captured by a 34-year-old who shared, "I can track every expense now. It gives me control and helps me plan." Third, digital payments were viewed as markers of social status and modernity, with one 28-year-old stating, "When my friends use Vodafone Cash, I feel I should too—it's the new normal." Fourth, trust was often anchored in platforms endorsed by national institutions, with a 41-year-old participant remarking, "I trust Fawry because it's everywhere and linked to the bank."

Table 1 Sentiment analysis results of interview responses

Sentiment category	Number of responses	Percentage of total responses
Positive sentiment	25	69.4%
Negative sentiment	11	30.6%
Total	36	100%

Negative themes were particularly pronounced among older and rural participants. Security anxiety and fear of fraud were recurrent, exemplified by a 65-year-old who said, "I heard stories of accounts being emptied. Cash feels safer in my hand." Usability challenges and cognitive overload were also common, with a 58-year-old rural participant explaining, "Too many steps, too many passwords. I get lost and give up." Cultural attachment to cash was another barrier, articulated by a 70-year-old: "Cash is real. You see it, you feel it. Digital numbers on a screen don't feel like real money." Lastly, infrastructural issues such as unreliable internet were cited, as noted by a 50-year-old from rural Upper Egypt: "The network disappears just when you need to pay. Then what?".

Intergenerational differences were evident in the responses. Younger women (ages 18–35) framed digital payments in terms of convenience, social integration, and modernity, with barriers often perceived as minor or technical. In contrast, older women (ages 50+) approached adoption through concerns over security, familiarity, and cultural preservation, with barriers described as more profound and existential. These qualitative findings help explain key quantitative results. The strong effect of effort expectancy in the structural model aligns with frequent mentions of usability challenges among older users. The moderating role of generational membership is reflected in the divergent narratives between younger and older participants. Moreover, the expressed trust deficits support the relevance of the Perceived Technology Sophistication framework, which

integrates institutional trust and social legitimacy beyond conventional constructs.

Together, the mixed-methods approach underscores that digital payment adoption in Egypt is not solely a technical or economic issue, but a socio-cultural transition shaped by age, trust, infrastructure, and deeply rooted financial behaviours.

Method

Research design and philosophical approach

The study is grounded in pragmatism, which prioritizes methodological flexibility and the practical resolution of complex research problems. Accordingly, an explanatory sequential mixed-methods design is adopted, beginning with a quantitative phase to test hypothesized relationships, followed by a qualitative phase to contextualize and explain the quantitative findings. The quantitative component utilizes a cross-sectional survey design to capture current digital payment adoption behaviours among Egyptian women at a single point in time. This design is appropriate for examining generational and geographic differences and for testing moderation effects within a large, geographically dispersed population in a cost-effective and time-efficient manner.

Target population and sampling strategy

The target population consists of Egyptian women aged 18–75 years with access to smartphones and residing in both urban and rural areas across Egypt's 27 governorates. This population was selected in response to the documented gender gap in fintech usage, where women remain underrepresented in digital financial services. A stratified random sampling technique was employed using age cohort and geographic location as stratification variables. Participants were categorized into four generational cohorts—Generation Z (18–26), Millennials (27–42), Generation X (43–58), and Baby Boomers (59–75)—with proportional representation from urban (40%) and rural (60%) areas to reflect Egypt's population distribution. Participants falling outside these predefined generational ranges were excluded from the analysis to maintain cohort integrity.

The quantitative sample size comprised 400 participants, determined using G*Power with an effect size of 0.15, a 0.05 significance level, and 0.80 statistical power, suitable for structural equation modeling. Each age cohort included 100 participants, ensuring sufficient representation of rural and older women, groups often underrepresented in fintech research.

Theoretical justification for age cohorts

The selected age range is theoretically grounded in Mannheim's Generational Theory, which posits that shared historical and social experiences shape generational values and behaviours. The study captures digital natives, adapters, and immigrants within the Egyptian context, reflecting differing exposures to technological and economic transformations. The lower age limit aligns with legal and financial independence, while the upper limit ensures inclusion of economically active and recently retired women, enabling analysis of long-term financial behaviour patterns.

Modeling generational cohorts as a latent construct

In this study, *Generation* is operationalized not merely as a categorical demographic variable, but as a formative latent construct that captures the shared technological exposure, experiential learning, and voluntariness of use characteristic of distinct age cohorts. This approach aligns with Mannheim's conceptualization of generations as social units shaped by collective historical experiences, rather than simple age brackets. The construct is measured reflectively through four indicators:

- *Exp1 and Exp2* Represent lifetime exposure to digital and financial technologies.
- *VU1 and VU2* Capture the degree of voluntariness in technology adoption, reflecting cohort-specific autonomy and resistance.

This modeling choice allows *Generation* to function as both a predictor and a moderator within the structural model, enabling a nuanced analysis of how cohort-based dispositions—not just chronological age—influence adoption pathways. For robustness, a Multi-Group Analysis (MGA) was also conducted treating generation as a categorical moderator, with results consistent with the latent-variable approach (see Appendix B).

