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The Impact of Electronic Payment, E-Commerce and Technological Innovation on China's Economic Growth

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Abstract

The digital transformation of China's economy, characterized by the widespread adoption of electronic payments and rapid e-commerce expansion, has reshaped the mechanisms through which technological innovation drives economic development. While previous studies have explored the individual effects of digital finance and innovation, a critical gap persists in understanding their interactive influence on macroeconomic outcomes within China's unique institutional framework. This study employs a balanced panel dataset comprising 30 Chinese provinces from 2013 to 2023 and applies a fixed effects models with robust standard errors to examine the individual and interactive effects of electronic payment, e-commerce, and technological innovation (measured by R&D investment) on economic growth (measured by GDP). The empirical results indicate that both electronic payment and e-commerce have significantly positive effects on economic growth, with e-commerce demonstrating a slightly greater magnitude of effect. Technological innovation also contributes positively; however, its interaction with electronic payment yields a negative and statistically significant coefficient, suggesting diminishing marginal returns or potential inefficiencies when these dimensions are not strategically aligned. Robustness checks validate the consistency of these findings across alternative specifications. This study offers a novel empirical contribution by uncovering the complex that interplay between digital financial infrastructure and technological innovation in shaping regional economic growth, providing both theoretical insights and practical guidance for the coordinated formulation of digital and innovation policies.

Keywords: Electronic Payment, E-commerce, Technological Innovation, Economic Growth, Panel Data Analysis

Introduction

The digital transformation of China's economy constitutes a defining economic transformation of the 21st century, fundamentally altering the pathways by which technological innovation drives economic growth (B. Wu et al., 2025). As the world's second-largest economy, China has emerged as a global leader in digital payments and e-commerce, offering valuable insights into the relationship between technological innovation and economic development (Guo et al., 2024; Yang et al., 2023; Zhou, 2022). This transformation has been particularly pronounced in the domain of electronic payment systems, where China has transitioned from a largely cash-dependent economy to a digital payment powerhouse, with an estimated 1.04 billion unique mobile payment users facilitating transactions amounting to roughly 672 trillion CNY in 2024 alone.

The theoretical foundations for understanding these relationships are grounded in two well-established theoretical frameworks: system dynamics theory and innovation diffusion theory. System dynamics theory, developed by Forrester et al. (1976), provides a comprehensive approach to understanding how complex systems evolve over time, making it particularly suitable for analysing the dynamic interactions among technological innovation, R&D investment, and economic outcomes. This theory posits that these relationships are characterized by non-linearities, feedback loops, and time delays that can either amplify or attenuate economic impacts over time. Innovation diffusion theory, pioneered by Rogers (1962), offers insights into how new technologies disseminate throughout economic systems and societies, offering a conceptual framework to explain the adoption patterns of electronic payment systems and e-commerce platforms.

The rapid adoption of electronic payment systems in China has fundamentally transformed consumer behavior and business operations by introducing new avenues for economic activity and lowering transaction costs (Tang et al., 2021). Simultaneously, China's e-commerce sector has undergone remarkable expansion, positioning China as the world's largest e-commerce market (Guo et al., 2024). Recent empirical evidence indicates that both e-commerce capital stocks and R&D capital stocks exert significant positive effects on output growth, with R&D demonstrating a comparatively stronger effect than e-commerce alone (Ballerini et al., 2023; Jiang et al., 2023). However, the potential synergistic effects of these factors when examined jointly have received limited scholarly attention, particularly within the context of China's distinctive economic and technological environment (Wang et al., 2023; Wu et al., 2024; Zhou, 2022).

The role of technological innovation as both a driver and an outcome of digital transformation introduces additional complexity into this dynamic relationship (Xu et al., 2023). (Ren et al., 2024). Furthermore, the unique characteristics of China's economic and institutional environment necessitate focused scholarly attention. China's rapid transition from a manufacturing-based economy to a digital economy that combined with its distinctive regulatory framework and market structures which constitutes an economic context that may elude generalizations derived from studies in other national settings (Sun & Wu, 2024; M. Zhang & Yin, 2023). The Chinese government's strategic emphasis on digital transformation and innovation, exemplified by initiatives such as the Digital Currency Electronic Payment (DCEP) system and the Digital Silk Road Initiative, illustrates a state-led model of digital economic development that diverges markedly from the market-driven strategies prevalent in other economies (Xu et al., 2023; Yang et al., 2023; Zheng et al., 2023; S. Zhong et al., 2023).

This study seeks to fill these gaps by examining three interconnected research questions that reflect the multifaceted dynamics of digital transformation's impact on economic growth. First, the study investigates whether electronic payment adoption promotes China's economic growth. Second, the analysis considers whether e-commerce expansion contributes to China's economic growth. Third, and most critically, this study explores whether the interactive effects of electronic payment systems and technological innovation generate synergistic effects that magnify their individual contributions to economic growth. The empirical investigation of these relationships offers important contributions to both economic policy and theoretical discourse. From a policy perspective, understanding the interplay among electronic payment systems, e-commerce, and technological innovation can guide the formulation of strategies aimed at fostering sustainable economic growth via digital transformation (Liu, 2023; Wang et al., 2023; Zhang et al., 2023). This is particularly pertinent as governments worldwide endeavor to leverage digital technologies for economic development while simultaneously addressing the attendant risks and challenges (Dorosh et al., 2023).

From a theoretical perspective, this study adds to the expanding body of literature on digital economics and innovation-driven growth by offering empirical insights into the mechanisms by which digital technologies influence economic outcomes. The focus on interactive effects moves beyond traditional linear models of technological impact and provides a more sophisticated understanding of how various digital technologies interact synergistically to drive economic growth.

The analysis focuses specifically on China's experience, drawing on an extensive dataset comprising electronic payment adoption, e-commerce development, R&D investment, and economic growth indicators. The Chinese context offers a unique empirical setting for examining these relationships, given the country's rapid digital transformation, substantial scale of technology adoption, and rich data availability across multiple dimensions of digital development. The findings from this analysis are expected to advance the understanding of how digital technologies may be harnessed to foster sustainable economic growth in both developed and developing economies.

