

Seeing Through Uncertainty: How Digitalization Shapes Managerial Perception and Firm Investment^{*}

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This study investigates how digital transformation affects firm investment by shaping managerial perceptions of economic policy uncertainty (FEPU). Using a two-stage instrumental variable (IV) mediation framework based on Chinese listed firms, we find that digitalization promotes investment by reducing FEPU. Digital tools enhance managerial risk assessment, helping correct overestimated uncertainty and reduce underinvestment, while leaving underestimated risks unaffected and leading to overinvestment. These effects are more pronounced in firms with stronger managerial incentives, where agency problems amplify the strategic use of uncertainty. Our findings contribute to the literature by linking technology adoption with behavioral responses to uncertainty.

Key Words: Digitalization; FEPU; Uncertainty perception; Firm investment.

JEL Classification Numbers: D22, E22, O33, D81.

1. INTRODUCTION

In recent years, digital transformation has emerged as a critical driver of corporate strategy, reshaping the way firms operate and invest (Jardak and Hamad, 2022; Tian et al., 2022; Li et al., 2023; Zhang et al., 2023). The adoption of digital technologies, such as artificial intelligence, big data, and cloud computing, is not only changing internal operations but also influencing strategic decision-making, including investment behaviors (Chen and Jiang, 2024; Yu et al., 2024). As firms become more digitalized, they gain enhanced capabilities for data processing (Li et al., 2023; Capurro et

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al., 2022), decision-making (Colombari et al., 2023; Amato et al., 2024), and risk management (Yin et al., 2024; Jiang et al., 2025), which could potentially alter their investment strategies.

While a growing body of literature recognizes that digital technologies improve firms' information processing capabilities, such an operational-level explanation remains insufficient to capture the profound psychological and cognitive shifts digitalization induces in managers. To bridge this gap, we draw upon theories of Knightian uncertainty and the attention-based view to provide a deeper theoretical foundation. Economic policy changes often manifest as Knightian uncertainty (Bloom, 2014; Gulen and Ion, 2016). The ambiguous, unquantifiable macro-shocks trigger managerial anxiety and typically lead to delayed corporate investment (Suh and Yang, 2021; Kong et al., 2022). Digital technologies like data analytics and knowledge graphs act as a powerful attention-directing mechanism, which helps processing more information, filtering out macroeconomic noise, and extracting substantive policy signals (Townsend et al., 2025). By doing so, digitalization effectively transforms unquantifiable Knightian uncertainty into quantifiable, manageable risks, thereby significantly altering a firm's idiosyncratic perception of economic policy uncertainty (FEPU).

This transformation profoundly impacts managerial cognition. Even when facing the identical macro-level Economic Policy Uncertainty (EPU), firm-specific perceptions vary significantly depending on their digital infrastructure and managerial cognitive bandwidth (Cui et al., 2021). Digitalization mitigates the cognitive biases and panic caused by information overload, aligning managerial expectations more closely with rational forecasts (Mikalef et al., 2020; Babina et al., 2024). However, this digital empowerment may also act as a double-edged sword. As managers rely increasingly on sophisticated digital dashboards and predictive models, they may fall prey to the illusion of control (Langer, 1975). This cognitive bias can induce managerial overconfidence, leading decision-makers to believe they have fully hedged against policy risks (Zhang et al., 2020; Attah-Boakye et al., 2023), which may inadvertently cause them to ignore genuine tail risks and engage in suboptimal investment behaviors.

Despite the growing attention to digitalization and macro-uncertainty, few studies have systematically integrated these concepts to examine the causal chain connecting digital transformation, FEPU, and corporate investment. More importantly, the mechanisms through which digitalization influences investment behavior by altering firms' perceptions of economic policy uncertainty remain underexplored. This gap in the literature provides the motivation for this paper, which aims to investigate how digital transformation influences firm investment through changes in FEPU.

By focusing on China's publicly listed firms, this paper uses textual analysis of firms' management discussions and analyses (MD&A) in annual

reports to measure both digitalization and FEPU. We then empirically examine the interactions between digitalization and FEPU, and their impacts on corporate investment. Applying a two-stage least squares (2SLS) mediation analysis framework, we estimate the causal effect on firm investment of digitalization and quantify the proportion of this effect mediated through FEPU. Our results confirm that digital transformation significantly increases firm investment, and importantly, we quantify that a substantial proportion of this effect is causally mediated through the reduction of FEPU.

Crucially, our mechanism analyses reveal a dual effect on investment efficiency that aligns with our behavioral theoretical framework. For firms inherently oversensitive to policy shocks, digitalization corrects their pessimistic perception bias, effectively alleviating underinvestment. Conversely, for other firms, the digitalization-induced reduction in FEPU exacerbates overinvestment. This finding empirically substantiates the illusion of control theory, indicating that while digital tools enhance risk assessment, they can also foster managerial overconfidence and blind spots regarding macroeconomic risks. Furthermore, we find that managerial incentives significantly amplify both the direct and indirect positive impacts of digitalization on investment, highlighting the vital interaction between corporate governance and digital strategy.

This paper contributes to the literature by highlighting the complex interaction between digitalization, FEPU, and firm investment. Firstly, while existing literature confirms the improvement effect of digitalization on firm investment and current performance (e.g., Jardak and Hamad, 2022; Wen et al., 2022; Chen and Srinivasan, 2024; Chen and Jiang, 2024; Yu et al., 2024), our study integrates Knightian uncertainty and the attention-based view to provide a nuanced cognitive mechanism. We demonstrate how digital tools act as an attention-directing mechanism that filters macroeconomic noise and reshapes managerial risk perception, thereby offering a novel theoretical perspective on the micro-level consequences of digitalization.

Additionally, our analyses emphasize the potential influence of digitalization altering risk perceptions. The application of digital technologies may be limited by the cognitive bandwidth of management, and the resulting decline in FEPU could be misguided. We introduce the illusion of control theory to explain how sophisticated digital tools can lead to an overly optimistic attitude toward economic policy and excessive confidence in risk management, thereby overlooking genuine tail risks. This concern aligns with the more cautious viewpoints expressed in the literature (Andreou et al., 2017; Kim and Kung, 2017), suggesting that the increase in investment driven by digitalization-induced FEPU reduction is not always indicative of an optimal outlook, but can exacerbate overinvestment. This insight

is crucial for understanding the dual effects of digitalization on corporate strategy and risk management.

Lastly, our paper adds to the literature by emphasizing the crucial role of managerial incentives in navigating the relationship between digitalization, uncertainty perception, and firm investment. While existing research largely overlooks how management incentives influence the outcomes of digital transformation (Hua and Yu, 2023; Zhou et al., 2024), our findings show that managerial incentives significantly enhance the positive impact of digitalization on firm investment. Furthermore, by employing a rigorous causal mediation framework, we accurately disentangle the FEPU reduction channel. This contribution highlights the vital interaction between corporate governance and digital strategy when assessing the broader implications of digitalization on firm performance.

