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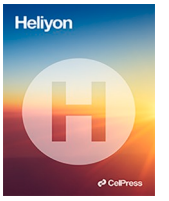

Research article

Economic policy uncertainty and enterprise export resilience in China: Does the digital economy matter?

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ABSTRACT

In the new era of international trade, escalating uncertainty and the swift development of the digital economy stand out as two pivotal transformations. These phenomena individually exert significant influences on enterprises' exports; however, their combined effects on export resilience remain underexplored. Hence, drawing on existing theories, this paper analyzes the weakening effect of economic policy uncertainty on export resilience and explores the influence of regional digital economic development on this attenuation effect. Furthermore, empirical tests are conducted using micro-level data from China. The study findings reveal: (1) Economic policy uncertainty weakens firms' export resilience by increasing transaction costs; (2) Digital economic development mitigates this weakening effect by reducing transaction costs, with a more pronounced effect observed among highly efficient firms. The findings suggest that amid escalating uncertainty, vigorously promoting digital economic development holds profound policy significance for the high-quality development of international trade.

1. Introduction

In the backdrop of recurrent international trade disputes, the global economy has experienced profound repercussions, contributing to escalating uncertainty on a global scale. Concurrently, the ongoing progression of The emergence of the Industrial Revolution's latest wave alongside the rapid growth of the digital economy has significantly influenced the global economic. Strengthening China's economic stability stands as a critical necessity for ensuring consistent growth and fostering the growth of domestic businesses amidst unpredictable circumstances. There's a growing focus on understanding the intricate dynamics between the digital economy, international trade, and how they respond to external uncertainties, marking a significant trend in contemporary research endeavors.

There exists a lack of consensus regarding the definition of economic resilience [1], encompassing factors such as the ability of economic entities to withstand the impact of shocks, recover, and undergo self-renewal. Existing studies focus on examining the resilience specifically concerning the rebound of enterprises' exports following the 2008 financial crisis. Prior studies have highlighted notable variations in how economic entities react to external shocks, including heightened uncertainty and the emergence of the digital economy. While certain entities demonstrate swift recoveries due to robust supply chains, others experience substantial contractions and face prolonged recuperation periods [2–4]. Disparities in the performance are evident across diverse regions and industries within the same economy [5], and even among enterprises operating within the same region [6]. In order to analyze deeper on these phenomena, it is imperative to provide additional elucidation on how the characteristics of enterprises interplay with a range of

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dimensional variables to influence resilience.

In recent years, trade protectionism has been on the rise, accompanied by frequent changes in economic policies across nations. This has led to a rapid increase in global economic policy uncertainty, hindering the economic recovery worldwide and significantly impacting China's export resilience. Existing literature primarily focuses on two theoretical analyses: (1) Real Options Value: Due to irreversible investments, immediate investment yields immediate returns but foregoes potential future gains, while delayed investment allows for potential future gains but sacrifices immediate returns. With the escalation of economic policy uncertainty, investors tend to delay investments to mitigate risks [7,8]. (2) Portfolio Investment: Investors strive to optimize returns while mitigating risk, aiming to maximize returns at a given risk level and minimize risk at a given return level. As economic policy uncertainty rises, investors can actively diversify trade risks through portfolio investment strategies [9]. Currently, the literature on the impact of economic policy uncertainty on microeconomic behavior predominantly adopts an enterprise-centric research perspective. In such literature, research topics encompass aspects such as corporate investment efficiency [10], corporate merger and acquisition behavior [11,12], and corporate digital transformation [13,14].

As external uncertainties intensify, the existing literature fails to provide a consistent answer to the question of how the digital economy precisely influences enterprise export behavior. On one hand, the application of technologies such as informatization and artificial intelligence has enhanced the efficiency of communication, accelerated customs clearance, and greatly bolstered the convenience of trade, reducing transaction costs for exporting enterprises. This is advantageous in alleviating external shocks faced by businesses. Conversely, the rapid evolution of the digital economy introduces considerable uncertainties, heightening market competition and compelling traditional industries to undergo transformation and upgrades. This evolution may also contribute to widening wealth gaps, uneven economic development, and other adverse consequences, potentially further amplifying the external shocks faced by export-oriented enterprises. Therefore, it is imperative to further explore the impact of the digital economy on enterprise export behavior within the context of heightened uncertainty.

This paper principally examines the impact of economic policy uncertainty resulting from external shocks on the export resilience of enterprises. Furthermore, it explores the role played by the regional level of digital economic development and examines its heterogeneity from the perspective of differences in enterprise productivity. The study also confirms that the digital economy's influence on export resilience in uncertain environments occurs by reducing transaction costs. Thus, the paper provides empirical evidence for the microscopic impact mechanisms of the relationship between the digital economy, economic policy uncertainty, and enterprise export resilience.

The main theoretical contributions of this paper are twofold: (1) it analyzes the relationship and channels of influence between economic policy uncertainty and export resilience; (2) it explores the impact and channels of influence of the digital economy on the relationship between economic policy uncertainty and enterprise export resilience. Additionally, it examines the heterogeneous effects of the digital economy's regulatory role from the perspective of differences in enterprise productivity. The primary practical contributions of this paper also involve two aspects: (1) employing highly classified trade data, it empirically tests the moderating effect of the digital economy on the relationship between economic policy uncertainty and export resilience; (2) the conclusions of this paper bear significant policy implications, aiding emerging market countries, such as China, by providing relevant policy insights to cope with economic policy uncertainty.

The subsequent sections of this paper are organized as follows: The second section offers an extensive review of existing literature; the third section explores theoretical development and presents hypotheses; the fourth section outlines the methodologies utilized and describes the data sources; the fifth section presents the empirical findings; and lastly, the conclusion section summarizes the study and provides policy recommendations.