In addition to the four primary generational cohorts, a small subgroup of Emergent Adults (aged 18–21, born 2003–2006) was included to explore the digital payment behaviours of Egypt's youngest legally independent adults. While this group is sometimes colloquially referred to as 'Generation A' or 'Alpha,' their inclusion here is not based on strict generational boundaries but rather on their status as post-Gen Z digital natives entering the financial ecosystem. This exploratory inclusion allows for preliminary insights into whether adoption patterns among the very young differ meaningfully from those in late Gen Z.

Data collection methods

Quantitative data were collected using a structured questionnaire administered through face-to-face interviews by trained field researchers. This method was selected to address digital literacy limitations and uneven

internet access, particularly in rural areas. The questionnaire measured constructs derived from UTAUT2 and PTS using 5-point Likert scales. Data collection was conducted between March and May 2024, by a trained research team following standardized ethical and procedural guidelines to ensure data quality and cultural sensitivity. To assess common method bias, Harman's single-factor test was conducted, revealing that the first factor accounted for 38.6% of the variance (< 50%), indicating common method bias is not a major concern.

Data analysis

Descriptive analysis

Descriptive analysis provides an objective summary of the sample and variables, serving as a crucial first step in understanding the dataset. This process forms the foundation for producing reliable statistical results and employs a wide range of techniques to inspect the data's core characteristics.

The demographic profile of the sample, comprising 406 respondents, reveals a predominantly male and youth-oriented composition. The sample is heavily skewed, with males representing 81.3% of participants, a significant imbalance that limits the generalizability of the findings across genders and suggests the results will largely reflect male perspectives. In terms of generational distribution, the cohort is largely composed of younger generations, with Millennials (43.3%) and Generation Z (28.6%) together forming over 71% of the sample, indicating that the study's outcomes will be strongly influenced by the attitudes and experiences of these younger groups, see Table 2. Meanwhile, Generation X is substantially represented at 24.6%, while the presence of Generation Alpha is minimal. This demographic structure is a critical characteristic that must be considered when interpreting the study's results. The Generation construct was modelled as a latent variable reflecting cohort-based technological socialization. All indicators loaded strongly (> 0.85), supporting its internal consistency and theoretical coherence.

Table 2 Frequency table for demographics of the sample. Source Calculations based on 406 respondents using SPSS 26

Variables	Categories	Frequency	Percentage
Gender	Male	330	81.3%
	Female	76	18.7%
Generation	Generation X (1965 – 1980)	100	24.6%
	Millennials (1981 – 1996)	176	43.3%
	Generation Z (1997 – 2012)	116	28.6%
	Emergent Adults (2013–2024)	14	3.5%

Upon evaluating the dependability of the dimensions, it was noticed that all measures of Cronbach's alpha exceeded 0.7 (Cheung et al. 2023), indicating a high level of internal consistency. In contrast, all dimensions demonstrated a composite reliability above 0.7 and an average variance extracted above 0.5 [31], confirming their validity, see Table 3. Given that the Variance Inflation Factors (VIFs) are below five, it can be inferred that multicollinearity does not pose a problem in the model [31]. Furthermore, all item loadings surpassed 0.5, underscoring the significance of the statements (Cheung et al. 2023).

To further assess discriminant validity, the Heterotrait–Monotrait (HTMT) ratio was calculated. All HTMT values were below the conservative threshold of 0.90, supporting discriminant validity despite high inter-construct correlations (see Appendix A, Table 9).

The Fornell–Larcker Criterion table assesses discriminant validity, which confirms that each variable in the model is truly distinct and not simply a reflection of another. This is verified by comparing the square root of the Average Variance Extracted (AVE) to the correlations between constructs that are the off-diagonal values. A model has good discriminant validity if the diagonal value for each construct is greater than its correlations with any other construct. In this table, while the AVE values (all above 0.82) are strong, indicating good convergent validity, there is a serious issue with discriminant validity. For instance, the correlation between Effort Expectancy and Performance Expectancy (0.794) is higher than the square root of the AVE for Performance Expectancy (0.856), which violates the criterion. This pattern is repeated across several constructs like Social Influence, Facilitating Conditions, and User Behaviour, which all show inter-correlations above 0.70. This suggests that these constructs, despite having different names, are measuring highly overlapping concepts in the eyes of the respondents and are not statistically distinct. The only clear exception is the "PTS" construct, which shows near-zero correlations with all others, confirming it is a unique dimension, see Table 4.

Model building

The structural equation model is effectively used when the study involves latent factors that are measured by observed statements. Structural equation model allows for the simultaneous analysis of multiple relationships between these latent variables and their indicators, capturing complex relationships within the model.