Literature Review

The relationship between digital technologies and economic growth has emerged as a central theme in contemporary economic research, particularly in the context of China's rapid digital transformation (Fan et al., 2022; Wang et al., 2023; Xu et al., 2023). Electronic payment systems substantially reshape the cost dynamics of economic transactions, potentially lowering transaction frictions and stimulating overall economic activity (Tounekti et al., 2022). Early research in this area focused primarily on adoption patterns and implications for consumer behavior. Existing research found that electronic payment adoption significantly reduces transaction costs associated with traditional payment methods, creating efficiency gains that can translate into broader economic benefits (Khanin et al., 2022). Their analysis revealed that electronic payment significantly encourages household consumption of discretionary goods, with the underlying mechanism attributed to the reduction in transaction costs associated with physical purchases and cash handling.

The macroeconomic implications of electronic payment adoption have been explored through various theoretical lenses. Tang et al. (2021) applied endogenous growth theory to examine how electronic payment systems affect economic growth through several mechanisms, including increased consumption efficiency, enhanced financial inclusion, and improved monetary policy transmission. However, the literature also reveals notable gaps and limitations in the existing understanding of the relationship between electronic payment systems and economic growth. Most studies have concentrated on developed economies or relied on cross-sectional data, thereby constraining the ability to assess the temporal dynamics of electronic payment adoption (Khanin et al., 2022; Ogata, 2017).

The sectoral implications of e-commerce development have also received increasing scholarly attention. Existing research examined the impact of e-commerce on traditional retail sectors, finding that while e-commerce growth may displace segments of traditional retail, the net effect on overall economic activity is positive owing to efficiency improvements and expanded market reach(Criveanu, 2023; Oğuz et al., 2022). Similarly, there are researches investigated the impact of e-commerce on the manufacturing sector, concluding that e-commerce platforms facilitate broader market access and enable scale efficiencies (Ismail & Azab, 2023; Jiang et al., 2023; Lee et al., 2023). Recent studies have also explored the resilience implications of e-commerce development. The impact of urban e-commerce transformation on economic resilience has been shown to enhance a country's capacity to absorb shocks and maintain proactive economic development (Hassan et al., 2020; Yang et al., 2023). This body of research suggests that e-commerce development not only contributes to economic growth but also bolsters economic resilience by strengthening the capacity to absorb external shocks and adapt to structural changes (Guo et al., 2024; Oğuz et al., 2022).

However, the literature also reveals important challenges and limitations in comprehending the relationship between e-commerce development and economic growth (J. Zheng & Yang, 2022; M. Zhong et al., 2022). Many studies have focused on aggregate measures of e-commerce activity while neglecting the heterogeneous impacts across sectors and regions (Criveanu, 2023; Ismail & Azab, 2023). Furthermore, the rapid pace of technological change in e-commerce platforms renders many research findings rapidly obsolete, necessitating continual reassessment of theoretical and empirical insights (Keizer et al., 2023; Nerbel & Kreutzer, 2023; Reza-Gharehbagh et al., 2023).

The interaction between electronic payment systems and technological innovation remains a relatively underexamined domain of inquiry, despite its relevance for elucidating the drivers of economic growth in the digital era. Emerging scholarship increasingly acknowledges that the effects of digital technologies may be multiplicative rather than additive, thereby generating synergies that magnify their individual impacts on economic growth.

Despite the substantial body of research on digital technologies and economic growth, several critical gaps remain. First, while existing literature has extensively documented the adoption patterns and consumer behavior implications of electronic payment systems, empirical evidence remains limited regarding whether electronic payment systems contribute to economic growth within China's unique institutional and economic context, as most existing studies emphasize individual-level welfare effects over macroeconomic outcomes.

Second, although e-commerce development has been widely studied in terms of market structure and business model transformation, the direct causal relationship between e-commerce expansion and China's economic growth has not been sufficiently examined, with current research focusing predominantly on sector-specific impacts rather than broader economic outcomes. Third, and most importantly, the interactive effects between electronic payment systems and technological innovation on economic growth constitute a major research gap, as the literature has largely treated these factors in isolation, failing to account for their potential synergistic interactions that despite theoretical expectations that R&D investment and technological innovation may moderate and amplify the economic effects of electronic payment adoption. The integrated nature of China's digital ecosystem, where electronic payment, e-commerce, and technological innovation are deeply intertwined, necessitates a holistic examination of these interrelated dimensions. Yet systematic empirical research integrating all three components and their interactive effects on China's economic growth using rigorous econometric methods remains absent.

The theoretical framework has been constructed drawing upon the proposed hypotheses and a comprehensive analysis of relevant theoretical and empirical literature, as depicted in Figure_1.