2. Literature review

The literature relevant to this paper can be categorized into two main areas. The first category concentrates on examining the influence of economic policy uncertainty on firms' export activities. There are many factors contributing to the fluctuations in economic policy uncertainty, with common ones including economic, trade, financial, fiscal, and monetary factors [15–17]. Recently, Hoque et al. [18] have proposed that climate change policy is becoming increasingly unpredictable, adding an element of unpredictability to policy decision-making. Handley and Limão [19] have demonstrated that a reduction in economic policy uncertainty can stimulate export expansion and lead to decreased export prices, as evidenced by their firm trade model within a general equilibrium framework. Feng et al. [20] expound that a reduction in economic policy uncertainty can stimulate an increased number of Chinese firms to venture into the U.S. market, attributing this trend to what they refer to as the reconfiguration effect. Osnago et al. [21] argue that economic policy uncertainty primarily impacts the export aggregation margin, while [22] contend that it significantly affects the export expansion margin. Li and Huang [23] discover that economic policy uncertainty dissuades firms from entering foreign markets and hastens their exit from such markets [24]. found that mounting economic policy uncertainty decreases firms' export frequency due to trade costs and inventory costs. Conversely, Liu et al. [25] further investigate the country-specific agglomeration of diverse exporting firms within the framework of economic policy uncertainty. Liu et al. [26] found that economic policy uncertainty has a significant inhibitory effect on the export of electromechanical products. Conversely, intra-industry trade not only significantly promotes exports but also mitigates the inhibitory effects of export protection.

The second strand of literature relevant to this paper explores the impact of the digital economy on economic development. Some scholars argue that the digital economy acts as a catalyst for economic advancement. Zhang et al. [27] assert that the digital economy stimulates China's economic growth by promoting equal access to entrepreneurial opportunities. Wang et al. [28] note a progressive efficiency coefficient within China's digital economy over time, suggesting that digital technology applications enhance social

production efficiency. Zhao et al. [29] argue that by fostering public entrepreneurship, the digital economy can drive high-quality economic development. Li and Huang [23] maintain that the digital economy not only boosts residents' consumption of services but also creates positive spillover effects on service consumption in neighboring areas. Conversely, other scholars propose potential adverse effects of the digital economy on economic development. On one hand, they suggest that the digital economy may lead to issues such as overcapacity, excessive development, and cyclical patterns [30]. Furthermore, given the large-scale and long-term investment required for digital economy development, delayed observable outcomes may lead to a compression effect, hindering immediate economic benefits [31]. On the other hand, they suggest that the digital economy might not effectively address China's challenges related to insufficient innovation capacity in critical areas and restrictions within the industrial supply chain [32]. Furthermore, they caution against the monopolization of digital economy resources and user markets by major entities like Baidu and Tencent, warning of a "reverse market" scenario characterized by crowding-out effects and inhibitions on the innovation dynamics of economic actors [33].

Existing literature predominantly focuses on examining the effects of uncertainty on enterprise exports, with limited exploration from the perspective of export resilience. Moreover, there is a significant gap in current research regarding the relationship between economic policy uncertainty and enterprise export resilience within the context of digital economic development. Departing from the aforementioned studies, this paper adopts an analysis of export transaction costs to investigate the micro-level impact mechanisms of economic policy uncertainty on enterprise export resilience following external shocks. Subsequently, it focuses on the role of the digital economy in moderating these effects, considering its heterogeneity from the standpoint of export transaction costs.

3. Theoretical development and hypothesis

3.1. Economic policy uncertainty and enterprise export resilience

The prevailing literature suggests that economic policy uncertainty stemming from external shocks elevates firms' export transaction costs, consequently weakening firms' export resilience. It is commonly held that while economic policy uncertainty may have multifaceted effects on prices, its impact typically results in a cumulative positive response in terms of prices [34]. On one hand, heightened uncertainty increases the risk of corporate bankruptcy and moral hazard, exacerbates corporate financing constraints, diminishes the competitive incentive effect and innovation incentives, escalates corporate financing costs, and diminishes firms' ability to implement cost-saving measures [35–37]. On the other hand, heightened uncertainty raises export thresholds and triggers a "clean-up effect," compelling inefficient or smaller enterprises to exit the market. This subsequently intensifies the challenge of accessing trade information and communication, and amplifies the costs associated with market research and relationship maintenance [24,38,39]. In summary, mounting uncertainty presents obstacles to exporters' recovery from external shocks. Consequently, this paper proposes hypothesis 1.

Hypothesis 1. Controlling for other factors, economic policy uncertainty caused by external shocks weakens firms' export resilience.

3.2. Moderating effects of the digital economy

The prevailing literature highlights the profound influence of the digital economy on economic structure [40]. On one front, the advancement of the digital economy holds promise in alleviating various costs associated with export transactions. Enhanced networked communication is poised to bolster connectivity among trading entities, thus lowering communication expenses. Digital platforms are expected to diminish information asymmetry between trading counterparts, consequently reducing matching costs. Furthermore, digital technologies are anticipated to streamline the process of information acquisition, thereby curbing research expenditures. Additionally, the adoption of digital payment methods and streamlined customs clearance procedures is projected to mitigate challenges related to trade payments and traditional rule-based expenses [27,29].

However, significant disparities in productivity among firms persist [41]. The anticipated benefits that heterogeneous enterprises can derive from the advancement of the digital economy vary considerably. Enterprises with high efficiency typically command larger market shares and greater market competitiveness, thus poised to reap greater rewards from the evolution of the digital economy. Conversely, inefficient enterprises typically take up relatively smaller market shares, leading to limited "digital dividend effects" and exacerbating the challenges of the "digital divide effect." With smaller market shares, low-efficiency enterprises not only encounter constrained "digital dividend effects" but also face heightened competition. As a result, progress in the digital economy is anticipated to exacerbate the gap between high-efficiency and low-efficiency enterprises, thereby accentuating the "digital divide effect."

On the contrary, the evolution of the digital economy can optimize various export margins. Firstly, the integration of digital technologies such as big data, cloud computing, and the Internet of Things has the potential to improve production technology, strengthen enterprise innovation capacity, and lead to a sustained enhancement in overall productivity [28,42,43]. This is achieved through improvements in production processes, bolstering the organizational capabilities of enterprises, expediting capital turnover rates, and widening market access channels. Secondly, the digital economy's impact has facilitated a shift in export product dynamics from unilateral export to a paradigm of two-way communication, thereby stimulating diverse customer demands for export products [44]. This transformation presents opportunities for firms aiming to diversify their range of export offerings. Accordingly, this paper posits hypothesis 2.1 and hypothesis 2.2 (See Fig. 1).