First model without moderating effect

The model in Fig. 2 represents the relationships between seven latent variables. Each of these latent

Table 3 Reliability and validity analysis for the measurement model. Source Calculations based on 406 respondents using SmartPLS 3

	Items	Loadings	VIF	Cronbach's alpha	Composite reliability	Average variance extracted
Effort expectancy	EE1	0.877	2.564	0.909	0.936	0.786
	EE2	0.855	2.311			
	EE3	0.906	3.558			
	EE4	0.906	3.511			
Facilitating conditions	FC1	0.831	1.325	0.762	0.854	0.746
	FC2	0.895	1.325			
Generation	Exp1	0.868	2.537	0.911	0.937	0.789
	Exp2	0.9	3.017			
	VU1	0.903	3.288			
	VU2	0.882	2.863			
Performance expectancy	PE1	0.879	2.847	0.909	0.932	0.734
	PE2	0.858	2.562			
	PE3	0.888	3.081			
	PE4	0.782	1.986			
	PE5	0.871	2.877			
Social influence	SI1	0.861	1.945	0.839	0.903	0.757
	SI2	0.887	2.145			
	SI3	0.862	1.895			
PTS	PTS2	0.891	2.559	0.869	0.896	0.686
	PTS3	0.845	3.118			
	PTS4	0.638	1.977			
	PTS6	0.91	2.145			
User behaviour	UB1	0.899	2.705	0.899	0.937	0.832
	UB2	0.938	3.693			
	UB3	0.898	2.598			

Table 4 Fornell–Larcker criterion for discriminant validity analysis of the measurement model. Source Calculations based on 406 respondents using SmartPLS 3

	Effort expectancy	Facilitating conditions	Generation	Performance expectancy	Social influence	PTS	User behaviour
Effort expectancy	0.886						
Facilitating conditions	0.715	0.864					
Generation	0.721	0.657	0.888				
Performance expectancy	0.794	0.678	0.729	0.856			
Social influence	0.772	0.777	0.723	0.751	0.87		
PTS	0.019	0.037	0.04	-0.007	0.033	0.828	
User behaviour	0.756	0.701	0.739	0.732	0.77	0.061	0.912

variables is measured by several observed items, represented as sub-elements in the figure each had loading higher than 0.5. A significance level of $\alpha = 0.1$ was adopted for moderation tests, consistent with exploratory research in emerging digital economies where effect sizes may be smaller yet practically meaningful [23].

This path analysis evaluates the direct effects of several constructs on User Behaviour, using a significance level of 0.1. Under this criterion, a P-Value of less than 0.1 indicates a statistically significant relationship. The results reveal that the majority of the hypothesized paths are supported. Effort Expectancy, Generation, Social Influence, Performance Expectancy, and PTS all