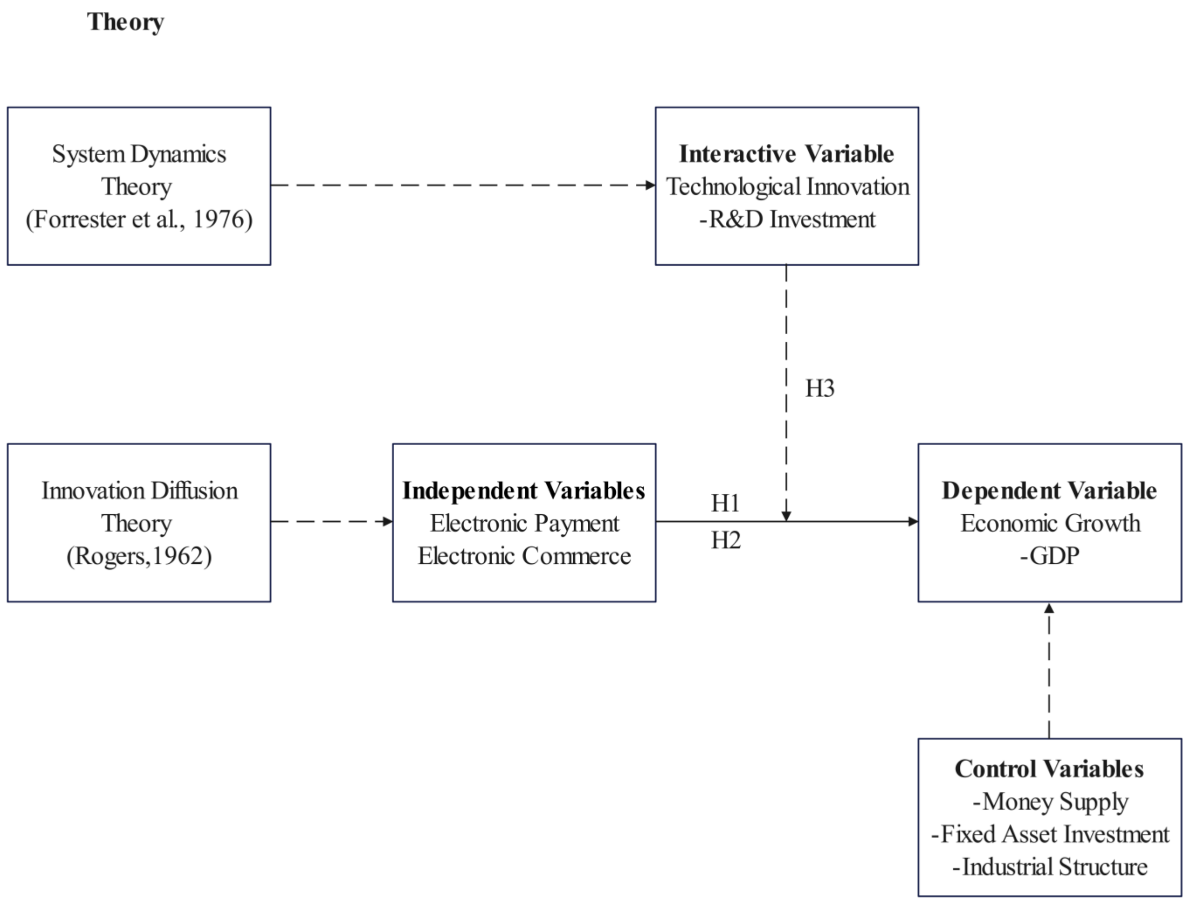

Figure_1. Theoretical Framework

Figure_1 presents the conceptual framework, depicting the impact of electronic payment and e-commerce on economic growth, as measured by GDP, while incorporating control variables: money supply, fixed asset investment, and industrial structure, to enhance the robustness of the empirical analysis concerning among electronic payment, e-commerce, technological innovation, and economic growth. The framework integrates two foundational theories: innovation diffusion theory and system dynamics theory. It formulates three primary hypotheses: H1, which proposes that electronic payment directly promotes economic growth; H2, which suggests that e-commerce directly promotes economic growth; and H3, which posits that technological innovation strengthens the effect of electronic payment on economic growth.

Methodology and Data Sources

Empirical Model

This study adopts a province level fixed effects model with robust standard errors to account for unobserved heterogeneity across provinces and corrected for heteroskedasticity, thereby ensuring the consistency and efficiency of the parameter estimates. Specifically, economic growth, measured by the log-transformed provincial GDP, serves as the dependent variable; the log-transformed values of provincial electronic payment and e-commerce are included as the main explanatory variables; and technological innovation, proxied by the log-transformed provincial R&D investment, is incorporated as a moderating variable through interaction terms. The study conducts Hausman specification tests to assess the appropriateness of the fixed-effects model relative to its random-effects counterpart and implements Breusch–Pagan diagnostic tests to justify the application of robust standard errors (Hausman, 1978; Hausman & Pesaran, 1983). All estimations are performed using Stata version 17.0.

To examine the economic impact of electronic payment, e-commerce, and technological innovation in the context of China, this study adopts a robust panel data regression framework. This approach facilitates a comprehensive analysis of datasets exhibiting both cross-sectional and temporal heterogeneity (Balazsi et al., 2017). Panel data, also known as longitudinal data, refers to a two-dimensional dataset comprising a spatial dimension ($i = 1, \dots, N$) and a temporal dimension ($t = 1, \dots, T$), where i denotes the province and t denotes the year. This type of data is indexed by (i, t), allowing for the examination of individual units across time (Kelejian & Piras, 2017). In this study, which covers 30 Chinese provinces over the period from 2013 to 2023, a panel data regression model is employed to empirically test the proposed hypotheses. The standard specification of the panel data regression model is formulated as follows:

$$Y_{it} = \beta_0 + \beta_1 X_{it} + \beta_2 X_{it} + \cdots + \beta_n X_{it} + \varepsilon_{it} \quad (1)$$

In the model specification, $\mathrm{Y_{it}}$ denotes the dependent variable, while $\mathrm{X_{it}}$ captures the independent variables across the pooled cross-sectional and time-series data. β_k represents the model coefficients, and ε_{it} captures the stochastic error term. In this context, i refers to the cross-sectional units (provinces), while t indicates the temporal dimension spanning from 2013 to 2023.

This study employs a panel data regression approach to assess the influence of electronic payment, e-commerce, and technological innovation on economic growth across 30 Chinese provinces over the period 2013–2023. The empirical analysis considers three models: the pooled ordinary least squares (POLS), fixed effects (FE), and random effects (RE) models, to capture unobserved provincial-level heterogeneity. The Hausman test is conducted to determine the most appropriate model specification, while robust standard errors are employed to address heteroskedasticity issues. Utilizing panel data from 30 provinces facilitates a detailed investigation into regional disparities in the adoption patterns of digital technologies and their associated effects on economic growth. To strengthen the empirical robustness of the results, diagnostic tests for heteroskedasticity (Breusch–Pagan test) and serial correlation (Durbin–Watson test) are implemented (Breusch & Pagan, 1979). Addressing heteroskedasticity through robust standard errors improves the accuracy and validity of the statistical inferences (Sevier et al., 1996).