Hypothesis 2.1. (a) Holding all other factors constant, the digital economy has the potential to mitigate the adverse effects of economic policy uncertainty on firms' export resilience. (b) Moreover, this mitigating effect is particularly pronounced for high-

efficiency firms.

Hypothesis 2.2. The mitigation effect of the digital economy can be achieved by reducing export transaction costs.

4. Methods and data

4.1. Model specification

To assess the validity of the aforementioned hypothesis, equations (1) and (2) are formulated.

$$RES_{ikjt} = \alpha_0 + \alpha_1 EPU_{jt} + \alpha_2 Z + \nu_{it} + \nu_{ij} + \varepsilon_{ikjt} \tag{1}$$

$$RES_{ikjt} = \beta_0 + \beta_1 EPU_{jt} + \beta_2 EPU_{jt} \times DE_{kt} + \beta_3 Z + \nu_{it} + \nu_{ij} + \xi_{ikjt} \tag{2}$$

Where the subscript i denotes the firm, k denotes the province, j denotes the destination, and t denotes year. RES is the firm export resilience. EPU × DE denotes the interaction term between the economic policy uncertainty and the development of the digital economy. The control variable Z encompasses control variables at each level; ν_{it} signifies firm-year fixed effects; ν_{ij} denotes firm-destination fixed effect. The province is determined based on the first two digits of the customs enterprise code to ensure consistency in enterprise location, thus enabling full control of province fixed effects after accounting for firm fixed effects; ε and ξ denote the random error terms.

4.2. Variables

4.2.1. Explanatory variables

In this study, firm export resilience (RES) is operationalized at the firm-destination-year level. Drawing from existing literature [44], firm export is defined as the disparity between the midpoint growth rate (G) of export value at the firm-destination-year level from 2011 to 2016 and the corresponding growth rate observed in 2008, during the international financial crisis. A larger difference indicates a higher level of export resilience among firms. The midpoint growth rate is computed according to equation (3), and the firm's export resilience is determined by equation (4), where EXPORT represents the number of exports.

$$G_{ikjt} = 2 \times \frac{EXPORT_{ikjt} - EXPORT_{ikjt-1}}{EXPORT_{ikjt} + EXPORT_{ikjt-1}} \tag{3}$$

$$RES_{ikjt} = G_{ikjt} - G_{ikj2008} \tag{4}$$

4.2.2. Core explanatory variables

4.2.2.1. Economic policy uncertainty (EPU). Baker et al. [15] developed a monthly index (EPU) for gauging economic policy uncertainty, which is employed in this study. To derive the annual index, separate calculations for the monthly weighted average and the quarterly weighted average are conducted following the procedures outlined in Ref. [36]. These calculations are presented in equations (5) and (6) as follows.

$$EPU_{jt} = \frac{\sum_{m=1}^{12} \frac{EPU_{jmt}^2}{\sum_{m=1}^{12} EPU_{jmt}}}{12 \times 100} \tag{5}$$

$$EPU2_{jt} = \frac{\sum_{q=1}^{4} \sum_{n=1}^{3} EPU_{jmnqt}}{4 \times 600 \times 100} \tag{6}$$

$$q = \begin{cases} 1 & m = 1,2,3 \\ 2 & m = 4,5,6 \\ 3 & m = 7,8,9 \\ 4 & m = 10,11,12 \end{cases} \tag{7}$$

$$n = \begin{cases} 1 & m = 1,4,7,10 \\ 2 & m = 2,5,8,11 \\ 3 & m = 3,6,9,12 \end{cases} \tag{8}$$

Where m means months, and q denotes quarters and is calculated using equation (7). N signifies the order of months within each quarter and is computed using equation (8). EPU denotes economic policy uncertainty, with higher values indicating increased economic policy uncertainty. Fig. 2 illustrates the trends of economic policy uncertainty and China's export resilience from 2000 to

2020. The impact of the 2008 financial crisis's external shock is evident, with economic policy uncertainty peaking during the period 2008–2011 as a direct consequence of the crisis. Subsequently, from 2011 to 2014, the direct effects of the financial crisis diminish, leading to a gradual reduction in economic policy uncertainty alongside an increase in China's export resilience. However, despite this improvement, uncertainty levels remain elevated compared to the pre-crisis period, signifying persistent crisis-induced uncertainty. From 2014 to 2016, global economic policy uncertainty rises again, coinciding with a decrease in China's export trade resilience, thereby maintaining opposing trends. In summary, economic policy uncertainty and China's export resilience demonstrate divergent trends over time. To better isolate the impact of uncertainty induced by the financial crisis (rather than the shock itself) on firms' export resilience, and taking into account limitations in data availability, this study primarily concentrates on data from 2011 to 2016 for regression analysis.

4.2.2.2. Digital economy (ED). Inspired by Ref. [29], in this study, the initial step involves identifying the three-level indicators listed in Table 1 from the annual provincial statistical review. Subsequently, the entropy weight method is employed to amalgamate the five indicators into a digital economy development index at the province-year level.

4.2.3. Control variables

At the firm-destination-year level, the study includes several control variables such as the logarithm of the number of HS6 categories, indicators for bilateral trade relationships, processing trade, and mixed trade. At the destination-year level, control variables consist of the logarithm of the population and the international economic freedom score. These control variables are employed to account for various factors influencing export resilience across different levels. For further details and descriptive statistics of these main variables, refer to Table 2.