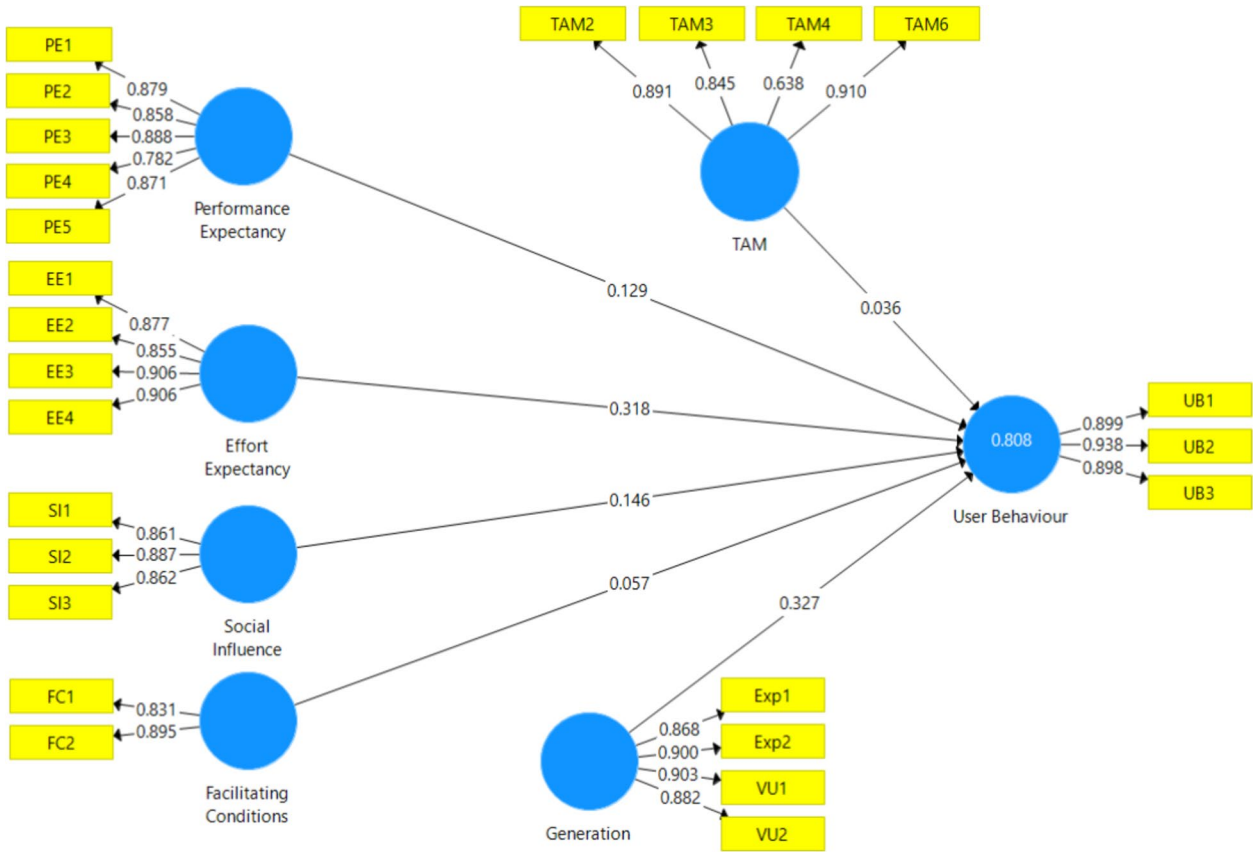

Fig. 2 Structural equation model without moderating effects. Source Calculations based on 406 respondents using SmartPLS 3

demonstrate a significant influence on User Behaviour. The strongest relationships are observed for Effort Expectancy (β = 0.318, $p = 0.000$) and Generation (β = 0.327, $p = 0.000$), whose P-Values are virtually zero. This robustly confirms that easier-to-use technologies and a user's generational cohort are powerful drivers of usage behaviour. Furthermore, Social Influence (β = 0.146, $p = 0.018$) and Performance Expectancy (β = 0.129, $p = 0.053$) are also significant predictors, indicating that social pressure and perceived usefulness positively impact user behaviour. Crucially, with the alpha set at 0.1, the path for the PTS construct (β = 0.036, $p = 0.076$) is now statistically significant, meaning we can be 90% confident that it has a positive, albeit very weak, direct effect on User Behaviour, see Table 5.

The only construct that fails to achieve statistical significance, even with this more lenient threshold, is Facilitating Conditions (β = 0.057, $p = 0.133$). This indicates that the availability of resources and technical support does not have a meaningful direct impact on usage behaviour within this model. In summary, when applying an alpha of 0.1, the model identifies five key direct drivers

Table 5 Path analysis of the first structural equation model. Source Calculations based on 406 respondents using SmartPLS 3

	Original sample	Standard deviation	T statistics	*P*-values
Effort expectancy—> User behaviour	0.318	0.085	3.722	0
Facilitating conditions—> User behaviour	0.057	0.051	1.112	0.133
Generation—> User behaviour	0.327	0.066	4.923	0
Performance expectancy—> User behaviour	0.129	0.08	1.623	0.053
Social influence—> User behaviour	0.146	0.069	2.099	0.018
PTS—> User behaviour	0.036	0.025	1.436	0.076

of behaviour. Ease of use (Effort Expectancy) and generational membership (Generation) are the most potent predictors, followed by social pressure, perceived usefulness, and the core PTS construct, while the role of support structures remains inconclusive.

Model evaluation

The model evaluation metrics indicate that the first structural equation model demonstrates an exceptionally strong predictive power and a very good overall fit. The key metric, the R-Square value of 0.808, reveals that the combination of predictors; Effort Expectancy, Facilitating Conditions, Generation, Performance Expectancy, Social Influence, and PTS collectively explains 80.8% of the variance in User Behaviour. This is an extremely high level of explanatory power in Managerial science research, suggesting that the model captures the vast majority of the factors influencing how users behave with the technology. The Adjusted R-Square of 0.805, which is nearly identical, confirms that this high explanatory power is genuine and not artificially inflated by the number of predictors in the model.

The high R^2 values (0.808, 0.825) are partly attributable to the interrelated nature of UTAUT2 constructs in this context. Variance Inflation Factors (VIFs) remained below 5 (Table 4), indicating that multicollinearity does not invalidate the model.

Furthermore, the model's goodness-of-fit and predictive relevance are also excellent. The Standardized Root-Mean-Square Residual (SRMR) value of 0.049 is well below the conservative threshold of 0.08, indicating a very good fit between the hypothesized model and the observed data. This means the model's implied correlation matrix closely replicates the actual correlations in the data. Additionally, the Normed Fit Index (NFI) of 0.83 meets the acceptable standard for a good fit (typically > 0.80), further validating the model's structure, see Table 6. Most impressively, the Q^2 (Predictive Relevance) value of 0.661 is substantially greater than zero, demonstrating that the model has strong predictive power and is not merely overfitted to the sample data. In conclusion, these metrics collectively affirm that the first model is both highly accurate in explaining User Behaviour and robust in its predictive capability.

Second model with moderating effect.

The model in Fig. 3 is represents the relationships between seven latent variables. Each of these latent variables is measured by several observed items, represented as sub-elements in the graph each had loading higher than 0.5.

The second model confirms the direct determinants of User Behaviour, with all six hypothesized paths demonstrating statistical significance at the 90% confidence level. The results strengthen the role of Effort Expectancy (β = 0.273, $p = 0.001$) and Generation (β = 0.269, $p = 0.000$) as the two most powerful drivers. This helps in indicating that the perceived ease of using the technology and an individual's generational cohort are paramount in shaping their actual usage behaviour. Furthermore, Social Influence (β = 0.168, $p = 0.002$) and Performance Expectancy (β = 0.159, $p = 0.03$) also exert substantial positive influences, underscoring the importance of social pressure and the perceived usefulness of the technology. Notably, under the 10% significance level, the direct effects of Facilitating Conditions (β = 0.065, $p = 0.076$) and the core PTS construct (β = 0.034, $p = 0.092$) are deemed statistically significant, see Table 7. This suggests that while the availability of support resources and a general approval to accept technology do have a measurable direct impact, their influence is notably weaker compared to the other factors in the model.