In this study, the interaction variable, technological innovation, is proxied by R&D investment (RD). The model includes an interaction term to examine the extent to which technological innovation moderates the impact of electronic payment on economic growth. Control variables consist of money supply (MS), fixed asset investment (FAI), and industrial structure (IS). The core regression equation is specified as follows:

Model 1: Impact of electronic payment on economic growth

$$\ln(GDP_{it}) = \beta_0 + \beta_1 \ln(EP_{it}) + \beta_2 (lnMS_{it}) + \beta_3 \ln(FAI_{it}) + \beta_4 \ln(IS_{it}) + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

$\ln(\mathrm{GDP_{it}})$ denotes the natural logarithm of provincial GDP, representing economic growth, and functions as the dependent variable in the model. $\ln(\mathrm{EP_{it}})$ denotes the natural logarithm of electronic payment in province i at time t, acting as a primary explanatory variable. $\ln(\mathrm{MS_{it}})$ is the natural logarithm of the money supply in province i at time t. $\ln(\mathrm{FAI_{it}})$ represents the natural logarithm of fixed asset investment, and $\ln(\mathrm{IS_{it}})$ captures the natural logarithm of industrial structure. μ_i represents province-specific fixed effects, capturing time-invariant, province-level unobserved characteristics. λ_t denotes time-specific fixed effects, capturing common shocks or national-level influences that vary over time. ε_{it} is the error term, representing unobservable factors influencing economic growth in province i at time t.

This model is designed to quantify the association between electronic payment and GDP growth across Chinese provinces over the study period. It accounts for both spatial (province-level) and temporal (year-specific) heterogeneity that may influence economic performance, thereby improving the reliability and internal validity of the estimates. The natural logarithmic transformation of variables facilitates coefficient interpretation in terms of percentage changes, enhancing the comparability and clarity of the results.

Model 2: Impact of e-commerce on economic growth

$$\ln(GDP_{it}) = \beta_0 + \beta_1 \ln(EC_{it}) + \beta_2 (lnMS_{it}) + \beta_3 \ln(FAI_{it}) + \beta_4 \ln(IS_{it}) + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

$\ln(\mathrm{EC_{it}})$ is the natural logarithm of e-commerce in province i at time t, serving as the independent variable in the model. This model aims to estimate the relationship between e-commerce and GDP growth across different provinces over time.

Model 3: Interaction between electronic payment and technological innovation on economic growth

$$ln(GDP_{it}) = \beta_0 + \beta_1 \ln(EP_{it}) + \beta_2 \ln(TI_{it}) + \beta_3 (lnEP_{it} \times lnTI_{it}) + \beta_4 \ln(MS_{it}) + \beta_5 \ln(FAI_{it}) + \beta_6 ln(\\ + \mu_i + \lambda_t + \varepsilon_{it}$$

$\mathrm{lnEP_{it}} \times \mathrm{lnTI_{it}}$ is the interaction term between the natural logarithm of electronic payment (EP) and technological innovation (TI) in province i at time t. This interaction captures the combined impact of electronic payment and technological innovation on economic growth. The model estimates how this interaction influences GDP growth while controlling for key macroeconomic variables The natural logarithmic transformation allows for interpreting the coefficients in percentage terms, providing a more intuitive understanding of their relative impacts on GDP growth.

Data

This study utilizes a balanced panel dataset of 30 Chinese provinces spanning from 2013 to 2023. Following established empirical protocols, regions with incomplete data—namely Hong Kong, Macau, Tibet, and Taiwan—were excluded owing to data limitations and divergent financial reporting mechanisms (Donohue et al., 2023). The dataset was compiled using data sourced from the China Statistical Yearbook and the online portal of the National Bureau of Statistics, and was further supplemented with information from the People's Bank of China on electronic payment indicators and from the Ministry of Commerce on e-commerce turnover.

Empirical Results and Analysis

Descriptive Statistics

The descriptive statistics provide a comprehensive summary of the key variables, including electronic payment, e-commerce, technological innovation, economic growth, and relevant control variables (Oyelami et al., 2020).

Table 1

Descriptive statistics of key variables (2013–2023)

Variable	Mean	Std. dev.	Min	Max	Obs
GDP	2.299568	0.089013	2.036031	2.469624	330
Electronic Payment	7.867322	1.446842	4.804021	11.04478	330
E-commerce	7.716784	1.238446	4.079231	10.35163	330
Technological Innovation	2.676409	0.0979254	2.405375	2.872844	330
Electronic Payment× Technological Innovation	14.60112	1.39206	11.08259	17.68725	330
Money Supply	2.359542	0.088133	2.111903	2.550851	330
Fixed Asset Investment	1.657923	0.036115	1.576605	1.731033	330
Industrial Structure	1.505491	0.012828	1.462365	1.527158	330

Technological innovation (measured by R&D investment) has a mean value of 2.6764 with a small standard deviation (0.0979), reflecting a consistent level of innovation input over time. The interaction term "electronic payment × technological innovation" shows the highest mean (14.6011) and a moderate standard deviation (1.3921), indicating the potential for meaningful synergistic effects on economic growth. The control variables: money supply (mean = 2.3595), fixed asset investment (mean = 1.6579), and industrial structure (mean = 1.5055), that all exhibit low dispersion, reflecting the relative stability of macroeconomic fundamentals. These statistics offer empirical grounding for the theoretical framework, which investigates the effects of electronic payment, e-commerce and technological innovation on China's economic growth.

Diagnostic Test

The selection of the POLS over alternative panel data models is guided by the results of the Breusch–Pagan Lagrange Multiplier test (Breusch & Pagan, 1979). The decision between the fixed effects (FE) and random effects (RE) models is informed by the Hausman specification test, which is employed to verify the consistency and efficiency of the chosen model in relation to the underlying data structure (Hoechle, 2007).

Impact of electronic payment on economic growth: Model 1

Table 2

Breusch and Pagan Lagrangian multiplier test for random effects for Model 1

Statistic	**GDP**	**e**	**u**
Var	0. 7435062	0. 0163687	0. 0150222
SD = sqrt (Var)	0.8622681	0.1279403	0. 122565
Test: Var(u) = 0			
$chibar^2(01)$	173.18		
Prob > $chibar^2$	0.0000		

Based on Table 2, which reports the results of the Breusch and Pagan Lagrangian Multiplier (LM) test for random effects in Model 1 (assessing the impact of electronic payment on economic growth), the null hypothesis that the variance of the individual-specific error component (u) is zero is decisively rejected. Specifically, the test statistic $chibar^2(01)$ is 173.18 with a p-value of 0.0000, demonstrating strong statistical significance. This result confirms that random effects are present and are statistically preferred to a pooled OLS specification. The estimated variance of the dependent variable GDP is 0.7435 (SD = 0.8623), while the variances for the idiosyncratic error term (e) and the panel-level effect (u) are 0.0164 and 0.0150, respectively. The presence of significant panel-level variance supports the application of panel data estimation techniques in analysing the relationship between electronic payment and economic growth.