4.3. Sample selection

The sample data utilized in this study are sourced from various databases, including: (1) China Customs database: Data is collected up to the year 2016. The China Digital Inclusion Index, necessary for calculating the level of digital economy development, has been available since 2011. Considering the impact of the 2008 external shock, and the difficulty in distinguishing its effects from economic policy uncertainty in the years immediately following, the sample years are selected as 2011–2016. (2) Chinese customs database: The HS6 code is standardized to the 1996 version, and the first 2 digits are adjusted based on the administrative division code to indicate the province. Each enterprise is associated with only one province, ensuring consistency in geographic location. Data is aggregated to the enterprise-destination-year level, and relevant variables are calculated accordingly. (3) Economic policy uncertainty index: Monthly EPU data from 23 countries or regions are obtained and aggregated to calculate annual EPU data using different weighting methods. (4) Data on internet usage, financial inclusion, and population from 31 provinces or municipalities directly administered by the central government (excluding Hong Kong, Macao, and Taiwan) are sourced from provincial and municipal statistical yearbooks. The level of digital economy development in each region is determined through diverse weighting methodologies. Furthermore, CEP II gravity data and global economic freedom data are incorporated into the analysis. Productivity data for individual enterprises in 2007 are retrieved from the Chinese industrial enterprises database using the LP method [46].

5. Empirical results

5.1. Baseline regression

In this section, the theoretical hypotheses are systematically examined through the econometric model, and the outcomes are elucidated in Table 3. The table encapsulates the results of hypothesis 1 testing. Columns (1)–(2) scrutinize the influence of economic policy uncertainty induced by external shocks on firms' export resilience, while columns (3)–(5) explore the underlying mechanisms of this phenomenon. Firm export resilience is the focal explanatory variable in all regressions, with economic policy uncertainty being the primary explanatory factor.

In columns (1)–(2) of Table 3, column (1) incorporates firm-year and firm-destination fixed effects without additional control variables. The findings reveal a significantly negative coefficient for EPU, indicating that economic policy uncertainty resulting from external shocks has a detrimental effect on firms' export resilience. Recognizing the multifaceted nature of firms' export resilience,

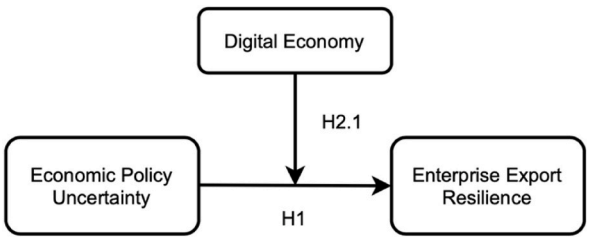

Fig. 1. Conceptual framework.

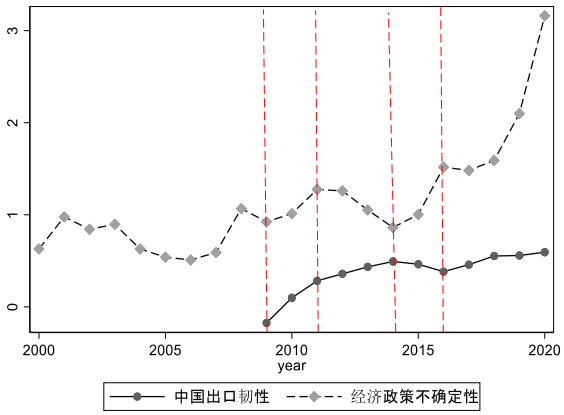

Fig. 2. The association between economic policy uncertainty and China's export resilience is a focal point of investigation in this study.

Table 1
Digital economy composite development index.

Level-1 Indicators	Level-2 indicators	Level-3 indicators
Comprehensive Digital Economy Development Index	Internet penetration rate	Internet users per 100 people
	Number of Internet-related employees	Percentage of employment in computer services and software
	Internet-related outputs	Telecommunications services per capita
	Number of mobile Internet users	Number of cell phone subscribers per 100 people
	Digital Financial Inclusion Development	China Digital Financial Inclusion Index

Table 2
Definitions and descriptive statistics of main variables.

Variable	Definition	Sample	Mean	St.dev	Min	Max
RES_{ikjt}	Export resilience	683,731	−0.026	0.315	−3.087	3.268
EPU_{jt}	Economic policy uncertainty	683,731	0.138	0.060	0.025	0.543
DE_{kt}	Digital economy	683,731	0.317	0.091	0.077	0.586
$EXIM_{ikjt}$	Whether bilateral trade	683,731	0.279	0.449	0.000	1.000
$MODE1_{ikjt}$	Whether processing trade	683,731	0.094	0.292	0.000	1.000
$MODE2_{ikjt}$	Whether mixed trade	683,731	0.444	0.497	0.000	1.000
POP_{jt}	Total population of the destination	683,731	18.045	1.248	15.244	21.004
$FREE_{jt}$	Economic freedom of the destination	683,731	4.349	0.231	3.921	5.219

Table 3
Results of baseline regression.

Variable	(1)	(2)	(3)	(4)	(5)
	Overall Sample		Shorter distance group	Medium distance group	Longer distance group
	RES	RES	RES	RES	RES
EPU	−0.070***	−0.071***	−0.021	−0.038***	−0.222***
	(-7.97)	(-8.61)	(-0.39)	(-4.50)	(-5.91)
Control variable	NO	YES	YES	YES	YES
Enterprise-Year	YES	YES	YES	YES	YES
Enterprise-Destination	YES	YES	YES	YES	YES
Observation	683,266	683,266	240,793	241,710	200,174
Adjust-R2	0.055	0.065	0.067	0.060	0.063

Note: t-values in parentheses; ***, ** and × indicate significant at the 1 %, 5 % and 10 % levels, respectively.

column (2) introduces additional control variables at both firm-destination-year and destination-year levels. Even with these additional controls, the EPU coefficient remains significantly negative. This consistent result underscores the conclusion that economic policy uncertainty induced by external shocks can indeed undermine firms' export resilience. Hu and Liu [47] found that during the pandemic, economic policy uncertainty had a significant short-term negative impact on China's total exports, particularly to countries

participating in the One Belt One Road (OBOR) initiative and the Regional Comprehensive Economic Partnership (RCEP). Under global economic policy uncertainty, this impact becomes even more pronounced. The findings of this study align with these observations.