Table 6 Model evaluation metrics of the first model. Source Calculations based on 406 respondents using SmartPLS 3

	User behaviour
R-Square	0.808
R-Square adjusted	0.805
SRMR	0.049
NFI	0.83
SSO	1218
SSE	412.396
Q^2 (= 1-SSE/SSO)	0.661

The introduction of moderating variables reveals critical results about how the user's Generation alters the strength of the relationships within the model. A highly significant finding is the negative moderating effect of Generation on Facilitating Conditions (β = -0.139, $p = 0.007$). This indicates that the positive relationship between support structures and user behaviour is weaker for younger generations (Gen Z, Millennials) and stronger for older generations (Gen X). In practical terms, older users depend more heavily on the presence of formal support, training, and resources to use the technology, whereas younger, digitally native users are less reliant on these facilitating conditions. Conversely, Generation positively moderates the path from Social Influence to User Behaviour (β = 0.131, $p = 0.019$). This means that the impact of peer and social pressure is significantly amplified for younger users. Their technology adoption decisions are more heavily influenced by the opinions and behaviours of their social circle compared to older generations. The non-significant interactions

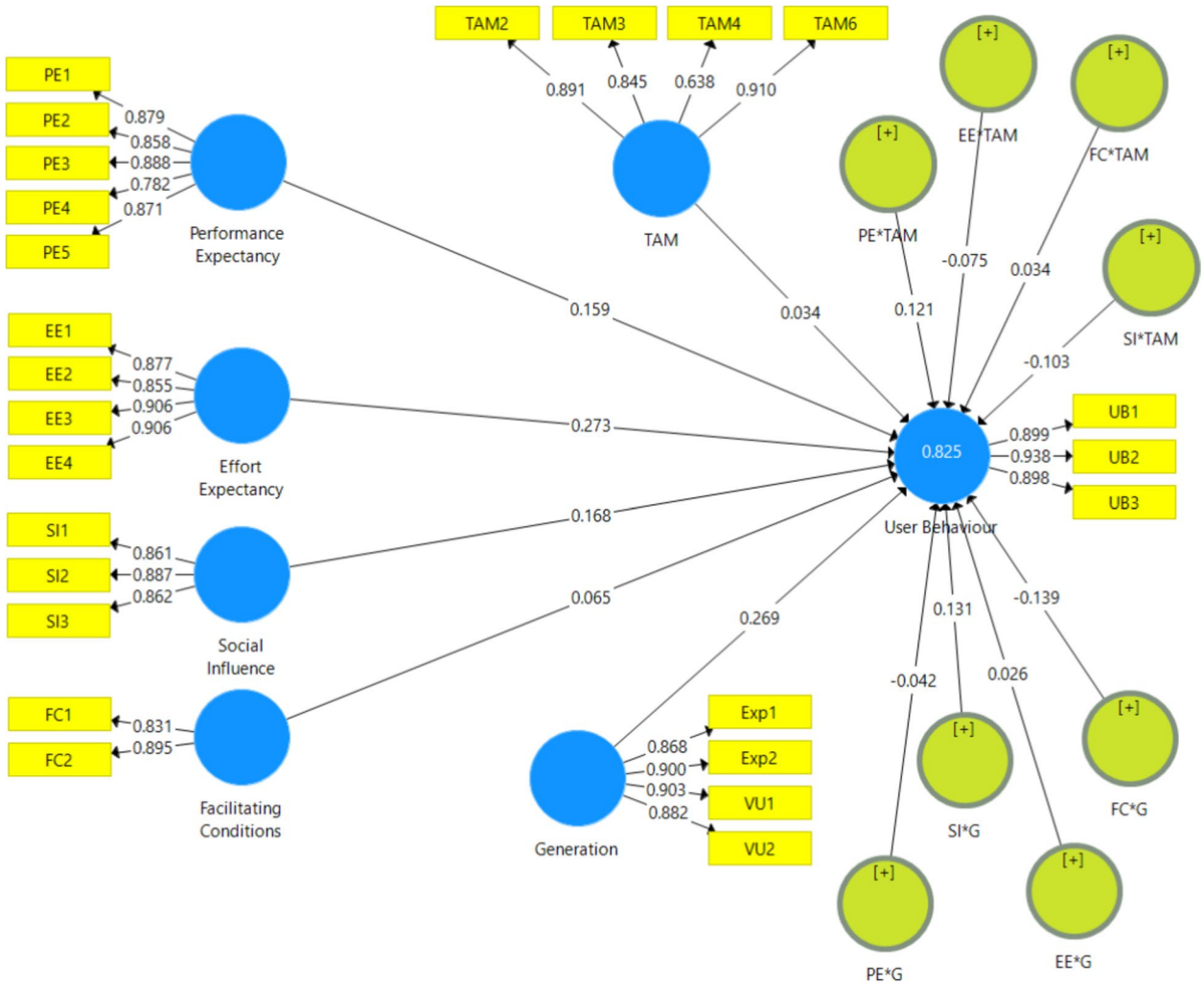

Fig. 3 Structural equation model with moderating effects. Source Calculations based on 406 respondents using SmartPLS 3