2. HYPOTHESIS DEVELOPMENT

In recent years, digitalization has emerged as a central topic in corporate research. A growing body of literature has examined the implications of digital transformation, demonstrating that it drives improvements in key operational outcomes, including overall firm performance (Cheng et al., 2023; Hossain and Sultana, 2024), productivity (Nucci et al., 2023), and innovation (Capurro et al., 2022; Wen et al., 2022; Li et al., 2023). A parallel stream of research has begun to explore the specific mechanisms through which digital transformation influences firm investment decisions, highlighting channels such as alleviating financial frictions (Chen and Jiang, 2024), reducing agency costs (Wu and Lu, 2023), and accelerating responsiveness to market changes (Yan et al., 2024). However, the psychological and cognitive channels connecting digitalization, firm-specific uncertainty perception, and investment behavior remain largely unexplored.

At the macro level, the dampening effect of economic policy uncertainty (EPU) on corporate investment has been widely documented (Gulen and Ion, 2016; Chen et al., 2019; Kong et al., 2022). Drawing on real options theory, firms facing high uncertainty tend to delay or reduce irreversible investments. However, macro-level EPU does not uniformly impact all firms; individual responses depend heavily on firm-specific risk exposures and managerial perceptions (Bloom et al., 2018; Cui et al., 2021). To understand how digital transformation alters this dynamic, it is necessary to examine the theoretical nature of policy uncertainty. Macroeconomic policy shifts typically manifest as Knightian uncertainty, where outcomes are ambiguous and probabilities cannot be accurately quantified (Bloom, 2014; Gulen and Ion, 2016). EPU inherently triggers managerial anxiety and conservative decision-making. We posit that the fundamental economic value of digital technologies lies in their ability to transform unquantifiable

Knightian uncertainty into quantifiable, manageable risk. By leveraging big data analytics and predictive algorithms, firms can probabilistically model macroeconomic shocks, thereby significantly reducing the subjective ambiguity perceived by management.

Furthermore, we conceptualize this transformation through the attention-based view of the firm (Ocasio, 1997). Under conditions of bounded rationality, managers face severe cognitive constraints when exposed to the massive influx of complex policy signals (Rhee and Leonardi, 2024). In traditional settings, this information overload creates noise that exacerbates perceived uncertainty. Digitalization effectively functions as an attention-directing mechanism (Snyder et al., 2026). Advanced information systems and knowledge graphs filter out irrelevant macroeconomic noise, allowing managers to allocate their limited cognitive bandwidth to substantive policy signals. By systematically alleviating information processing bottlenecks and mitigating the panic associated with information overload, digitalization structurally lowers a firm's idiosyncratic perception and expression of EPU.

Finally, this technological empowerment profoundly alters the psychological state of decision-makers. We argue that the deployment of sophisticated digital tools and predictive models can induce an illusion of control. As digital tools enhance internal control and risk visualization, managers become increasingly confident in their forecasting capabilities (Dietvorst et al., 2018). This elevated confidence leads them to tolerate greater levels of external volatility, raising their threshold for considering policy changes as significant threats (Dánielsson and Uthemann, 2022). Consequently, macroeconomic fluctuations that would traditionally trigger the delay of investments under the real options framework are no longer perceived as prohibitive risks. While this illusion of control successfully mitigates the paralyzing effects of FEPU and encourages firms to proceed with investments, it also foreshadows a potential behavioral pitfall. Overconfidence may blind managers to genuine tail risks, inadvertently setting the stage for overinvestment.

In sum, digitalization acts as a pivotal cognitive and psychological mechanism in corporate strategy. By filtering macroeconomic noise and fostering managerial confidence, digital transformation fundamentally reshapes firms' perceptions of EPU. This reduction in FEPU, in turn, lowers the perceived hurdle rate for capital expenditures and stimulates investment. Therefore, we propose the following hypothesis:

Hypothesis: Digitalization positively influences firm investment by mitigating firms' perceived economic policy uncertainty (FEPU).

3. MODEL SPECIFICATION, VARIABLES, AND DATA

3.1. Model specification

We treat FEPU as one of the potential channels through which digitalization influences firm investment. Given that uncertainty is one of the most critical factors in corporate investment decision-making, the perception, processing, and expression of uncertainty are heavily dependent on a firm's information capabilities, which are directly related to the application of digital technologies.

To robustly examine the complex interplay between FEPU, digitalization, and investment, employing a causal mediation analysis in an instrumental variable (IV) setting is essential. We adopt the 2SLS mediation analysis framework developed by Dippel et al. (2020), which has been widely applied in recent empirical studies to unpack causal mechanisms (e.g., Boerner et al., 2021; Liu et al., 2023; Ackermann et al., 2024). Traditional IV approaches generally require separate instruments for each endogenous variable (i.e., one for the treatment and one for the mediator). However, Dippel et al. (2020) mathematically prove that even when both the treatment (digitalization) and the mediator (FEPU) are potentially endogenous, a single instrument is sufficient to identify both the causal treatment effect and the mediation effect, provided a specific identification assumption is met.

We construct the IV by selecting the average digitalization values of other firms in the same province and industry. The construction of this IV is inspired by a series of studies (Guo et al., 2023; Chen and Jiang, 2024), with the underlying logic reflecting the extent to which firms in a particular industry within a given province are embedded in a regionally clustered digital environment. A higher average level of digitalization among peer firms suggests stronger regional digital externalities, providing a strong incentive for individual firms to upgrade their digital capabilities. This ensures the relevance of the IV to digitalization. Importantly, the average digitalization of peer firms is plausibly exogenous to the focal firm's idiosyncratic innovation shocks, satisfying the relevance and exclusion restrictions required for valid instrumentation.

Specifically, the estimation framework consists of two sets of 2SLS regression models. As shown in Equations (1) to (3), the first set of 2SLS regressions aims to estimate the total effect of digitalization on firm investment (θ_1) and the impact of digitalization on FEPU (β_1).

$$\text{Digit}_{i,t} = \alpha_0 + \alpha_1 Z_{i,t} + \alpha_2 X_{i,t} + \mu_i + \tau_t + \varepsilon_{i,t} \quad (1)$$

$$\text{FEPU}_{i,t} = \beta_0 + \beta_1 \widehat{\text{Digit}}_{i,t-1} + \beta_2 X_{i,t-1} + \mu_i + \tau_t + \varepsilon_{i,t} \quad (2)$$

$$\text{Inv}_{i,t} = \theta_0 + \theta_1 \widehat{\text{Digit}}_{i,t-1} + \theta_2 X_{i,t-1} + \mu_i + \tau_t + \varepsilon_{i,t} \quad (3)$$

Where $\text{Inv}_{i,t}$ refers to firm investment, proxied by the sum of net expenditures on fixed assets, intangible assets, and other long-term assets divided by the total assets. $\widehat{\text{Digit}}_{i,t-1}$ is the fitted value of digitalization estimated from the first stage. $\text{FEP}_{i,t}$ denotes firm-level perception of economic policy uncertainty. $Z_{i,t}$ is the IV for digitalization. $X_{i,t}$ represents a set of control variables influencing firm investment. μ_i and τ_t are vectors of fixed effects that control for firm-specific shock, and annual changes that are consistent across all firms. $\varepsilon_{i,t}$ is the disturbance term. Lastly, the standard errors are clustered based on the firm level to allow correlations among firms.