Table 3

Random versus fixed effects model: Hausman test for Model 1

Variable	**(b) Fixed**	**(B) Random**	**(b-B) Difference**	**Sqrt (diag(V_b-V_B)) Std. Err.**
Electronic Payment	0.0925515	0.0623776	0.0301738	.
Money Supply	0.1511875	0.254995	-.1038075	.
Fixed Asset Investment	0.2935043	0.4738046	-.1803003	0.0211219
Industrial Structure	3.088921	2.21814	0.8707803	0.280196
chi^2 (6)	68.02			
Prob > chi^2	0.0000			

Table 3 presents the results of the Hausman test for Model 1, which compares the fixed effects and random effects estimators to assess the appropriateness of the model specification. The test yields a chi-squared statistic of 68.02 with a p-value of 0.0000, leading to the strong rejection of the null hypothesis that the random effects estimator is both consistent and efficient. This result indicates that the fixed effects model is the more appropriate specification for analysing the impact of electronic payment on economic growth.

Table 4
Diagnostic checks and serial correlation for Model 1

Diagnostic Checks					Serial Correlation	
Multicollinearity			Heteroskedasticity			
Variable	VIF	1/VIF	Test	Value	Test	Value
Money Supply	3.82	0.261869	chi2 (30)	805.88	F (1, 29)	1.557
Electronic Payment	2.65	0.377250	Prob > chi2	0.0000	Prob > F	0.2221
Fixed Asset Investment	1.95	0.512513				
Industrial Structure	1.49	0.672934				
Mean VIF	2.48					

Table 4 presents the results of diagnostic checks and serial correlation analysis for Model 1, which assess the robustness and specification validity of the regression model evaluating the effect of electronic payment on economic growth. Multicollinearity check shows the variance inflation factor (VIF) values for all variables are below the conventional threshold of 10, with a mean VIF of 2.48, suggesting the absence of serious multicollinearity. Heteroskedasticity test: the chi-squared statistic is 805.88 with a p-value < 0.0000, revealing statistically significant heteroskedasticity in the residuals. This violation of the homoskedasticity assumption necessitates the application of robust standard errors in the fixed effects regression to ensure valid statistical inference. Serial correlation test: The test yields an f-statistic of 1.557 with a p-value of 0.2221, indicating the absence of significant first-order autocorrelation. Therefore, serial correlation does not pose a specification concern in this model. In summary, while Model 1 is not affected by multicollinearity or serial correlation, it does exhibit heteroskedasticity, necessitating the use of heteroskedasticity-robust standard errors in subsequent estimation procedures.

Impact of e-commerce on economic growth: Model 2

Table 5
Breusch and Pagan Lagrangian multiplier test for random effects for Model 2

Statistic	GDP	e	u
Var	0. 7435062	0.0193957	0.0148345
SD = sqrt (Var)	0.8622681	0.1392683	0.121797
Test: Var(u) = 0			
$chibar^2(01)$	204.29		
Prob > $chibar^2$	0.0000		

Table 5 reports the Breusch and Pagan Lagrangian Multiplier (LM) test for random effects in Model 2, which assesses the influence of e-commerce on economic growth. The null hypothesis assumes no panel-level effects. The test yields a $chibar^2(01)$ statistic of 204.29 with a p-value of 0.0000, leading to strong rejection of the null hypothesis and confirming the presence of significant panel-level heterogeneity. The estimated variance components are as follows: GDP (dependent variable) exhibits a variance of 0.7435 with a standard deviation of 0.8623; the idiosyncratic error term (e) has a variance of 0.0194 (SD = 0.1393); and the random effect component (u) has a variance of 0.0148 (SD = 0.1218). These results support the use of panel data estimation techniques, such as random or fixed effects models for analysing Model 2. Given the significance of the panel-level variance, a pooled OLS model is statistically unsuitable, and the choice between random and fixed effects requires further specification testing through the Hausman test.

Table 6
Random versus fixed effects model: Hausman test for Model 2

Variable	(b) Fixed	(B) Random	(b-B) Difference	Sqrt (diag(V_b-V_B)) Std. Err.
Electronic Payment	0.1266125	0.1480912	-.0214787	0.0082971
Money Supply	0.2347537	0.2573942	-.0226405	0.0035362
Fixed Asset Investment	0.3752616	0.4865089	-.1112473	0.0262292
Industrial Structure	3.640409	1.817509	1.822901	0.3571869
chi^2 (6)	49.26			
Prob > chi^2	0.0000			

Table 6 presents the Hausman test results for Model 2, comparing fixed and random effects estimators to assess the appropriate specification for analysing the impact of e-commerce on China's economic growth. The test yields a chi-squared statistic of 49.26 with a p-value of 0.0000, leading to strong rejection of the null hypothesis that the random effects estimator is consistent. Therefore, the fixed effects model is the more appropriate specification for estimating Model 2. Overall, the Hausman test confirms that the fixed effects model better accounts for unobserved heterogeneity across provinces and is more suitable for drawing robust inferences in Model 2

Table 7
Diagnostic checks and serial correlation for Model 2

Diagnostic Checks					Serial Correlation	
Multicollinearity			Heteroskedasticity			
Variable	VIF	1/VIF	Test	Value	Test	Value
Money Supply	5.21	0.191817	chi2 (30)	4850.55	F (1, 29)	2.257
E-commerce	4.78	0.209010	Prob > chi2	0.0000	Prob > F	0.1438
Fixed Asset Investment	1.95	0.511847				
Industrial Structure	1.63	0.614673				
Mean VIF	3.39					