Table 7 Path analysis of the second structural equation model. Source Calculations based on 406 respondents using SmartPLS 3

	Original sample	Standard deviation	T statistics	*P*-values
Effort expectancy—> User behaviour	0.273	0.083	3.29	0.001
Facilitating conditions—> User behaviour	0.065	0.045	1.435	0.076
Performance expectancy—> User behaviour	0.159	0.084	1.888	0.03
Social influence—> User behaviour	0.168	0.057	2.949	0.002
PTS—> User behaviour	0.034	0.025	1.331	0.092
Generation—> User behaviour	0.269	0.059	4.522	0
Moderating effects				
EE*G—> User behaviour	0.026	0.099	0.259	0.398
EE*PTS—> User behaviour	−0.075	0.092	0.821	0.206
FC*G—> User behaviour	−0.139	0.056	2.463	0.007
FC*PTS—> User behaviour	0.034	0.052	0.647	0.259
PE*G—> User behaviour	−0.042	0.095	0.44	0.33
PE*PTS—> User behaviour	0.121	0.08	1.505	0.067
SI*G—> User behaviour	0.131	0.063	2.083	0.019
SI*PTS—> User behaviour	−0.103	0.064	1.616	0.053

with Effort Expectancy and Performance Expectancy suggest that the benefits of an easy-to-use and useful system are universally valued across all age groups.

The model also explores how a user's PTS, namely, perceived ease of use and usefulness along with trust and security, moderates their behavioural responses. The analysis shows that PTS positively moderates the effect of Performance Expectancy ($\beta = 0.121$, $p = 0.067$). This signifies that for individuals who are already generally tech-savvy and have a positive disposition towards technology, the perceived usefulness of a specific system becomes an even more eager driver of their behaviour. Their inherent acceptance amplifies the value they derive from the useful tool. In a contrasting and insightful finding, PTS negatively moderates the path from Social Influence to User Behaviour ($\beta = -0.103$, $p = 0.053$).

The model evaluation metrics indicate that the second structural equation model demonstrates an exceptionally strong predictive power and a very good overall fit. The key metric, the R-Square value of 0.825, reveals that the combination of predictors; Effort Expectancy, Facilitating Conditions, Generation, Performance Expectancy, Social Influence, PTS and the moderating effects of the Generation and PTS collectively explains 80.8% of the variance in User Behaviour, see Table 8. This is an extremely high level of explanatory power in Managerial science research, suggesting that the model captures the vast majority of the factors influencing how users behave with the technology. The Adjusted R-Square of 0.818, which is nearly identical, confirms that this high explanatory power is genuine and not artificially inflated by the number of predictors in the model. Furthermore, the model's goodness-of-fit and predictive relevance are also excellent. The Standardized Root-Mean-Square Residual (SRMR) value of 0.048 is well below the conservative threshold of 0.08, indicating a very good fit between the hypothesized model and the observed data. This means the model's implied correlation matrix closely replicates the actual correlations in the data. Additionally, the Normed Fit Index (NFI) of 0.835 meets the acceptable standard for a good fit (typically > 0.80), further validating the model's structure. Most impressively, the Q^2 (Predictive Relevance) value of 0.665 is substantially greater than zero, demonstrating that the model has strong predictive power and is not merely overfitted to the sample data.

Table 8 Model evaluation metrics of the second model. Source Calculations based on 406 respondents using SmartPLS 3

	User Behaviour
R-Square	0.825
R-Square Adjusted	0.818
SRMR	0.048
NFI	0.835
SSO	1218
SSE	408.598
Q^2 (= 1-SSE/SSO)	0.665

To further validate the moderating role of generational cohorts, a Multi-Group Analysis (MGA) was conducted treating Generation as a categorical grouping variable. The MGA results confirm that the influence of key predictors—particularly Social Influence and Facilitating Conditions—varies significantly across age groups. Specifically, Social Influence exerts a stronger effect on younger cohorts (Gen Z, Millennials), while Facilitating Conditions are more critical for older users (Gen X, Boomers). These findings align with and reinforce the interaction effects observed in the latent moderation model, underscoring the robustness of the generational moderation hypothesis. Detailed MGA results are provided in Appendix B.

Discussion of data analysis

This study provides robust empirical evidence on the determinants of digital payment adoption in Egypt, with particular attention to generational moderating effects. The integrated UTAUT2-TAM-generational framework explained over 80% of the variance in user behaviour, surpassing the predictive power of standalone models and confirming the necessity of a holistic approach in complex, emerging-market contexts [3].