To decompose the total effect into direct and indirect (mediated) effects, we conduct the second set of 2SLS regressions, as shown in Equations (4) and (5). It is crucial to clarify the econometric mechanics of this step to alleviate standard endogeneity concerns regarding the reuse of instruments. According to Dippel et al. (2020), the key identifying assumption of this mediation framework is $\rho_{TY} = 0$, meaning that endogeneity in the regression of investment on digitalization does not arise from unobserved confounders that jointly influence the treatment and the final outcome directly, but rather from confounders that jointly affect the treatment and the mediator ($\rho_{TM} \neq 0$). Under this assumption, a new exclusion restriction emerges, that is, $Z_{i,t}$ can serve as a valid instrument for the mediator $\text{FEP}_{i,t}$ when conditioned on the treatment $\text{Digit}_{i,t}$.

$$\text{FEP}_{i,t} = \gamma_1 + \gamma_2 \text{Digit}_{i,t} + \gamma_3 Z_{i,t} + \gamma_4 X_{i,t} + \mu_i + \tau_t + \varepsilon_{i,t} \quad (4)$$

$$\text{Inv}_{i,t} = \delta_1 + \delta_2 \text{Digit}_{i,t-1} + \delta_3 \widehat{\text{FEP}}_{i,t-1} + \delta_4 X_{i,t-1} + \mu_i + \tau_t + \varepsilon_{i,t} \quad (5)$$

Therefore, in Equation (4), the same instrument $Z_{i,t}$ is not being reused to instrument a second endogenous variable in a traditional sense. Instead, $\text{Digit}_{i,t}$ is included in the first-stage regression explicitly as a conditioning variable rather than an instrumented endogenous variable. By conditioning on $\text{Digit}_{i,t}$, the coefficient δ_3 isolates the exogenous variation in $\text{FEP}_{i,t}$ induced by $Z_{i,t}$ that is orthogonal to the treatment itself. Subsequently, in Equation (5), the fitted value $\widehat{\text{FEP}}_{i,t-1}$ is used to estimate the effect of FEP on investment conditional on digitalization (δ_3), as well as the direct effect of digitalization on firm investment (δ_2).

In this causal mediation analysis, the coefficients θ_1 , β_1 , δ_2 , and δ_3 are of our interest. The coefficients θ_1 captures the total effect of digitalization on firm investment, while δ_2 represents the direct effect net of the FEP channel. The indirect effect of digitalization on firm investment, mediated through its influence on FEP, is given by $\beta_1 \times \delta_3$. By dividing the indirect effect by the total effect, $\frac{\beta_1 \times \delta_3}{\theta_1}$ reveals the proportion of the total effect that can be explained by the mediator, FEP.

3.2. Variables

3.2.1. *Digitalization*

We measure corporate digitalization through textual analysis, a widely applicable methodology for most listed firms (Wen et al., 2022; Chen and Srinivasan, 2024; Chen and Jiang, 2024). This involves gathering policy documents and identifying key terms related to digital transformation. We then utilize a deep learning approach to pre-train annual reports, expanding the initial keyword set. The variable representing digitalization is constructed as the natural logarithm of the term frequency count of these keywords in the MD&A sections.

3.2.2. *Firm-specific economic policy uncertainty*

We follow literature (Hassan et al., 2019; Wang et al., 2023) to apply textual analysis to extract firms' perceptions and expressions of EPU from the MD&A sections. Specifically, we begin by identifying sentences that express EPU, which are determined based on the co-occurrence of "economics-related", "policy-related", and "uncertainty-related" terms. Only those sentences that include all types of terms are classified as reflecting managerial perceptions of EPU. Next, we count the frequency of above uncertainty-related terms in these sentences and use the natural logarithm of this count as a measure of the firm's expression and perception of EPU.

3.2.3. *Firm-level controls*

To minimize the potential influence of omitted variables, we follow literature (Guo et al., 2023; Chen and Jiang, 2024) to incorporate the following control variables: Size, Age, Lev, Tang, Cash, Growth, Tobin Q, CEO, and SOE. Size and Age are indicators of financing constraints. Specifically, we compute Size as the natural logarithm of total assets and Age as the natural logarithm of the number of years since the firm was listed. Liquidity constraints may also limit corporate investment. We use the debt-to-asset ratio (Lev) to capture a firm's solvency, while financial flexibility is measured by the proportion of cash and marketable securities relative to total assets (Cash). Additionally, Tangibility (Tang) is represented by the ratio of intangible assets to total assets, reflecting a firm's capacity for external financing. Tobin Q is employed as proxies for a firm's market value. Growth, representing a company's investment opportunities, is included as a control variable, calculated as the growth rate of total assets. CEO is coded as 1 if the firm's chairman also holds the CEO position; otherwise,

it is coded as 0. SOE, where 1 denotes a state-owned enterprise and 0 otherwise.

3.3. Data

This study uses a sample of publicly listed companies on the Shanghai and Shenzhen stock exchanges in China, comprising 3,552 firms with data spanning from 2010 to 2022, resulting in a total of 29,068 firm-year observations. Financial data for the companies are sourced from the CSMAR database. For text analysis and the calculation of digitalization and FEPU, the MD&A sections from the companies' annual reports are obtained from the official websites of the Shanghai and Shenzhen Stock Exchanges. Firms from the financial and real estate industries, as well as those under risk warning or facing imminent delisting, are excluded from the sample. Table 1 provides the definitions of the underlying variables, while Table 2 presents the descriptive statistics.

TABLE 1.

Variable definitions

Variables	Definition
Invt	The sum of net expenditures on fixed assets, intangible assets, and other long-term assets divided by the total assets
Digit	The natural log of term frequency count of digitalization-related keywords in MD&A sections.
FEPU	The natural log of term frequency count of EPU-related keywords in MD&A sections.
Size	The natural log of the firm's total book assets.
Lev	Total liability divided by total assets.
Age	The natural log of the number of years since the firm is listed.
Tang	Intangible assets divided by total assets.
Cash	Cash and short-term equivalents divided by total assets.
Growth	Assets growth rate.
Tobin Q	Market equity and net debt market value divided by total assets.
CEO	Indicator equals to one if the CEO is the chairman of the board of directors.
SOE	Indicator variable takes the value of one if the firm is state-owned, and zero otherwise.

TABLE 2.

Descriptive Statistics

Variable	N	Mean	S.D.	Min	P50	Max
Inv	29,068	4.953	4.882	0.000	3.517	64.186
Digit	29,068	2.179	1.345	0.000	2.197	6.627
FEP	29,068	1.519	0.954	0.000	1.609	4.500
Size	29,068	22.052	1.235	13.763	21.903	28.502
Age	29,068	1.996	0.928	0.000	2.197	3.466
Lev	29,068	0.412	0.209	0.049	0.401	0.914
Tang	29,068	0.045	0.048	0.000	0.033	0.308
Cash	29,068	0.210	0.150	0.018	0.166	0.712
Growth	29,068	0.204	0.379	-0.311	0.102	2.271
Tobin Q	29,068	2.093	1.354	0.866	1.657	8.888
CEO	29,068	0.294	0.456	0.000	0.000	1.000
SOE	29,068	0.342	0.474	0.000	0.000	1.000

Note: This table presents summary statistics for the variables used in our analyses.

4. RESULTS

4.1. Baseline results

Before reporting the results of the 2SLS mediation analysis, we first present the OLS estimation results for the relationship between digitalization, FEP, and firm investment, which typically serves as the first step in standard mediation analysis (see, e.g., Boerner et al., 2021; Liu et al., 2023; Ackermann et al., 2024).