Table 7 presents the diagnostic checks and serial correlation test results for Model 2, which analyses the effect of e-commerce on economic growth. Multicollinearity check: all variance inflation factor (VIF) values fall below the commonly accepted threshold of 10, indicating that multicollinearity is not a major concern. Money supply exhibits the highest VIF at 5.21, followed by E-commerce at 4.78, that both reflecting moderate multicollinearity, yet remaining within acceptable bounds. The mean VIF of 3.39 supports the overall stability of the model specification. Heteroskedasticity test: The $chi^2(30)$ statistic is 4850.55 with a p-value of 0.0000, confirming a violation of the homoskedasticity assumption and necessitating the use of robust standard errors for valid inference. Serial correlation test: the F-statistic of 2.257 with a p-value of 0.1438 indicates the absence of statistically significant serial correlation in the residuals of Model 2; hence, no adjustments for autocorrelation are necessary. In summary, Model 2 is not affected by severe multicollinearity or serial correlation, but heteroskedasticity is present, underscoring the necessity of applying heteroskedasticity-robust standard errors in fixed effects estimation.

Interaction between electronic payment and technological innovation on economic growth: Model 3

Table 8

Breusch and Pagan Lagrangian Multiplier test for random effects for Model 3

Statistic	**GDP**	**e**	**u**
Var	0.7435062	0.0143222	0.0101604
SD = sqrt (Var)	0.8622681	0.1196754	0.1007987
Test: Var(u) = 0			
$chibar^2(01)$	125.48		
Prob > $chibar^2$	0.0000		

Table 8 presents the results of the Breusch and Pagan Lagrangian Multiplier (LM) test for random effects in Model 3, which investigates the interactive effects of electronic payment and technological innovation on China's economic growth. The variance of the dependent variable GDP is 0.7435 (SD = 0.8623), consistent with previous models. The idiosyncratic error component (e) exhibits a variance of 0.0143, while the individual-specific random effect (u) has a variance of 0.0102, suggesting modest variability both within and between cross-sectional units. The LM test yields a $chibar^2(01)$ statistic of 125.48 with a p-value of 0.0000, leading to strong rejection of the null hypothesis that Var(u) = 0. These results confirm the presence of significant unobserved heterogeneity across entities, thus supporting the use of panel data estimators over pooled OLS in Model 3. Given the presence of significant panel-level variance, a Hausman test is warranted to determine whether to employ fixed effects or random effects for consistent estimation.

Table 9

Random versus fixed effects model: Hausman test for Model 3

Variable	**(b) Fixed**	**(B) Random**	**(b-B) Difference**	**sqrt(diag(V_b-V_B)) Std. Err.**
Electronic Payment	0.2759458	0.3241144	-0.0481686	.
Technological Innovation	0.2122493	0.2994648	-0.0872155	.
Electronic Payment × Technological Innovation	-0.0126975	-0.0177371	0.0050396	.
Money Supply	0.1045724	0.1842381	-0.0796657	.
Fixed Asset Investment	0.2543526	0.3786038	-0.1242512	0.0197681
Industrial Structure	2.371179	1.023559	1.347627	0.2866028
$chi^2(6)$	196.46			
Prob > chi^2	0.0000			

Table 9 presents the Hausman test results for Model 3, which examines the interactive effects of electronic payment and technological innovation on economic growth. The objective is to assess whether the fixed effects or random effects model is more appropriate. The Hausman test yields a chi-squared statistic of 196.46 with a p-value of 0.0000, leading to a strong rejection of the null hypothesis that the random effects estimates are consistent. This result confirms that the fixed effects model is preferred for Model 3, owing to the correlation between unobserved individual effects and the explanatory variables. Substantial differences are observed between the fixed and random effects estimates, particularly for industrial structure and fixed asset Investment, suggesting that neglecting entity-specific heterogeneity may result in biased estimates. Although the difference in the coefficient of the interaction term (0.0050) is relatively small indicating stability the overall rejection of the random effects assumption supports the application of fixed effects estimation with heteroskedasticity-robust standard errors for drawing reliable conclusions in Model 3.

Table 10
Diagnostic checks and serial correlation for Model 3

Diagnostic Checks					**Serial Correlation**	
Multicollinearity			Heteroskedasticity			
Variable	VIF	1/VIF	Test	Value	Test	Value
Electronic Payment	2.29	0.437617	chi2 (30)	726.60	F (1, 29)	1.691
Technological Innovation	5.20	0.192205	Prob > chi2	0	Prob > F	0.2038
Electronic Payment× Technological Innovation	8.24	0.121392				
Money Supply	5.18	0.193228				
Fixed Asset Investment	3.67	0.272444				
Industrial Structure	2.15	0.464475				
Mean VIF	4.455					

Table 10 summarizes the diagnostic checks and serial correlation test results for Model 3, which examines the interactive effects of electronic payment and technological innovation on economic growth. In summary, Model 3 is not affected by severe multicollinearity or serial correlation but does exhibit heteroskedasticity, which must be corrected through the application of heteroskedasticity-robust standard errors. While the interaction term contributes to moderate multicollinearity, it remains within tolerable limits for panel data estimation.

Estimation Results and Robustness Analysis

To enhance the robustness of the empirical findings, a series of diagnostic tests was performed to evaluate multicollinearity, heteroskedasticity, and serial correlation (Burnside, 1994). Variance Inflation Factor (VIF) diagnostics reveal no substantial multicollinearity, as all VIF values remain below the standard threshold of 10 (Farley et al., 2013). In addition, the Breusch–Pagan test for heteroskedasticity and the Durbin–Watson test for serial correlation were employed to detect the presence of heteroskedasticity and autocorrelation in the residuals (Bilkova, 2023). While multicollinearity and serial correlation are not considered problematic in the estimated models, heteroskedasticity is present and necessitates the application of robust standard errors to obtain consistent and reliable coefficient estimates.