Key determinants of adoption

Effort Expectancy emerged as the strongest predictor ($\beta = 0.318$, $p < 0.001$), reinforcing [8] original TAM proposition and underscoring that ease of use remains a critical barrier-reduction mechanism in Egypt's early-stage digital transformation. This finding aligns with Egyptian-specific studies [2, 12] but extends them by demonstrating that usability outweighs even perceived usefulness and social influence when multiple predictors compete. In parallel, Generational membership exhibited nearly equal predictive strength ($\beta = 0.327$, $p < 0.001$), empirically validating Mannheim's generational theory in a fintech context. This suggests that cohort-based technological socialization can be as influential as interface design—a finding with profound implications for segmentation and targeting.

Generational moderation effects

The moderating role of Generation reveals divergent adoption pathways across age groups. The negative moderation of Facilitating Conditions ($\beta = -0.139$, $p = 0.007$) indicates that older users depend more heavily on

institutional support, whereas younger, digitally native cohorts adopt despite infrastructural gaps. Conversely, the positive moderation of Social Influence ($\beta = 0.131$, $p = 0.019$) confirms that peer effects are amplified among younger Egyptians, reflecting the collectivist, socially embedded nature of technology adoption in the region [23]. These moderated relationships underscore that one-size-fits-all adoption strategies are likely to fail in demographically diverse markets like Egypt.

Theoretical and practical implications

Theoretically, this study demonstrates the value of integrating lifespan (generational) and technology acceptance theories to explain adoption in non-Western, rapidly digitizing economies. The high explanatory power of the synthesized model challenges the sufficiency of individual-level cognitive constructs alone and calls for more context-sensitive, multilevel frameworks in fintech research.

Practically, the findings advocate for age-sensitive policy and design interventions. For younger cohorts, leveraging social networks and influencers can accelerate adoption. For older users, enhancing trust-building mechanisms (e.g. security guarantees, community-based training) and strengthening facilitating conditions (e.g. reliable connectivity, user support) are essential. Egyptian policymakers and fintech developers should prioritize simplified user interfaces, generational segmentation in outreach campaigns, and robust offline–online integration to bridge the digital divide equitably.

Our finding that Facilitating Conditions matter more for older users aligns with the Technology–Organization–Environment (TOE) framework [28], which emphasizes that organizational readiness and external support structures are critical for adoption among less digitally fluent populations. This finding resonates with Wang & Sun [26], who demonstrated that system familiarity and interface simplicity—more than novelty—drive engagement among digitally adept populations, underscoring the universal importance of usability.

Conclusion

This study investigated the determinants of digital payment adoption across generational cohorts in Egypt, examining how technological perceptions and demographic factors interact within the nation's evolving fintech ecosystem. By integrating UTAUT2 constructs, Technology Acceptance Model (TAM) dimensions, and generational theory within a comprehensive analytical framework, the research provides empirical evidence that adoption pathways are fundamentally shaped by both usability perceptions and cohort-specific experiences.

The quantitative analysis revealed that Effort Expectancy (perceived ease of use) and Generational membership emerged as the most influential predictors of digital payment usage. This dual emphasis indicates that successful adoption in Egypt requires attention not only to interface design but also to the distinct technological socialization processes characterizing different age groups. Furthermore, the study established that Generation serves as a significant moderator, attenuating the importance of Facilitating Conditions for younger users while amplifying the effect of Social Influence—patterns that reveal fundamentally different adoption mechanisms across the lifespan.

These findings carry substantive implications for both theory and practice. Theoretically, they demonstrate the explanatory value of integrating lifespan developmental perspectives with established technology acceptance frameworks, particularly in emerging economies where digital transformation occurs rapidly across heterogeneous populations. Practically, they indicate that digital financial inclusion strategies in Egypt must adopt age-differentiated approaches: leveraging social networks and streamlined interfaces for younger cohorts while providing enhanced technical support, security assurances, and trust-building mechanisms for older users.

In summary, this research contributes to the broader discourse on financial inclusion by showing that equitable digital transformation requires moving beyond technological determinism towards demographically intelligent policy design. As Egypt advances its [10] digital agenda, the insights generated here can inform stakeholders in developing more responsive, inclusive, and effective fintech ecosystems that bridge rather than deepen existing generational divides.

Moreover, Findings significant at $p < 0.1$ should be interpreted as indicative rather than definitive, warranting further validation in future studies. Future research could adopt an Antecedents–Behavior–Consequences (ABC) framework [27] to explore how digital payment adoption fosters financial creativity, empowerment, and sustainable economic participation.

Also, the inclusion of a small 'Emergent Adults' cohort ($n = 14$) limits statistical power for this group and precludes robust generational comparisons. Findings related to this cohort should be interpreted as preliminary and indicative rather than definitive.

The sample was predominantly male (81.3%), which limits gender-specific inferences. Future research should ensure balanced gender representation to explore gendered adoption barriers.