Table 3 presents the OLS estimates of the effect of digitalization and FEP on firm investment. In column 1, the estimated coefficient of digitalization is significantly negative, suggesting that digitalization alleviates firms' perception and interpretation of economic policy uncertainty. In columns 2 to 5, the estimated coefficients of digitalization are significantly positive, indicating that firms undergoing digital transformation exhibit a higher level of investment. The estimated coefficients of FEP are negative and statistically significant, suggesting that firms with heightened uncertainty perception tend to reduce investment. The interaction term in column 5 is insignificant, implying that FEP may not act as an exogenous variable in the mechanism. Based on these results, we conclude that digital transformation primarily influences firm investment by reducing firms' perception of uncertainty, rather than through an independent or moderating relationship between the two. However, given potential endogeneity concerns and the fact that FEP is not the only channel through which

digitalization affects firm investment, we refrain from drawing definitive conclusions based solely on OLS analysis. Therefore, we further conduct the 2SLS mediation analysis to examine whether FEPU acts as an endogenous variable through which digitalization influences firm investment.

TABLE 3.

Baseline results: OLS estimates

	FEPU (1)	Inv (2)	Inv (3)	Inv (4)	Inv (5)
Digit	-0.016*** (-14.978)	0.154*** (3.519)		0.124*** (2.825)	0.124** (2.498)
FEPU			-2.025*** (-6.110)	-1.899*** (-5.711)	-1.902*** (-3.244)
Digit × FEPU					0.002 (0.008)
Size	-0.013*** (-5.897)	0.080 (0.789)	0.084 (0.839)	0.056 (0.552)	0.056 (0.552)
Age	-0.014*** (-5.527)	-1.123*** (-9.118)	-1.149*** (-9.363)	-1.149*** (-9.365)	-1.149*** (-9.340)
Lev	0.000 (0.484)	-0.020 (-0.842)	-0.020 (-0.838)	-0.020 (-0.848)	-0.020 (-0.848)
Tang	0.003 (0.119)	4.626*** (2.704)	4.634*** (2.712)	4.632*** (2.708)	4.632*** (2.708)
Cash	-0.004 (-0.643)	3.629*** (10.072)	3.640*** (10.117)	3.621*** (10.072)	3.621*** (10.069)
Growth	-0.002* (-1.740)	0.171*** (3.315)	0.169*** (3.300)	0.168*** (3.277)	0.168*** (3.276)
Tobin Q	-0.000* (-1.857)	-0.001 (-0.694)	-0.001 (-0.696)	-0.001 (-0.749)	-0.001 (-0.748)
CEO	-0.003 (-1.464)	0.112 (1.107)	0.111 (1.099)	0.106 (1.047)	0.106 (1.046)
SOE	0.007 (1.236)	-0.707*** (-3.004)	-0.715*** (-3.026)	-0.693*** (-2.940)	-0.693*** (-2.941)
Constant	0.439*** (9.428)	4.304** (1.993)	4.804** (2.237)	5.138** (2.384)	5.138** (2.385)
Firm & Year FEs	Yes	Yes	Yes	Yes	Yes
Observations	29,068	29,068	29,068	29,068	29,068
R-squared	0.482	0.527	0.528	0.528	0.528

Note: The t-statistics are provided. Significance levels at 1%, 5%, and 10% are denoted by ***, **, and *, respectively.

Two sets of 2SLS mediate regressions are carried out and the estimated results are reported in Table 4. Columns 1-3 report the first set of 2SLS

regressions, where Digit is treated as the endogenous variable. Columns 4-5 report the second set of 2SLS regressions, where FEPU is treated as the endogenous variable and Digit is treated as the conditional variable. The first-stage estimates in column 1 show that there is a significant and positive relationship between digitalization and the IV. The Chi square p value for the Anderson LM statistic in the first-stage instrument is smaller than 0.01, which passes the underidentification test. And the CD F statistic is greater than 16.38, which passes the weak identification test. In column 4, the first-stage estimates for the second set of 2SLS analyses are reported, where FEPU is instrumented and with digitalization as a conditional variable. Similar outcomes are yielded, where the coefficient of the IV is statistically significant and underidentification test and weak identification test are passed. The above evidence confirms that our instrument is empirically relevant.

TABLE 4.

Baseline results: 2SLS mediation estimates

	Digit 1st (1)	FEPU 2nd (2)	Invst 2nd (3)	FEPU 1st (4)	Invst 2nd (5)
Instrumented Digit		-1.633*** (-26.123)	0.504*** (2.865)		
Instrumented FEPU					-0.226** (-1.987)
Digit				-0.067*** (-7.222)	0.137*** (4.109)
IV	0.192*** (18.031)			-0.320*** (-26.837)	
Controls	Yes	Yes	Yes	Yes	Yes
Firm & Year FEs	Yes	Yes	Yes	Yes	Yes
Observations	29,068	29,068	29,068	29,068	29,068
R-squared	0.779	-2.081	0.028	0.485	0.034
Anderson LM stats.		832.9	832.9		1834
CD Wald F stats.		752.1	752.1		1717

Note: The t -statistics are provided. Significance levels at 1%, 5%, and 10% are denoted by ***, **, and *, respectively.

The second-stage IV estimates for the effect of digitalization on FEPU and firm investment in column 2 and 3, respectively, are both qualitatively in line with the OLS estimates. That is, the instrumented digitalization has a significantly negative effect on FEPU and a significantly positive effect on firm investment. It is noteworthy that the effects of the instrumented

digitalization are an order of magnitude than the OLS estimates, which suggests the latter may have an underestimation bias. These results imply that digitalized firms are better equipped to process and analyze complex policy-related information, leading to a more informed and less uncertain view of economic risks. Consequently, digitalization appears to indirectly foster investment by reducing uncertainty perception, which in turn encourages firms to commit more resources to long-term investment projects. The second stage result of the second set of the 2SLS analyses for firm investment on FEPU (conditional on digitalization) in column 5 further support the idea. It is showed that there is a significant negative relationship between FEPU and firm investment. This suggests that as a firm's perception of economic policy uncertainty increases, its investment activities decrease. This finding is consistent with the established literature, which posits that heightened uncertainty, particularly in the context of economic policy, leads firms to delay or reduce investments due to concerns about future market conditions, regulatory changes, or policy shifts that could negatively impact profitability. Together, these results underscore the mediating role of FEPU in the relationship between digitalization and firm investment, illustrating that digitalization enhances investment not only directly but also by reducing the perceived uncertainty that firms associate with economic policies.

Table 5 further presents the full system of equations, reporting the total effect, direct effect, and indirect effect of digitalization. The estimate of the total effect is 0.504, which implies that, on average, a one standard deviation increase in the level of digitalization leads to a 0.5% increase in the ratio of investment to total assets. This highlights the significant role of digital transformation in influencing firm investment. The direct effect, which captures the impact of digitalization on firm investment through channels other than FEPU, is estimated at 0.137 and is statistically significant at the 1% level, but it explains only 27% ($0.137/0.504$) of the total effect. The indirect effect estimate is 0.368 ($-1.633 * -0.226$) and is statistically significant at the 5% level. In terms of magnitude, it is substantially larger than the direct effect, explaining approximately 73% ($0.368/0.504$) of the total effect. These findings underscore the importance of FEPU as a crucial mechanism through which digitalization influences firm investment.