Table 11
Use robust standard error estimation for Model 1

VARIABLES	(1) Pooled OLS	(2) RE Model	(3) FE Model	(4) FE Robust Model
Electronic Payment	0.0428***	0.0624***	0.0926***	0.0926***
	(0.0130)	(0.0103)	(0.00947)	(0.0158)
Money Supply	0.461***	0.255***	0.151***	0.151***
	(0.0246)	(0.0279)	(0.0270)	(0.0495)
Fixed Asset Investment	0.507***	0.474***	0.294***	0.294***
	(0.0197)	(0.0310)	(0.0375)	(0.0634)
Industrial Structure	0.841***	2.218***	3.089***	3.089***
	(0.246)	(0.395)	(0.485)	(0.479)
Constant	-3.935***	-7.790***	-9.097***	-9.097***
	(1.060)	(1.721)	(2.104)	(1.924)
Observations	330	330	330	330
R-squared	0.9412	0.7463	0.7684	0.7684
Number of Province	30	30	30	30

Note: *, **, and *** denote the 10%, 5%, and 1% levels of significance, respectively.

Standard errors in parentheses: this indicates that the values in parentheses below the estimated coefficients represent the standard errors.

Table 11 presents the regression results for Model 1, which examines the impact of electronic payment on economic growth, estimated using four econometric techniques: pooled OLS, random effects (RE), fixed effects (FE), and fixed effects with robust standard errors. The coefficient for electronic payment increases across specifications, rising from 0.0428 % in the pooled OLS model to 0.0926% in the fixed effects model, indicating that failure to account for unobserved heterogeneity which as in pooled OLS and RE models that may lead to an underestimation of its true effect on economic growth. The fixed effects robust model (Column 5) is considered the most reliable specification, as it accounts for heteroskedasticity identified in prior diagnostic tests. Control variables such as money supply, fixed asset investment, and industrial structure exhibit consistently positive and statistically significant coefficients across all models, aligning with their expected positive relationship with GDP. The relatively high R-squared values which particularly 0.9412% for OLS and 0.7684% for FE that suggest strong explanatory power. These results provide robust evidence for a positive and significant relationship between electronic payment and economic growth in China. Given the outcomes of the Hausman test and heteroskedasticity diagnostics, the Fixed Effects Robust model offers the most statistically credible basis for policy interpretation.

Table 12
Use robust standard error estimation for Model 2

VARIABLES	(1) Pooled OLS	(2) RE Model	(3) FE Model	(4) FE Robust Model
E-commerce	0.152***	0.148***	0.127***	0.127***
	(0.0190)	(0.0199)	(0.0216)	(0.0311)
Money Supply	0.354***	0.257***	0.235***	0.235***
	(0.0267)	(0.0265)	(0.0267)	(0.0763)
Fixed Asset Investment	0.500***	0.487***	0.375***	0.375***
	(0.0183)	(0.0293)	(0.0393)	(0.102)
Industrial Structure	0.336	1.818***	3.640***	3.640***
	(0.239)	(0.381)	(0.522)	(0.623)
Constant	-1.305	-6.785***	-13.51***	-13.51***
	(1.050)	(1.642)	(2.227)	(2.406)
Observations	330	330	330	330
R-squared	0.9493	0.7117	0.7256	0.7256
Number of Province	30	30	30	30

Note: *, **, and *** denote the 10%, 5%, and 1% levels of significance, respectively.
Standard errors in parentheses: this indicates that the values in parentheses below the estimated coefficients represent the standard errors.

Table 12 reports the regression results for Model 2, which investigates the impact of e-commerce on economic growth while controlling for key macroeconomic factors. Four estimation techniques are employed: pooled ordinary least squares (OLS), random effects (RE), fixed effects (FE), and fixed effects with robust standard errors. E-commerce demonstrates a consistently positive and highly significant association with GDP across all models, with the largest coefficients observed in the OLS (0.152) and RE (0.148) models, and a slightly reduced coefficient under FE (0.127), suggesting a robust and persistent contribution to economic growth even after accounting for province-level fixed effects. Control variables such as money supply and fixed asset investment also exert positive and significant effects, although their magnitudes decline in the FE models, implying potential overestimation in the pooled and random effects specifications. The effect of industrial structure increases substantially in the FE models reaching 3.640 that highlighting substantial heterogeneity in provincial economic structures. The fixed effects robust model (Column 5) is considered the most reliable specification, as it corrects for heteroskedasticity, as confirmed by prior diagnostic tests. Overall, the findings reinforce that e-commerce contributes significantly to China's economic growth, even when structural and macroeconomic variations are considered. Given its ability to control for unobserved heterogeneity and heteroskedasticity, the fixed effects model with robust standard errors (Column 5) is the most appropriate and statistically sound specification for policy and theoretical interpretation.

Table 13
Use robust standard error estimation for Model 3

VARIABLES	(1) Pooled OLS	(2) RE Model	(3) FE Model	(4) FE Robust Model
Electronic Payment	0.255***	0.324***	0.276***	0.276***
	(0.0744)	(0.0708)	(0.0641)	(0.0875)
Technological Innovation	0.317***	0.299***	0.212***	0.212***
	(0.0437)	(0.0427)	(0.0398)	(0.0575)
Electronic Payment × Technological Innovation	-0.0141***	-0.0177***	-0.0127***	-0.0127**
	(0.00482)	(0.00463)	(0.00422)	(0.00603)
Money Supply	0.329***	0.184***	0.105***	0.105***
	(0.0249)	(0.0270)	(0.0262)	(0.0366)
Fixed Asset Investment	0.341***	0.379***	0.254***	0.254***
	(0.0234)	(0.0301)	(0.0360)	(0.0544)
Industrial Structure	-0.574**	1.024***	2.371***	2.371***
	(0.257)	(0.369)	(0.468)	(0.447)
Constant	0.798	-5.099***	-8.052***	-8.052***
	(1.232)	(1.671)	(2.060)	(1.897)
Observations	330	330	330	330
R-squared	0.9560	0.7786	0.7987	0.7987
Number of Province	30	30	30	30

Note: *, **, and *** denote the 10%, 5%, and 1% levels of significance, respectively.
Standard errors in parentheses: this indicates that the values in parentheses below the estimated coefficients represent the standard errors.