In columns (3)–(5) of Table 3, the sample is segmented into three groups based on the distance of the destination from China, with each group representing short-distance, medium-distance, and long-distance destinations. Column (3) pertains to the short-distance group, revealing a non-significant negative coefficient for EPU. Column (4) represents the medium-distance group, indicating a significantly negative EPU coefficient with a larger absolute value compared to column (3). Column (5) corresponds to the long-distance group, demonstrating a significantly negative EPU coefficient with a much larger absolute value compared to column (4).

These results suggest that the detrimental impact of economic policy uncertainty on firms' export resilience becomes more pronounced and stronger as export transaction costs increase.

In summary, the analysis corroborates the hypothesis asserting that economic policy uncertainty resulting from external shocks diminishes firms' export resilience by amplifying export transaction costs.

Proceeding further, Table 4 delineates the findings pertaining to hypothesis 2. Columns (1)–(2) scrutinize the impact of the digital economy on the hypothesized weakening effect explicated in hypothesis 1, whereas columns (3)–(4) dissect the varied effects of the digital economy on firms of differing efficiencies. The explanatory variable remains firm export resilience, while the principal explanatory variables encompass interaction terms between economic policy uncertainty and the digital economy.

In columns (1)–(2) of Table 4, column (1) integrates firm-year and firm-destination fixed effects without supplemental control variables. The findings unveil a significantly negative coefficient for EPU, signifying the adverse effect of economic policy uncertainty on firms' export resilience. Furthermore, the coefficient for the interaction term EPU × DE is positively significant, indicating that the digital economy exacerbates the deleterious impact of economic policy uncertainty. Acknowledging the multifaceted factors influencing firms' export resilience, column (2) introduces additional control variables at both firm-destination-year and destination-year levels. Despite these supplementary controls, the EPU coefficient retains its significant negativity, while the coefficient for the interaction term EPU × DE remains positively significant. These results suggest that the digital economy holds promise in alleviating the adverse impact of economic policy uncertainty on firms' export resilience. The findings of Wang et al. [48] corroborate the significant positive influence of the digital economy on the export competitiveness of China's manufacturing industry. Consistent with their research, the conclusions of this study also support this notion, suggesting that the digital economy fortifies the export competitiveness of enterprises, thereby mitigating the adverse effects of economic policy uncertainty on businesses' export resilience.

In columns (3)–(4) of Table 4, the sample is divided into three cohorts based on firm productivity in 2007, with the first 30 % constituting the low-productivity group and the second 30 % comprising the high-productivity group. Column (3) pertains to the low-productivity group, revealing a non-significant positive coefficient for the interaction term EPU × DE. Column (4) corresponds to the high-productivity group, indicating a significantly positive coefficient for EPU × DE, with a larger absolute value compared to column (3).

These findings indicate that the digital economy's ability to alleviate the adverse effects of economic policy uncertainty is more prominent for high-efficiency firms. In summary, the analysis confirms the hypotheses proposing that the digital economy mitigates the negative impact of economic policy uncertainty on firms' export resilience, with this effect being particularly notable for high-efficiency firms. This provides evidence in support of hypotheses 2.1 and 2.2. Table 5 presents the test results for the second part of Hypothesis 2, examining the channels through which the digital economy exerts a mitigating effect. Columns (1) to (3) investigate the channel of export transaction costs, with the dependent variable being the resilience of firms' exports. The key explanatory variables in the table are the interaction terms between economic policy uncertainty and the development of digital economy.

Firstly, mirroring the structure of Table 3, Table 5 divides the sample into three groups based on the distance from China to the destination, depicted in columns (1) to (3). The first column corresponds to the short-distance group, revealing a positive yet statistically insignificant coefficient for the EPU × DE interaction. Moving to the second column, representing the medium-distance group, a statistically significant positive coefficient for the EPU × DE interaction is observed, with its magnitude surpassing that of the first column. Similarly, in the third column representing the long-distance group, a statistically significant positive coefficient for the EPU × DE interaction is evident, with its magnitude exceeding that of the second column. Generally, greater distances correspond to higher

Table 4
Tests for mediating effects and productivity heterogeneity.

Variable	(1)	(2)	(3)	(4)
	Overall Sample		Low productivity group	High productivity group
	RES	RES	RES	RES
EPU	−0.094***	−0.117***	−0.112***	−0.132***
	(-5.19)	(-6.90)	(-2.73)	(-4.17)
EPU × DE	0.269*	0.500***	0.359	0.783***
	(1.77)	(3.59)	(1.10)	(2.79)
Control Variable	NO	YES	YES	YES
Enterprise-Year	YES	YES	YES	YES
Enterprise-Destination	YES	YES	YES	YES
Observation	683,266	683,266	90,129	89,399
Adjust-R2	0.055	0.065	0.100	0.134

Note: t-values in parentheses; ***, ** and × indicate significant at the 1 %, 5 % and 10 % levels, respectively.

Table 5
Tests the mechanism of the mediating effects of digital economy.

variable	(1)	(2)	(3)
	Short distance	Medium distance	Long distance
	RES	RES	RES
EPU	−0.093	−0.094***	−0.243***
	(-0.94)	(-5.71)	(-5.77)
EPU × *DE*	1.525	0.583***	0.802***
	(1.51)	(4.20)	(2.64)
Control Variable	YES	YES	YES
Enterprise-Year	YES	YES	YES
Enterprise-Destination	YES	YES	YES
Observation	240,793	241,710	200,174
Adjust-R2	0.069	0.060	0.063

export transaction costs. These results underscore the critical role of export transaction costs as a conduit through which the digital economy mitigates the impact.

In summary, the digital economy mitigates the relationship between economic policy uncertainty and firms' export resilience through reducing export transaction costs, confirming the hypothesis 2.2.

5.2. Endogeneity issue and robustness tests

5.2.1. Measurement error problem

First, the potential impact of measurement error on the explanatory variables is considered. Given the abstract nature of export resilience and the diversity of indicators, this study adopts four alternative indicators, inspired by Ref. [45], to measure enterprise export resilience. These indicators encompass the export value and its recovery relative to 2008, alongside the midpoint growth rate and the chain growth rate. Although the export value and growth rates may not explicitly embody the notion of "resilience," they provide valuable insights into the competitive prowess of exporters and the trend of export fluctuations.