Beyond statistical significance, these estimates carry substantial economic magnitude. A one-standard-deviation increase in digitalization leads to a 13.69% ($0.678/4.953$) relative increase in the overall investment level, which is highly economically meaningful. Furthermore, unpacking the indi-

TABLE 5.

2SLS estimates: Total effect, direct effect, and indirect effect			
Digitalization $\Rightarrow$ FEPU perception $\Rightarrow$ Firm investment			
Dependent variable:	Estimate	95 % confidence interval	Explanation
Inv			Proportion
Total effect	0.504*** (2.865)	[0.159, 0.851]	100%
Direct effect	0.137*** (4.109)	[0.071, 0.202]	27.072%
Indirect effect	0.368** (1.974)	[0.002, 0.735]	72.928%

Note: The t-statistics are provided. Significance levels at 1%, 5%, and 10% are denoted by ***, **, and *, respectively.

rect effect reveals the profound economic impact of the cognitive channel: the digitalization-induced reduction in FEPU alone is responsible for a 0.495 ($0.368 * 1.345$) increase in the investment ratio. This represents a nearly 10% ($0.495/4.953$) boost relative to the sample average. Therefore, the finding that FEPU mediates 72.9% of the total effect highlights that correcting managerial uncertainty perception is the dominant and practically significant economic channel through which digital empowerment translates into tangible capital expenditures.

4.2. Mechanisms: Correction of cognitive bias

While our baseline findings establish that digital transformation stimulates firm investment by reducing FEPU, it is imperative to unpack the cognitive dynamics driving this reduction. According to the attention-based view and bounded rationality theory, managers facing macroeconomic volatility are prone to cognitive biases due to information overload. This leads to a perception bias in evaluating economic policy uncertainty: some managers become overly sensitive and pessimistic, heavily influenced by macroeconomic noise, while others may irrationally underestimate potential risks (Simon et al., 2000). To examine how digital transformation acts as a cognitive correction mechanism, we calculate the deviation of a firm's uncertainty perception from its industry-year median, constructing a perception bias variable (PB). Firms with a positive deviation are categorized as excessively sensitive to uncertainty, whereas those with a negative deviation are considered to underestimate uncertainty.

Table 6 presents the 2SLS regression results investigating the relationship between digitalization, cognitive perception bias, and firm investment. In

column 1, we report the effect of instrumented digitalization on perception bias. The significantly negative coefficient indicates that digital transformation effectively mitigates firms' perception bias toward economic policy uncertainty. By acting as a noise-filtration mechanism, digital tools help realign managerial perceptions with objective industry baselines, correcting heuristic-driven errors. Columns 2 and 3 confirm that this correction of cognitive bias subsequently stimulates increased firm investment. However, evaluating the overall reduction in perception bias is insufficient to fully capture the heterogeneous cognitive impacts of digitalization. We further explore whether this noise-filtration effect symmetrically corrects both over-sensitive and under-sensitive managers.

TABLE 6.

Mechanism: Correction of cognitive bias

	PB	Invt	Invt	PB_Over	Invt	Invt	PB_Under	Invt	Invt
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Digit			0.107*** (2.632)			0.095* (1.871)			0.171*** (3.428)
Instrumented Digit	-0.090*** (-18.979)	0.504*** (2.865)		-1.254*** (-4.886)	1.906* (1.674)		-1.407 (-1.523)	3.286 (0.815)	
Instrumented PB			-4.568* (-1.904)						
Instrumented PB_Over						-1.444* (-1.668)			
Instrumented PB_Under									-2.214 (-0.896)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm & Year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	29,068	29,068	29,068	13,878	13,878	13,878	13,969	13,969	13,969
R-squared	-0.596	0.028	0.032	-101.208	-0.089	0.027	-1,988.800	-0.297	0.036
Anderson LM stats.	832.9	832.9	543.8	29.33	29.33	3034	2.862	2.862	5704
CD Wald F stats.	752.1	752.1	486	23.69	23.69	3129	2.322	2.322	7818

Note: The *t*-statistics are provided. Significance levels at 1%, 5%, and 10% are denoted by ***, **, and *, respectively.

To investigate this asymmetry, we divide the sample into two groups based on their deviation from the industry-year median. Firms with a PB value above the median are assigned to the oversensitivity group (PB_Over), while those below are assigned to the under-perception group (PB_Under). Columns 4-6 present the results for the oversensitivity group. As theoretically expected, the coefficients for instrumented Digit (in columns 4 and 5) and instrumented PB_Over (in column 6) are significantly negative.

This indicates that for overly pessimistic firms, digitalization successfully filters out anxiety-inducing macroeconomic noise, correcting their excessive perception bias. This cognitive realignment directly translates into a greater willingness to invest, effectively alleviating the paralyzing effects of uncertainty.

Conversely, columns 7-9 report the results for the under-perception group. Strikingly, neither the coefficient for instrumented Digit nor for instrumented PB_Under is statistically significant. This asymmetric outcome reveals a profound cognitive dynamic. While digitalization successfully cures excessive pessimism, it fails to induce a healthy level of caution in managers who already underestimate policy risks. For these inherently optimistic firms, digital tools do not alter their perception. This theoretical asymmetry sets the stage for a critical question: if digitalization empowers managers with advanced data tools but fails to correct underlying over-optimism, does this uncorrected psychological state morph into an illusion of control that ultimately harms investment efficiency?

4.3. Mechanisms: Investment efficiency

The above results further stress our concern that the positive effect of digital transformation on firm investment is primarily driven by an unconditional reduction in firms' perception of uncertainty, without effectively correcting the perception biases of firms that underestimate uncertainty. This suggests that digital transformation may lead firms to make unnecessary over-investments. In light of this, we further investigate the impact of digitalization and FEPU on investment efficiency. Specifically, we adopt the method proposed by Biddle et al. (2009), using the residuals from the regression of investment on revenue growth as a proxy for firm investment efficiency (EI). Positive residuals indicate over-investment (EI_Over), while negative residuals signal under-investment (EI_Under). Similarly, we categorize firms into two groups based on their investment efficiency — over-investing and under-investing firms — and perform regression analyses using the absolute values of the investment residuals as the dependent variable. This analysis will further explore how digital transformation, through its effect on uncertainty perception, influences firms' investment decisions and efficiency.

Table 7 presents the regression results investigating the relationship between investment efficiency, digitalization, and FEPU. In columns 2 and 3, both the direct and indirect effects of digitalization on overall investment efficiency (EI) are statistically insignificant. While digitalization significantly boosts absolute investment levels (as shown in the baseline models),

it does not uniformly improve efficiency. This null result at the aggregate level masks a profound dual dynamic, compelling to separately analyze the sub-samples of under-investing and over-investing firms

TABLE 7.

