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How does digital technology administrative penalty affect big data technology innovation: evidence from China

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Administrative regulation is an essential institutional arrangement for governing innovation in big data technology. Administrative penalties are one of its main methods. It is worth investigating whether administrative penalties can serve as an institutional safeguard to promote technological innovation. This study collects data on digital technology administrative penalty (DTAP) and big data technology innovation (BDTI) from 2008 to 2020 in 281 cities in China and empirically evaluates the impact and mechanism of DTAP on BDTI. The findings suggest that the normative impact of the DTAP system can foster a conducive business ecosystem for big data innovation. The incentive mechanism motivates firms to increase their long-term investment in technological innovation, while the deterrence mechanism ensures the existence of a regulated competitive market. These mechanisms play a crucial role in facilitating BDTI. Mechanism tests show that the DTAP has the potential to promote novel business models in the digital economy and accelerate progress in industrial digitalisation, which in turn promotes innovation in big data technologies. The impact of the DTAP on promoting BDTI is diverse, with a significantly greater impact in the first-tier cities. DTAP plays a more important role in fostering BDTI in places where the digital factor-driven industry is still in its early stages of development.

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Introduction

An unparalleled amount of data generation has resulted from the information technology industry's rapid growth (Lin et al., 2020). Big data is the foundation and vital core of the digital economy (Wang and Lu, 2022), defined by its volume, velocity, and value (Rehman et al., 2016). By creating, gathering, storing, processing, and analysing enormous volumes of data, big data technology has the potential to boost productivity and operational efficiency (Lambrecht and Tucker, 2015; Yang, 2022; Farboodi et al., 2019; Zhang et al., 2021; Sun and Li, 2022). Moreover, it can facilitate the integration of the digital and real economies (Wang and Lu, 2022) and promote long-term productivity growth (Acemoglu and Restrepo, 2018; Ciarli et al., 2021; Svahn et al., 2017; Huang et al., 2023). The widespread adoption of big data technologies in the fintech industry has revolutionised the traditional credit model (Chen et al., 2022) and provided access to credit to previously excluded borrowers facing financial difficulties (Bao and Huang, 2023). However, the widespread adoption of big data technology also poses significant risks, such as data misuse, privacy violations, and vulnerability to cyber threats. These market failures may hinder the innovation of digital technologies (Jiang et al., 2023). Therefore, the governance of externalities is crucial to creating a supportive digital economic ecosystem that can drive high-quality development.

It is a practical necessity for countries to accelerate the development of the digital economy by creating appropriate policies for managing big data technology innovation (BDTI) and ensuring their effective implementation. In addition to favourable stimuli such as industrial and tax policies, the establishment of a regulatory policy system is an important approach to enable technology innovation (Jiang et al., 2023). Enhanced regulation may have a bidirectional impact on innovation in digital technology. Regulating digital externalities can foster a conducive environment for digital innovation and accelerate its momentum. Inappropriate digital regulatory policies may raise the cost of digital innovation or even create administrative barriers and constrain technological innovation activities. China has emerged as a prominent player in the global digital technology innovation and digital economy development. Has China's rapidly expanding digital economy and dynamic digital technology innovation been positively influenced by this institutional arrangement? Administrative penalties, along with public disclosure of information regarding such penalties, are important management tools used by China in the field of digital technology innovation and application management. Empirical testing is required to address this issue and aid policymakers in improving laws and regulations. We address this gap by conducting an initial investigation into the impact of digital technology administrative penalties (DTAP), which are the administrative penalties imposed on enterprises engaging in digital technology innovation for illegal activities, on BDTI. In addition, the comparative analysis of different regions enables a better understanding of the regional disparities in big data innovation and provides guidance for policy formulation.