Regression results are presented in Table 6, where columns (1)–(2) correspond to the export value, columns (3)–(4) pertain to the recovery of export value, columns (5)–(6) represent the midpoint growth rate, and columns (7)–(8) depict the chain growth rate. Analysis of Table 6 reveals significantly negative coefficients for EPU and significantly positive coefficients for the interaction term EPU × DE across all indicators. These consistent findings align with previous research, indicating that the conclusions of this study remain robust despite potential measurement errors in the explanatory variables.

To address potential measurement errors in core explanatory variables, this study employs robust methodologies. Economic policy uncertainty (EPU) exhibits quarterly fluctuations tied to significant events, thus necessitating the use of a quarterly weighted average method to derive annual figures. Similarly, the digital economy's development level, a composite indicator, is computed using the principal component method for enhanced accuracy.

Table 7 presents regression outcomes under various scenarios. In column (1), the EPU calculation method is altered, while column (2) modifies the DE calculation method while retaining the benchmark for EPU. Conversely, column (3) adjusts the DE calculation method while keeping the EPU calculation consistent with the benchmark. Finally, column (4) updates both the EPU and DE calculation methods.

Upon examination of Tables 7 and it is evident that the EPU coefficient consistently remains significantly negative, and the interaction term EPU × DE coefficient consistently remains significantly positive across all scenarios. These findings corroborate those of previous studies, suggesting that potential measurement errors in core explanatory variables do not undermine the conclusions of this paper.

Table 6
Effect of the measurement error of the explanatory variables.

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	VALUE	VALUE	VALUE-R	VALUE-R	GROW	GROW	GROW2	GROW2
EPU	−0.168***	−0.344***	−0.164**	−0.374***	−0.081***	−0.122***	−0.086***	−0.128***
	(-3.25)	(-5.67)	(-2.58)	(-4.39)	(-12.79)	(-8.66)	(-11.75)	(-6.98)
EPU × *DE*		1.951***		2.322***		0.456***		0.469***
		(3.76)		(3.41)		(3.87)		(3.06)
Control Variable	YES	YES	YES	YES	YES	YES	YES	YES
Enterprise-Year	YES	YES	YES	YES	YES	YES	YES	YES
Enterprise-Destination	YES	YES	YES	YES	YES	YES	YES	YES
Observation	683,266	683,266	683,266	683,266	683,266	683,266	683,238	683,238
Adjust-R2	0.436	0.436	0.189	0.189	0.046	0.046	0.025	0.026

Note: t-values are presented in parentheses; significance levels are denoted by ***, **, and *, indicating significance at the 1 %, 5 %, and 10 % levels, respectively.

Table 7
Effect of considering measurement error in core explanatory variables.

Variable	(1)	(2)	(3)	(4)
	Replace EPU indicators only		Replace DE indicators only	Replace EPU and DE indicators
	RES	RES	RES	RES
EPU	−0.009***	−0.013***	−0.090***	−0.011***
	(-10.09)	(-8.63)	(-7.91)	(-9.39)
EPU × *DE*		0.045***	0.045***	0.005***
		(3.71)	(3.15)	(3.28)
Control Variable	YES	YES	YES	YES
Enterprise-Year	YES	YES	YES	YES
Enterprise-Destination	YES	YES	YES	YES
Observation	683,266	683,266	683,266	683,266
Adjust-R2	0.065	0.065	0.065	0.065

Note: t-values are presented in parentheses; significance levels are denoted by ***, **, and *, indicating significance at the 1 %, 5 %, and 10 % levels, respectively.

5.2.2. Issues on omitted variables

Given the intricate and multifaceted nature of factors influencing enterprise export resilience, this study addresses the issue of omitted variables through two approaches.

In an effort to enhance the robustness of our analysis, we employ additional strategies to address potential confounding variables.

Firstly, we augment the original set of control variables by introducing additional factors at the destination-year level. These include gross product, import and export trade scales, and governance level. The results of these regressions are detailed in Table 8, columns (1)–(2).

Secondly, to mitigate the influence of regional and industrial factors such as industrial agglomeration, we introduce province-industry (HS4)-year fixed effects. These fixed effects control for variations at the intersection of province, industry (HS4 code), and year. The corresponding results are presented in Table 8, columns (3)–(4).

Upon scrutiny of the outcomes, it becomes apparent that the coefficient for EPU remains consistently negative, while the interaction term EPU × DE coefficient remains consistently positive across all model specifications. This steadfastness in our findings underscores the robustness of our analysis and reinforces the validity of our conclusions.

5.2.3. Sample selection problem and treatment

In light of potential biases introduced by specific samples in our benchmark dataset, whose export resilience may be disproportionately influenced by unique factors such as economic policies, geographical location, and international environment rather than solely by economic policy uncertainty and the digital economy, this study adopts a methodology proposed by Ref. [44] to exclude such samples.

The excluded special samples are categorized as follows: i) Trade-free port samples, such as Singapore and Hong Kong, which are often treated as tax havens rather than final export destinations. ii) Trade intermediary samples, characterized by export intermediaries facilitating off-site exports. iii) Foreign-owned enterprise samples, comprising enterprises tightly linked to the international market and reliant on their parent companies. iv) Non-general trade samples, encompassing cases where processing trade is integrated into the international value chain cycle and segregated from domestic production cycles, exhibiting dual characteristics.

Table 9 displays the corresponding regression results, with columns (1)–(2) excluding the trade-free port sample, columns (3)–(4)

Table 8
Effect of considering omitted variables.