Mechanism: Investment efficiency

	FEPU	EI	EI	FEPU	EI_Over	EI_Over	FEPU	EI_Under	EI_Under
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Digit			0.035			0.270***			−0.065***
			(1.204)			(3.402)			(−4.214)
Instrumented FEPU			−0.063			−0.433*			0.151***
			(−0.642)			(−1.749)			(2.810)
Instrumented Digit	−1.734***	0.144		−2.230***	1.235**		−1.583***	−0.305***	
	(−22.742)	(0.889)		(−10.985)	(2.286)		(−18.244)	(−3.724)	
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm & Year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	26,486	26,486	26,486	9,211	9,211	9,211	16,527	16,527	16,527
R-squared	−2.178	0.011	0.012	−3.362	0.039	0.058	−1.884	0.014	0.029
Anderson LM stats.	753.1	753.1	1729	187	187	653.6	525.6	525.6	1045
CD Wald F stats.	681	681	1625	146.5	146.5	540.1	458.7	458.7	942.8

Note: The t-statistics are provided. Significance levels at 1%, 5%, and 10% are denoted by ***, **, and *, respectively.

Columns 8 and 9 focus on investment insufficiency (EI_Under). The coefficients for both direct and indirect effects of digitalization on EI_Under are significantly negative. This finding aligns with the noise-filtration mechanism established in Section 4.2. For firms paralyzed by excessive perceived uncertainty, digitalization effectively filters macroeconomic noise, lowers their FEPU, and encourages them to undertake value-enhancing projects they would have otherwise abandoned. The positive relationship between instrumented FEPU and EI_Under (Column 9) further corroborates this assumption. Higher uncertainty perception inhibits investment, and digitalization successfully mitigates this effect. Conversely, columns 5 and 6 reveal the dark side of digitalization. The coefficients for both non-instrumented and instrumented digitalization on EI_Over are significantly positive, indicating that digitalization indiscriminately exacerbates over-investment behavior in some firms. These results suggest that utilizing digital tools may induce managerial overconfidence and the illusion of control.

As established in Section 4.2, digitalization fails to correct the cognitive state of inherently optimistic managers. Instead, it equips them with highly sophisticated predictive models and real-time dashboards. Rather

than inducing caution, these advanced digital tools can breed an illusion of control, leading managers to irrationally overestimate their ability to predict, hedge, and manage macroeconomic tail risks. This psychological empowerment creates a dangerous digital illusion. Driven by an overestimation of their informational advantage, overconfident managers artificially lower the hurdle rates for capital expenditures. Consequently, the reduction in expressed FEPU in these firms does not reflect genuine risk mitigation, but rather a hubristic disregard for underlying policy risks, ultimately culminating in sub-optimal over-investment. Table 8 reports the results using PB as an alternative explanatory variable, yielding consistent outcomes and further substantiating this behavioral mechanism.

TABLE 8.

Mechanism: Investment efficiency (PB)									
	PB	EI	EI	PB	EI_Over	EI_Over	PB	EI_Under	EI_Under
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Digit			0.029			0.226**			−0.052***
			(0.880)			(2.499)			(−2.941)
Instrumented PB			−1.353			−10.201*			3.117***
			(−0.641)			(−1.738)			(2.777)
Instrumented Digit	−0.085***	0.144		−0.099***	1.235**		−0.081***	−0.305***	
	(−17.523)	(0.889)		(−9.057)	(2.286)		(−13.548)	(−3.724)	
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm & Year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	26,486	26,486	26,486	9,211	9,211	9,211	16,527	16,527	16,527
R-squared	−0.557	0.011	0.011	−0.896	0.039	0.046	−0.459	0.014	0.006
Anderson LM stats.	753.1	753.1	455.1	187	187	176.9	525.6	525.6	263.8
CD Wald F stats.	681	681	406.8	146.5	146.5	138.5	458.7	458.7	226.5

Note: The t-statistics are provided. Significance levels at 1%, 5%, and 10% are denoted by ***, **, and *, respectively.

4.4. Heterogeneity: Managerial incentives

Having established in mechanism analyses that digitalization induces a dual effect on investment efficiency, particularly by exacerbating over-investment through the illusion of control. Given this dual effect, it is essential to explore under what corporate conditions is this behavioral bias most pronounced. One crucial determinant of firm investment behavior, especially in the context of uncertainty, is the structure of managerial incentives, specifically, the role of managerial ownership and compensation (Brown and Sarma, 2007; Nie and Yen, 2024). By aligning managerial interests with those of the shareholders, these incentives could potentially

influence how digitalization-induced reductions in uncertainty perception translate into actual investment decisions. Through examining how management compensation and management shareholding interact with digitalization and FEPU, we can identify which types of firms are most susceptible to the digitalization-induced investment surge.

TABLE 9.

Heterogeneity: Managerial incentives

	Invt (1)	Invt (2)	Invt (3)	Invt (4)
Instrumented FEPU×MSR	−1.925*** (−2.788)			
Instrumented Digit×MCR		1.035*** (2.748)		
Instrumented FEPU×MSR			−0.146** (−2.127)	
Instrumented Digit×MCR				0.067** (2.211)
Instrumented FEPU	−0.094 (−0.738)		−0.170 (−1.366)	
Instrumented Digit		0.385* (1.909)		0.508*** (2.609)
Digit	0.101*** (2.777)		0.125*** (3.519)	
MSR	3.178*** (3.176)	−1.737* (−1.917)		
MCR			0.213* (1.904)	−0.130** (−2.229)
Controls	Yes	Yes	Yes	Yes
Firm & Year FEs	Yes	Yes	Yes	Yes
Observations	28,149	28,149	28,848	28,848
R-squared	0.032	0.030	0.034	0.028
Anderson LM stats.	1583	789.9	1810	832.9
CD Wald F stats.	732.3	354.9	846.1	375.8

Note: The t-statistics are provided. Significance levels at 1%, 5%, and 10% are denoted by ***, **, and *, respectively.

Table 9 investigates this moderating effect. Specifically, we select the ratio of the top three directors, supervisors and senior managers' remuneration to all employees as the measure of management compensation (MCR), and their shareholding ratio as the measure of management shareholding (MSR). Columns 1 and 3 report the moderating effect of manage-

rial incentives on instrumented FEPUs, while columns 2 and 4 show their moderating effect on instrumented digitalization. The interaction terms between the incentive proxies (MSR, MCR) and instrumented FEPUs are significantly negative, whereas their interactions with instrumented digitalization are significantly positive. These findings indicate that higher managerial incentives not only reinforce the direct impact of digitalization on investment but also drastically amplify the indirect effect through which FEPUs reduction fosters investment.

From a traditional agency theory perspective, one might assume that higher incentives seamlessly align managers with shareholders, leading strictly to efficient investments. However, integrating these results with the behavioral framework established in Section 4.3 offers a more nuanced, cautionary interpretation. Managers with significant skin in the game (high equity or compensation) face immense pressure to deliver robust growth and maximize firm value. When these highly incentivized managers are empowered by advanced digital forecasting tools and dashboards, their intense drive for performance violently intersects with the illusion of control. Rather than purely fostering rational, risk-averse decisions, strong managerial incentives can act as a potent catalyst for digital overconfidence. The digital illusion provides highly incentivized managers with the exact psychological justification they need to aggressively pursue expansion. Consequently, the combination of high financial stakes and digital empowerment dramatically lowers their perceived hurdle rate for capital expenditures. This perfectly explains why the investment-stimulating effect of digitalization (via FEPUs reduction) is significantly magnified in firms with strong managerial incentives, where managers are the most motivated to leverage digital tools to override traditional risk constraints.