Table 13 presents the regression results for Model 3, which explores the interaction effect between electronic payment and technological innovation on economic growth. Both Electronic Payment and Technological Innovation each exert a positive and statistically significant effect on GDP, indicating their individual contributions to economic development. However, the interaction term (electronic payment × technological innovation) is negative and statistically significant, suggesting that the marginal effect of one on GDP diminishes in the presence of the other. This finding may reflect diminishing returns, coordination inefficiencies, or misalignment between digital infrastructure and innovation outputs across Chinese provinces. Control variables: money supply, fixed asset investment, and industrial structure are also statistically significant and consistent with theoretical expectations. The R-squared value of 0.7987 indicates that the model possesses strong explanatory power, even after accounting for province-level heterogeneity and correcting for heteroskedasticity. Model 3, as shown in Table 13, Column 5, that highlights the need for a more coordinated policy approach. While both electronic payment and technological innovation are essential growth drivers, their combined effect may generate unintended inefficiencies without strategic integration. Policymakers are therefore advised to implement harmonized policies that align financial digitalization efforts with regional R&D capacities to mitigate potential overlaps or counterproductive interactions. The fixed effects model with robust standard errors emerges as the most statistically valid specification, supported by diagnostic assessments including the Hausman test and heteroskedasticity corrections.

Conclusion and Policy Implications

Conclusion

This study offers robust empirical evidence on the intricate relationships among electronic payment, e-commerce, technological innovation, and economic growth in China over the period 2013–2023. Utilizing rigorous econometric techniques which specifically fixed effects models with robust standard errors that the analysis addresses three fundamental research questions that explore the mechanisms by which digital transformation shapes economic development.

The first research question investigated whether electronic payment adoption promotes China's economic growth. The empirical findings provide strong support for this hypothesis, with the fixed effects robust model demonstrating that electronic payment systems exert a positive and statistically significant impact on GDP growth. The second research question examined whether e-commerce expansion contributes to China's economic growth. The analysis reveals a robust and statistically significant association between e-commerce development and GDP growth. The third and most theoretically nuanced research question assessed whether the interaction between electronic payment and technological innovation generates interactive effects on economic growth. Surprisingly, the empirical results indicate a negative and statistically significant interaction term, suggesting that the marginal contribution of electronic payment to GDP declines when accompanied by higher levels of technological innovation.

The control variables across all models behave in accordance with theoretical expectations, with money supply, fixed asset investment, and industrial structure exhibiting statistically significant positive associations with economic growth. These findings lend empirical support to the theoretical framework and reinforce confidence in the robustness of the primary results. The diagnostic tests confirm that the fixed effects models with robust standard errors constitute the most appropriate econometric specification, effectively addressing heteroskedasticity and accounting for unobserved provincial heterogeneity.

This study offers several important theoretical and contextual contributions to the literature on electronic payment, e-commerce and technological innovation led economic growth. Theoretically, it extends existing knowledge by empirically identifying both the distinct and interactive effects of electronic payment, e-commerce, and technological innovation on economic growth. By incorporating both individual variables and interaction terms within a panel data framework, the study moves beyond conventional linear models and a negative interaction between electronic payment systems and technological innovation. This finding highlights the need for more nuanced theoretical frameworks that account for digital-institutional alignment. Contextually, the research deepens understanding of China's distinctive digital transformation, characterized by state-led infrastructure development, rapid technological diffusion, and institutional particularities. These findings provide actionable insights for emerging economies seeking to emulate China's digitalization strategy while avoiding potential inefficiencies in integrating technological innovation and financial systems.

Policy Implications

The empirical findings yield several critical policy implications for advancing sustainable economic growth via digital transformation in China, as well as for other developing economies undertaking comparable digitalization initiatives.

(1) Strengthening electronic payment infrastructure: the positive and statistically significant impact of electronic payment systems on economic growth underscores the need for sustained policy support aimed at expanding digital payment infrastructure. Policymakers should prioritize investments in payment system security, interoperability, and accessibility to maximize the macroeconomic benefits of digital finance. This includes developing robust regulatory frameworks that balance the promotion of innovation with the protection of consumer interests, to facilitate scalable implementation of electronic payment systems across diverse sectors and regions. (2) Accelerating e-commerce development: the consistently positive association between e-commerce development and economic growth warrants continued policy prioritization of digital commerce platforms. Governments should focus on creating an enabling environment for e-commerce expansion by enhancing digital infrastructure, streamlining regulatory procedures, and strengthening logistics and delivery capabilities. (3) Coordinated innovation and digitalization policies: the negative interaction effect observed between electronic payment systems and technological innovation underscores the necessity for coordinated digital transformation strategies. Rather than advancing electronic payment systems and R&D investments in isolation, governments should pursue integrated policies that ensure complementarity between these investments. This could involve establishing innovation hubs focused on financial technology, creating incentive mechanisms to foster collaboration between digital payment providers and research institutions, and implementing synchronized timelines for infrastructure and innovation deployment.

Limitations and Future Research Directions

While this study provides valuable insights into the interrelationships among electronic payment, e-commerce, technological innovation, and economic growth, several limitations offer avenues for future research. The analysis focuses specifically on the Chinese context, which may constrain the generalizability of the findings to other economic contexts characterized by different institutional frameworks, market structures, and stages of development. Future research should examine these relationships across diverse international settings to assess the external validity and broader applicability of the conclusions.

The negative interaction effect between electronic payment and technological innovation merits further empirical investigation to uncover the underlying mechanisms that shape this relationship. Future studies should examine the temporal dynamics of these interactions, explore sector-specific effects, and investigate the role of institutional factors in mediating or moderating these relationships. Additionally, while the use of R&D investment as a proxy for technological innovation is well established in the literature, it may not fully capture the multifaceted nature of innovation processes, highlighting the need for more nuanced and multidimensional indicators of innovation.

The study's focus on aggregate effects on economic growth may obscure important distributional dynamics and sector-specific impacts. Future research should examine how digital transformation influences various economic sectors, income groups, and geographic regions to provide a more comprehensive understanding of the social and economic implications of digitalization policies. Finally, the rapid pace of technological change underscores the necessity for continuous empirical inquiry to monitor how these relationships evolve over time and respond to emerging technological developments and policy interventions.

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