Variable	(1)	(2)	(3)	(4)
	Adding control variables		Adding fixed effects	
	RES	RES	RES	RES
EPU	−0.054***	−0.077***	−0.070***	−0.117***
	(-5.48)	(-4.76)	(-8.84)	(-6.73)
EPU × *DE*		0.238*		0.519***
		(1.73)		(3.59)
Original control variables	YES	YES	YES	YES
Adding control variables	YES	YES	NO	NO
Enterprise-Year	YES	YES	YES	YES
Enterprise - Destinations	YES	YES	YES	YES
province-hs4-year	NO	NO	YES	YES
Observation	683,266	683,266	668,892	668,892
Adjust-R2	0.065	0.065	0.081	0.081

Note: t-values are presented in parentheses; significance levels are denoted by ***, **, and *, indicating significance at the 1 %, 5 %, and 10 % levels, respectively.

excluding the trade intermediary sample, columns (5)–(6) excluding the foreign-owned enterprise sample, and columns (7)–(8) excluding the non-general trade sample.

Upon scrutinizing Tables 9 and it becomes evident that the coefficient for EPU remains consistently negative, while the interaction term EPU × DE coefficient remains consistently positive across all scenarios. This uniformity in our findings suggests that the regression outcomes remain consistent with those of the previous study, underscoring the robustness of our conclusions and indicating that the selection of regression samples does not alter the findings of this paper.

5.2.4. Shock year problem and treatment

Acknowledging that the actual onset of the financial crisis occurred in late 2007, the choice of 2008 as the shock year in the benchmark dataset may introduce bias. To address this concern, this study replaces the shock year with 2007 to recalibrate enterprise export resilience. Table 10 presents the corresponding regression results.

Upon scrutiny of Tables 10 and it is evident that the coefficient for EPU retains its significant negativity, while the coefficient for the interaction term EPU × DE remains significantly positive. These results are consistent with the previous findings, indicating that changing the chosen shock year from 2008 to 2007 does not impact the conclusions drawn in this paper.

5.2.5. Issues on casualty

The dynamics of economic policy uncertainty, the digital economy, and enterprise export resilience operate at distinct levels: macro, meso, and micro, respectively. Economic policy uncertainty, a macro-level variable at the destination-year level, is primarily influenced by international situations and changes in destination countries' economic and trade policies. Conversely, the digital economy, a meso-level variable at the province-year level, is mainly shaped by national economic policies and provincial economic and trade development strategies. Enterprise export resilience, a micro-level variable at the enterprise-destination-year level, is influenced by firm-specific factors.

Examining potential endogeneity between economic policy uncertainty and the digital economy is essential. While it might be expected that enterprise export resilience would have minimal impact on macro or meso variables, and vice versa, rigorous testing is necessary. To this end, this study conducts correlation tests between economic policy uncertainty and the digital economy while controlling for year and firm-destination fixed effects.

Table 11 presents the results of these tests. In column (1), economic policy uncertainty serves as the explanatory variable, while the digital economy is the dependent variable. The coefficient for the digital economy (DE) is negative but not significant. In column (2), the roles are reversed, with the digital economy as the explanatory variable and economic policy uncertainty as the dependent variable. Here, the coefficient for economic policy uncertainty (EPU) is negative and insignificant.

In summary, these results suggest that there is no significant mutual causality between economic policy uncertainty and the digital economy. Therefore, the conclusions drawn in this paper remain robust.

5.3. Heterogeneity tests

5.3.1. Heterogeneity test based on the geographic location of the enterprises

In columns (1)–(2) of Table 12, firms are categorized into eastern firms (SAM = 1) and central and western firms (SAM = 0) based on the geographic location of the province where the firm is situated. The results in column (1) indicate that the interaction term EPU × SAM is negative but not statistically significant, suggesting that the impact of economic policy uncertainty does not significantly vary for firms located in different regions. Conversely, the results in column (2) show that EPU × DE × SAM is significantly negative, implying that the mitigating effect of the digital economy is weaker for eastern firms. Possible explanations for these findings are multifaceted. On one hand, eastern enterprises generally exhibit stronger economic capabilities but concurrently face more substantial competitive pressures. In contrast, Central and Western enterprises, despite possessing comparatively weaker overall capabilities, benefit from various policy safeguards. As a result, the capacity of the two to withstand economic policy uncertainty shows no significant difference. On the other hand, the robust economic strength of Eastern enterprises, coupled with their tendency to export products with higher quality and greater variety, contributes to their resilience. Additionally, as agglomeration effects deepen, the difficulty of obtaining information and maintaining trade relationships significantly decreases for Eastern enterprises. Consequently, these enterprises progressively minimize transaction costs, limiting the extent to which the digital economy can play a mitigating role. Conversely, Central and Western enterprises are currently undergoing a phase of transformation and upgrading, enhancing their overall capabilities through the significant application of digital technology. This has led to increased production capacities, improved export product quality, and a diversification of exported product types. Furthermore, the development of information technology has reduced communication difficulties between Central and Western enterprises and foreign markets, substantially cutting transaction costs. Hence, the regulatory role of the digital economy is particularly robust for Central and Western enterprises.

5.3.2. Heterogeneity test based on the level of development of enterprises' export destinations

In columns (3)–(4) of Table 12, the sample is stratified into two groups: a developed destination sample (SAM = 1) and a developing destination sample (SAM = 0) based on the economic development level of the destination. The results in column (3) demonstrate that the interaction term EPU × SAM is positively significant, indicating that the impact of economic policy uncertainty is less pronounced for firms exporting to developed regions. Additionally, the results in column (4) show that the coefficient for the interaction term EPU × DE × SAM is significantly positive, suggesting that the moderating effect of the digital economy is stronger for firms exporting to developed regions.

Table 9
Effect of considering the range of regression sample selection.

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Excluding trade free ports		Excluding trade intermediaries		Excluding foreign enterprises		Excluding non-general trade samples	
	RES	RES	RES	RES	RES	RES	RES	RES
EPU	−0.056***	−0.086***	−0.061***	−0.104***	−0.080***	−0.124***	−0.079***	−0.144***
	(-7.13)	(-5.70)	(-5.49)	(-5.15)	(-9.95)	(-7.30)	(-6.48)	(-6.34)
EPU × *DE*		0.319**		0.473***		0.497***		0.655***
		(2.41)		(3.01)		(3.59)		(3.91)
Control variable	YES	YES	YES	YES	YES	YES	YES	YES
Enterprise-year	YES	YES	YES	YES	YES	YES	YES	YES
Enterprise-destination	YES	YES	YES	YES	YES	YES	YES	YES
observation	604,520	604,520	431,827	431,827	439,848	439,848	315,004	315,004
Adjust-R2	0.066	0.066	0.065	0.065	0.085	0.085	0.067	0.067

Note: t-values are presented in parentheses; significance levels are denoted by ***, **, and *, indicating significance at the 1 %, 5 %, and 10 % levels, respectively.