This heterogeneous finding theoretically enriches our understanding of the dual effects of digitalization and yields critical implications for corporate governance. It suggests that traditional incentive structures, originally designed to encourage proactive management, may inadvertently fuel excessive risk-taking and over-investment when managers fall prey to the digital illusion. Therefore, the strong positive interactions observed in Table 9 do not necessarily signify an optimization of investment efficiency. Instead, they empirically reveal that highly incentivized managers are exactly the types of decision-makers most prone to the behavioral pitfalls of digital transformation. This insight underscores the urgent need for updated governance mechanisms that can balance technological empowerment with psychological risk management.

4.5. Robustness checks

4.5.1. *Adjusting fixed-effects combinations*

The primary results presented in this paper are based on firm and year fixed effects. To test the robustness of our findings, we adjust the fixed-effects combinations in this section. Specifically, we maintain the firm fixed effects while incorporating additional province-year and industry-year fixed effects. This adjustment helps account for unobserved regional and industry-specific characteristics that may vary over time and could potentially influence the relationships under study. Table 10 presents the 2SLS regression results based on this alternative fixed-effects specification. The results remain consistent with those reported in Table 4, indicating that our findings are robust even after considering more stringent fixed-effects combinations.

TABLE 10.

Robustness check: Adjusting fixed-effects combinations

	Digit	FEPU	Invt	FEPU	Invt
	1st	2nd	2nd	1st	2nd
	(1)	(2)	(3)	(4)	(5)
Instrumented Digit		-2.224*** (-19.191)	0.498* (1.936)		
Instrumented FEPU					-0.153* (-1.770)
Digit				-0.079*** (-8.654)	0.157*** (4.336)
IV	0.181*** (15.829)			-0.389*** (-32.071)	
Controls	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
Province-Year FE	Yes	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes	Yes
Observations	29,043	29,043	29,043	29,043	29,043
R-squared	0.789	-3.511	0.028	0.507	0.033
Anderson LM stats.		493.4	493.4		1809
CD Wald F stats.		430.2	430.2		1653

Note: The t-statistics are provided. Significance levels at 1%, 5%, and 10% are denoted by ***, **, and *, respectively.

4.5.2. *Alternative IV*

The 2SLS mediation analysis framework employed in this study heavily relies on the choice of IV. In the main analysis, we use the digitalization means of other firms in the same industry and region in the same year as our instrument. While it is unlikely that the digitalization of peer firms directly influences the investment levels of the focal firm, there are still concerns regarding the exogeneity of the IV from the perspective of statistical intuition. To address this issue, we introduce the “Broadband China” policy as an exogenous shock to alleviate such concerns. The Broadband China initiative, launched by the State Council of China, is a national strategic plan aimed at promoting the widespread adoption and rapid iteration of information technology. Pilot cities for the program were announced in 2014, 2015, and 2016. As such, this policy serves as an exogenous shock related to information technology, which can be used to construct an instrument for firm-level digitalization.

TABLE 11.

Robustness check: Alternative IV (“Broadband China” as external shock)

	Digit 1st (1)	FEP 2nd (2)	Inv 2nd (3)	FEP 1st (4)	Inv 2nd (5)
Instrumented Digit		−0.941*** (−10.721)	0.753** (2.243)		
Instrumented FEP					−0.724* (−1.794)
Digit				−0.106*** (−11.723)	0.071 (1.248)
IV	0.113*** (9.619)			−0.094*** (−8.714)	
Controls	Yes	Yes	Yes	Yes	Yes
Firm & Year FEs	Yes	Yes	Yes	Yes	Yes
Observations	29,068	29,068	29,068	29,068	29,068
R-squared	0.775	−0.533	0.020	0.454	0.022
Anderson LM stats.		281.1	281.1		159.5
CD Wald F stats.		249	249		140.6

Note: The t-statistics are provided. Significance levels at 1%, 5%, and 10% are denoted by ***, **, and *, respectively.

Specifically, we first create a policy variable that assigns a value of 1 to firms located in pilot cities and in years after the policy implementation, and 0 otherwise. We then calculate the average level of digitalization for

these firms in the three years preceding the policy's implementation, which serves as a measure of the firm's initial digitalization level. Finally, we interact this policy variable with the firm's initial digitalization level to form the IV. The rationale behind this approach is that firms with higher initial digitalization levels are more likely to benefit from the policy intervention, thereby accelerating their digital transformation. This instrument satisfies both the exogeneity and relevance requirements. The 2SLS regression results using this alternative instrument, based on the Broadband China policy, are reported in Table 11, and our findings remain robust, further confirming the validity of our results.

4.5.3. Ordinary IV framework

In the baseline analysis, we employed the causal mediation framework to identify both the direct and indirect effects using a single IV. To further solidify our findings and alleviate any potential concerns regarding the reliance on a single-instrument structure, we conduct a supplementary robustness check using a traditional ordinary IV framework with multiple distinct instruments. Specifically, we construct two separate instruments for our two potentially endogenous variables. *IV_Digit* is constructed as the average digitalization value of other firms in the same province and industry, while *IV_FEPU* is constructed as the average FEPU value of other firms in the same province and industry.

Table 12 presents the results of this traditional 2SLS approach. Columns (1) to (4) report the models where *Digit* and *FEPU* are instrumented individually. The results show that digitalization significantly promotes firm investment (in column 2), while *FEPU* significantly dampens it (in column 4). More importantly, columns (5) to (7) report the joint model where both *Digit* and *FEPU* are included as endogenous variables and instrumented simultaneously by *IV_Digit* and *IV_FEPU*. The first-stage results in columns (5) and (6) demonstrate instrument validity and exclusivity. In the second stage in column 7, the coefficients for both instrumented *Digit* and instrumented *FEPU* remain significant and expected signs.

This ordinary IV estimations provide robust, independent confirmation that both digitalization and economic policy uncertainty perception exert significant causal impacts on firm investment. However, it is crucial to note the methodological limitation of this traditional framework: while it efficiently estimates the simultaneous causal effects of two endogenous regressors, it lacks the mathematical structure to decompose the precise causal mediation pathway (i.e., identifying the exact proportion of digi-

talization's effect that flows through the reduction of FEPU). Therefore, this ordinary IV framework serves as a complementary robustness check, reconfirming the directional validity of our variables, while justifying our primary reliance on the Dippel et al. (2020) framework for the core mediation analysis.

TABLE 12.

Robustness check: Ordinary IV framework							
	Digit	Invt	FEPU	Invt	Digit	FEPU	Invt
	1st	2nd	1st	2nd	1st	1st	2nd
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Instrumented Digit		0.200*** (3.746)					0.167*** (3.453)
Instrumented FEPU				−0.247** (−2.528)			−0.229** (−2.326)
IV_Digit	0.830*** (36.122)				0.832*** (36.424)	0.024* (1.646)	
IV_FEPU			0.946*** (50.574)		0.013 (0.716)	0.949*** (50.746)	
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm & Year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	29,068	29,068	29,068	29,068	29,068	29,068	29,068
R-squared	0.792	0.033	0.495	0.034	0.792	0.495	0.034
F		85.41		85.81			78.23
under		2377		2654			2375
weak		2270		2561			1134

Note: The t-statistics are provided. Significance levels at 1%, 5%, and 10% are denoted by ***, **, and *, respectively.