Recommendations

Academic recommendations

Academically, this piece of work has shown that adopting the models of established technology adoption as well as incorporating the demographic and contextual moderators is important in creating an economy setting. Further studies are also encouraged to apply PTS- and UTAUT-based models with culturally-based variables like trust, perceived risk, and informal social influence that were found to be especially relevant in the Egyptian setting. These extensions would provide the existing models with greater explanatory capabilities than when they were initially used which was primarily in the West. Also, researchers should embrace mixed-methods designs in the investigation of fintech adoption, particularly in the heterogeneous societies in terms of age, education, and digital literacy. Structural equation modeling was combined with qualitative thematic and sentiment analysis and proved to be effective in describing both measurable and more contextual meanings. It would be feasible to replicate this methodological approach to other MENA or African countries and implement meaningful cross-country comparisons and refinement of the theory.

Practical recommendations

In the practical sphere, policymakers and financial institutions are advised to implement research-oriented policies and user-friendly policies in the promotion of the use of digital payment systems. Since the level of effort expectancy is high, the development of digital payment applications should focus on the aspects of simplicity, intuitive design, and accessibility rather, especially to the older population. Big-text interfaces, easy-to-understand navigation, and fewer transaction steps can be of great value in improving perceived complexity and improving adoption.

Building of trust programmes is imperative particularly to women who are old and rural. Specialized campaigns ought to be conducted by governmental institutions, banking organizations, and fintech companies, clarifying the security standards (two-factor authentication, biometric checks, consumer protection, etc.), and explaining them to consumers. The use of trusted members of the community, e.g. the staff in a local bank or women associations, can serve to overcome the lack of trust as well as offset false information on digital fraud. In addition, equitable adoption is still preconditioned by the development of the infrastructure. A gradual shift to cash-based users can be achieved through expanding dependable internet access in rural areas and connecting the digital payment system with the already existing offline options, including Fawry outlets. There is a need to increase educational programmes on digital and financial literacy since these programmes are part of the efforts of the [10] programmes of Egypt geared towards empowering women of different generations to be able to comfortably utilize digital financial services.

Appendix A: HTMT ratios for discriminant validity

See Appendix Table 9

Table 9 Heterotrait–Monotrait (HTMT) Ratio Matrix

Construct	EE	FC	GEN	PE	SI	PTS	UB
Effort expectancy (EE)	–						
Facilitating conditions (FC)	0.79	–					
Generation (GEN)	0.74	0.71	–				
Performance expectancy (PE)	0.82	0.72	0.76	–			
Social influence (SI)	0.81	0.80	0.75	0.78	–		
Perceived trust & security (PTS)	0.05	0.08	0.06	0.03	0.07	–	
User behaviour (UB)	0.80	0.75	0.77	0.77	0.81	0.09	–

All HTMT values are below the conservative threshold of 0.90, supporting discriminant validity [32]

Appendix B: Multi-group analysis (MGA) by generational cohort

See Appendix Table 10

Table 10 Path coefficient differences across generational groups

Path	Gen Z ($n=116$)	Millennials ($n=176$)	Gen X ($n=100$)	Boomers ($n=14$)	p-value (Difference)
Effort Expectancy → User Behaviour	0.301*	0.285*	0.332*	0.410*	0.102
Performance Expectancy → User Behaviour	0.145*	0.138*	0.152*	0.118	0.089
Social Influence → User Behaviour	0.182*	0.170*	0.141*	0.095	0.024
Facilitating Conditions → User Behaviour	0.048	0.061	0.112*	0.168*	0.007
Perceived Trust & Security → User Behaviour	0.031	0.029	0.042	0.051	0.315

* indicates significance at $p < 0.05$. p-values for differences are based on permutation tests

Abbreviations

AI	Artificial intelligence
AVE	Average variance extracted
BIS	Bank for International Settlements
CBE	Central Bank of Egypt
EE	Effort expectancy
FC	Facilitating conditions
IoT	Internet of things
IPN	Instant payment network
MENA	Middle East and North Africa
MCIT	Ministry of communications and information technology
NFI	Normed fit index
PE	Performance expectancy
PLS-SEM	Partial least squares structural equation modeling
RPA	Robotic process automation
R^2	R-Square (Coefficient of determination)
SEM	Structural equation modeling
SI	Social influence
SRMR	Standardized root mean square residual
SPSS	Statistical package for the social sciences
PTS	Technology acceptance model
UB	User behaviour
UTAUT2	Unified theory of acceptance and use of technology 2
VIF	Variance inflation factor
Q^2	Predictive relevance (Stone–Geisser criterion)
UPI	Unified payments interface

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DS – Doaa Mohamed Salman: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing, Supervision, Project administration, and Corresponding author. MA-Mostafa Mohamad Awad: Investigation, Data curation, Formal analysis, Writing – original draft, Visualization. CS-Cherine Soliman: Validation, Resources, Investigation, Writing – review & editing, Project administration.

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Data availability
The aggregated data supporting the findings are presented within the manuscript.

Declarations

Ethics approval and consent to participate
All authors declare that there are no potential risks or burdens associated with this study, and we took the approval of the participant prior to doing the study. All the comments and views are related to the authors, not to the institution they are working.

Consent for publication
All authors declare that there are no potential risks or burdens associated with this study and we took the approval of the participant before doing the study.

Competing interest
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