Table 10
Effect of considering the range of impact years selected.

Variable	(1)	(2)
	Inhibitory effect	Mitigation effect
	RES	RES
EPU	−0.082***	−0.123***
	(-12.11)	(-8.55)
EPU × *DE*		0.476***
		(3.80)
Control variable	YES	YES
Enterprise-year	YES	YES
Enterprise-destination	YES	YES
Observation	688,596	688,596
Adjust-R2	0.093	0.093

t-values are presented in parentheses; significance levels are denoted by ***, **, and *, indicating significance at the 1 %, 5 %, and 10 % levels, respectively.

Table 11
The correlation between economic policy uncertainty and the digital economy.

Variable	(1)	(2)
	EPU	DE
EPU		−0.000
		(-0.08)
DE	−0.001	
	(-0.08)	
Control variable	YES	YES
Year	YES	YES
Enterprise-destination	YES	YES
Observation	683,458	683,458
Adjust-R2	0.710	0.995

Note: Controlling for firm-year fixed effects eliminates the digital economy indicator. Therefore, this paper modifies it to incorporate year fixed effects.

A plausible explanation for these findings is that developed countries often impose stringent trade regulations and require higher trade standards and quality. To protect their domestic industries, they may implement measures to restrict the entry of foreign enterprises into their markets, leading to higher transaction costs for Chinese exporters. Conversely, developing regions may have less restrictive policies, resulting in a smaller weakening effect of economic policy uncertainty for companies exporting to these regions.

In summary, while the impact of economic policy uncertainty is less pronounced for firms exporting to developed regions, the regulatory effect of the digital economy is more significant for these firms.

The central focus of our study is to determine the influence of economic policy uncertainty on enterprise export resilience and the moderating effect of the digital economy. To enhance the credibility of empirical results, we address endogeneity and robustness concerns from five perspectives. (1) Measurement error issues: We address measurement errors in economic policy uncertainty, the digital economy, and enterprise export resilience by employing different formulas for calculation. (2) Omitted variable concerns: To

Table 12
Test for heterogeneity.

	(1)	(2)	(3)	(4)
	Location of enterprise		economic development of the destination	
	RES	RES	RES	RES
EPU	−0.059**	−0.070***	−0.166***	0.004
	(-2.36)	(-2.70)	(-5.50)	(0.09)
EPU × *SAM*	−0.013	−0.049	0.102***	−0.080*
	(-0.48)	(-1.52)	(3.20)	(-1.77)
EPU × *DE*		1.271***		−1.518***
		(3.43)		(-3.04)
EPU × *DE* × *SAM*		−0.785*		1.755***
		(-1.94)		(3.78)
Control variable	YES	YES	YES	YES
Enterprise-year	YES	YES	YES	YES
Enterprise-destination	YES	YES	YES	YES
Observation	683,266	683,266	683,266	683,266
Adjust-R2	0.065	0.065	0.065	0.065

Note: t-values in parentheses; ***, ** and × indicate significant at the 1 %, 5 % and 10 % levels, respectively.

mitigate omitted variable issues, potentially related to other explanatory variables, we introduce additional control variables and control for province-industry (hs4)-year-country fixed effects. (3) Sample selection issues: Special samples in the baseline dataset may be influenced by unique factors such as economic policy, geographical location, and international environment. To tackle this, we exclude specific outlier samples. (4) Shock duration issues: Considering the true onset of the financial crisis in late 2007, we adjust the baseline shock year from 2008 to minimize potential biases. (5) Endogeneity concerns: Due to potential reverse causality between economic policy uncertainty and the digital economy, we examine their relationship after controlling for year and firm-destination fixed effects. Even after addressing these five endogeneity concerns, our conclusions remain robust.

6. Conclusions and policy recommendations

In the context of intensifying global uncertainty, bolstering the sustained export capacity of enterprises is crucial for stabilizing foreign trade. This paper employs a high-dimensional linear estimation model to dissect the relationships between economic policy uncertainty, the digital economy, and enterprise export resilience from the standpoint of export transaction costs. The theoretical analysis suggests that economic policy uncertainty inhibits enterprise export resilience by affecting export transaction costs negatively. Conversely, the digital economy mitigates the adverse impact of economic policy uncertainty on enterprise export resilience through its positive economic effects. Empirical analysis, based on micro-level data of firms at the firm-destination-year level spanning from 2000 to 2016, provides evidence supporting the theoretical mechanisms. A series of robustness tests, including changes in the calculation method of core explanatory variables, exclusion of samples from special economic zones, removal of non-general trade samples, exclusion of large export enterprises, and the addition of samples from trade transit locations, reinforce the robustness of the conclusions.

Based on the conclusions above, this article provides some policy recommendations. Firstly, the government should strive to reduce the volatility of economic policies and employ continuous and stable economic policies for macroeconomic regulation. Specifically, before enacting relevant economic policies, full-scale pilot experiments should be conducted to enhance the rationality of economic policy implementation. By gradually adjusting economic policies during the pilot process, the volatility of economic policies can be reduced. Secondly, it is recommended to guide enterprises to use hedging tools to diversify risks. Enterprises can seek protection for their own interests by using export credit insurance and insurance services, thereby reducing the negative impact on export enterprises in an uncertain economic policy environment.

Data availability statement

The data that support the findings of this study are openly avaliable in Mendeley Data at https://doi.org/10.17632/3d82bz2tsd.1.

CRediT authorship contribution statement

Xiugang Zhu: Writing – review & editing, Methodology, Formal analysis, Data curation, Conceptualization. **Yunxin Ye:** Writing – original draft, Validation.

Declaration of competing interest

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

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