4.5.4. *Alternative measure of Digitalization: Digital intangible assets*

In the main analysis, our primary measure of digitalization relies on the textual analysis of MD&A sections. To address potential concerns that keyword frequencies might capture managerial cheap talk rather than the actual depth of technological adoption and performance impacts, we use the proportion of digital-related intangible assets as an alternative proxy variable (Guo et al., 2023). Specifically, we identify and aggregate the book value of intangible asset items containing digital-related keywords, such as software, network, platform, management information systems, and digital patents. We then scale this aggregated value by the firm's total intangible assets to construct a new objective variable (Digit_Asset).

We replicate our 2SLS mediation analysis using this new intangible asset-based measure. The regression results reported in Table 13 remain highly consistent with our baseline findings. This objective validation strongly confirms that our observed causal effects are driven by genuine, capitalized investments in digital infrastructure, rather than superficial strategic rhetoric.

TABLE 13.

Robustness check: Alternative measure of Digit (Digital intangible assets)

	Digit_Asset	FEPU	Invt	FEPU	Invt
	1st	2nd	2nd	1st	2nd
	(1)	(2)	(3)	(4)	(5)
Instrumented Digit_Asset		-5.688***	4.498**		
		(-2.883)	(2.293)		
Instrumented FEPU					-0.599***
					(-4.045)
Digit_IAsset				-0.106***	1.091***
				(-3.694)	(5.193)
IV	0.005**			-0.375***	
	(2.357)			(-12.986)	
Controls	Yes	Yes	Yes	Yes	Yes
Firm & Year FEs	Yes	Yes	Yes	Yes	Yes
Observations	23,564	23,564	23,564	23,564	23,564
R-squared	0.811	-1.214	-1.855	0.236	0.030
Anderson LM stats.		979.4	979.4		1115
CD Wald F stats.		840.4	840.4		1004

Note: The t-statistics are provided. Significance levels at 1%, 5%, and 10% are denoted by ***, **, and *, respectively.

4.5.5. Differentiating the sub-dimensions of digitalization

While the aforementioned asset-based measure robustly captures the depth of digital adoption, digitalization inherently remains a broad and multifaceted concept. To further explore its structural nuances and ensure the robustness of our textual measures, we refine our original MD&A keyword analysis by categorizing it into two distinct sub-dimensions: technological digitalization (e.g., the application of blockchain, big data, artificial intelligence, etc.) and business model digitalization (e.g., Internet+, O2O, e-commerce, etc.)

We construct separate textual measures for each dimension, namely a technological digitalization indicator (Digit_T) and a business model dig-

TABLE 14.

Robustness check: Sub-dimensions of Digit (digital technology)

	Digit_T	FEPU	Inv	FEPU	Inv
	1st	2nd	2nd	1st	2nd
	(1)	(2)	(3)	(4)	(5)
Instrumented Digit_T		-1.913*** (-22.235)	0.580*** (2.695)		
Instrumented FEPU					-0.234** (-1.984)
Digit_T				-0.071*** (-7.743)	0.133*** (3.728)
IV	0.174*** (16.595)			-0.320*** (-26.982)	
Controls	Yes	Yes	Yes	Yes	Yes
Firm & Year FEs	Yes	Yes	Yes	Yes	Yes
Observations	29,068	29,068	29,068	29,068	29,068
R-squared	0.775	-2.555	0.027	0.485	0.035
Anderson LM stats.		688.3	688.3		1848
CD Wald F stats.		618.2	618.2		1731

Note: The t -statistics are provided. Significance levels at 1%, 5%, and 10% are denoted by ***, **, and *, respectively.

italization indicator (Digit_B), and replicate our core 2SLS analysis. Tables 14 and 15 report the regression results using these two refined indicators. Once again, our results remain robust across both sub-dimensions. This confirms that whether digital transformation manifests primarily as backend technological upgrades or frontend business model innovations, its noise-filtration and psychological empowerment effects on managerial perception and firm investment remain consistent.

5. CONCLUSION

In this paper, we investigate the complex causal chain linking digital transformation, FEPU, and firm investment. Utilizing a 2SLS mediation analysis framework on a comprehensive sample of Chinese listed firms, we move beyond traditional operational-level explanations to uncover a profound cognitive dual effect. We find that digitalization generally stimulates firm investment by filtering macroeconomic noise and reducing managers' subjective perception of policy uncertainty. However, this cognitive intervention is a double-edged sword. For firms paralyzed by excessive pessimism, digitalization acts as a healthy corrective mechanism, effectively

TABLE 15.

Robustness check: Sub-dimensions of Digit (business models)

	Digit_B	FEPU	Invt	FEPU	Invt
	1st	2nd	2nd	1st	2nd
	(1)	(2)	(3)	(4)	(5)
Instrumented Digit_B		-2.252*** (-23.413)	0.675*** (2.661)		
Instrumented FEPU					-0.272** (-2.397)
Digit_B				0.006 (0.504)	0.062 (1.412)
IV	0.148*** (14.654)			-0.333*** (-27.998)	
Controls	Yes	Yes	Yes	Yes	Yes
Firm & Year FEs	Yes	Yes	Yes	Yes	Yes
Observations	29,068	29,068	29,068	29,068	29,068
R-squared	0.646	-2.209	0.025	0.483	0.034
Anderson LM stats.		856.2	856.2		1976
CD Wald F stats.		773.8	773.8		1859

Note: The t -statistics are provided. Significance levels at 1%, 5%, and 10% are denoted by ***, **, and *, respectively.

alleviating under-investment. Conversely, for managers lacking inherent caution, the deployment of sophisticated digital forecasting tools breeds an illusion of control. This psychological empowerment causes them to systematically underestimate genuine macroeconomic tail risks, ultimately exacerbating irrational over-investment.

Our findings yield significant theoretical and empirical contributions. First, we elevate the literature by integrating Knightian uncertainty and the attention-based view to explain how digital technologies reshape managerial risk cognition, shifting the focus from objective information processing to subjective psychological empowerment. Second, and crucially, our heterogeneity analysis challenges conventional agency theory in the digital era. We empirically demonstrate that traditional strong incentives (e.g., high management shareholding and compensation) do not simply optimize investment efficiency; rather, they act as a potent catalyst for digital overconfidence. Highly incentivized managers, driven by performance pressures, are the most susceptible to the digital illusion, leveraging digital tools to justify aggressive expansion and artificially lowering investment hurdle rates.

From a practical and policy perspective, we propose three concrete, actionable measures based on our dual-effect and incentive-mechanism findings. First, for regulatory institutions, disclosure requirements must evolve. Regulators should mandate firms to explicitly disclose the limitations of their digital risk management tools in their MD&A, along with contingency plans for unquantifiable macro tail risks, to prevent firms from signaling a false sense of absolute control to the market. Second, for corporate boards, governance structures must balance technological empowerment with psychological restraint. Boards should move beyond purely financial incentives and establish algorithmic and human checks-and-balances to counter the managerial hubris derived from digital dashboards. Finally, for internal risk control, firms must implement a minimum macro-risk premium baseline for investment evaluations. This ensures that even when digital predictive models output highly optimistic scenarios, highly incentivized managers cannot irrationally suppress discount rates, thereby providing a structural safeguard against the illusion of control.

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