To explore the effects and functioning of DTAP on BDTI, this study analyses the normative, incentive and deterrent effects of administrative penalty. DTAP, coupled with the disclosure of penalty information, reduces information asymmetry and enhances the business environment. Penalised firms are incentivised by DTAP, inspiring them to increase innovation investment for long-term gain. DTAP has a deterrent effect on firms in the region. The disclosure of penalty outcomes has both a spillover and diffusion impact, whereas the disclosure of penalty details defines the boundaries of behaviour in the form of cases. This acts as a warning and deterrent to companies in the region and standardises their operations. Ultimately, all three effects will encourage innovation in regional big data technology. This study conducted an empirical test on a sample of 281 cities in China and found that DTAP is an effective implementation mechanism for promoting the development of BDTI. The level of BDTI in a city is positively correlated with the level of DTAP intensity. This finding remains consistent even after altering variable measurements, accounting for endogeneity, introducing control variables, analysing different time periods, and modifying the estimation model. In addition, DTAP can promote the creation of new businesses and the digitalisation of industries, thereby supporting BDTI. Finally, the role of DTAP in promoting BDTI varies and is more prominent in Beijing, Shanghai, Guangzhou, and Shenzhen. DTAP plays a more significant role in driving BDTI in cities with relatively low levels of digital factor-driven industry development.

This study adds to the existing literature on digital technological innovations. Academic research focuses on assessing the factors that influence digital technology innovation. Existing literature mainly analyses two perspectives: the intrinsic qualities of enterprises and the external environment. Studies that address the intrinsic qualities of enterprises are analysed from the perspectives of firms' human capital (Yuan et al., 2021), executives' digital technology expertise (Firk et al., 2021), market players' communication (Kohli and Melville, 2019), and involvement in digital technology innovation alliances (Huang et al., 2023), along with the involvement in mergers and acquisitions of digital industry firms (Hanelt et al., 2021; Pan and Xu, 2023). Studies that address the external environment are conducted from the viewpoints of market demand, digital infrastructure, industrial structure (Peng et al., 2022), and foreign direct investment (Zhou et al., 2022). Studies into government involvement in digital technology innovation typically concentrate on several key areas. These include industrial policy (Yu et al., 2021), infrastructure development (Sun et al., 2022), financial incentives (Sun et al., 2022), Big Data pilot schemes (Xu et al., 2022), intellectual property rights protection (Huang et al., 2023), and environmental pollution levels and regulatory policies (Han and Wang, 2022; Yue et al., 2023). Market regulation is a fundamental function of the government, serving as a crucial force in upholding market order and as a key external element that affects enterprise innovation. However, few studies adopt the institutional perspective, particularly in regard to administrative penalties. This study presents evidence of the impact of administrative penalties and contributes to understanding the effect of government regulation on firms' innovation.

Our study adds to the literature on enforcement mechanisms. Reminders, social preferences, and financial incentives are the main enforcement mechanisms to deter non-compliance activities (Huang and Bao, 2020). We investigate the impact of DTAP on BDTI from an institutional enforcement perspective and suggest that penalties for corporate violations are the fundamental regulatory tool used by the government to ensure fair market competition. The government's active involvement in BDTI is essential because it gives data governance research and practice a foundation for decision-making. Existing literature rarely explores the effects of administrative penalties on technological innovation from a technical stance (Jiang et al., 2023). This study adds to the existing literature on the real impact of administrative penalties. Previous studies have focused on public penalty announcements made by stock exchanges for listed companies, with little attention given to non-listed companies (Yu et al., 2023). By analysing administrative penalty announcements from various administrative departments, we extend the empirical evidence on administrative penalties to non-listed firms.

The paper is structured as follows: The hypotheses are presented in the section 'Background and hypothesis', the methodology is explained in the section 'models, variables, and data', the empirical results and robustness tests are discussed in the section 'Results', transmission mechanism tests are carried out in section 'Mechanism verification', and heterogeneity analysis is carried out in the section 'Regional heterogeneity'. The results are presented in the section 'Discussion', and policy recommendations are summarised and given in the section 'Implications and policy suggestions'. The research outlook is described in the last section.

Background and hypothesis

Institutional background. Administrative penalties are crucial for ensuring the effective implementation of laws and regulations. They have traditionally been the primary tool employed by Chinese government departments to manage the market and maintain a well-organised and trustworthy marketplace. Its primary objective is to uphold market order and foster a culture of honesty and integrity. The *Administrative Punishment Law of the People's Republic of China* was established in 1996 and subsequently revised in 2009, 2017, and 2021. The Law outlines administrative penalties as 'measures taken by an administrative body, in the process of administering tasks, to discipline an individual, legal entity or other organisation that contravenes administrative regulations by infringing upon their rights or increasing their obligations as stipulated by the law'.

China is promoting the establishment of a comprehensive administrative law enforcement system. There is a relative concentration of administrative penalty powers within these areas. Other administrative organisations possess distinct powers to impose penalties within the scope of their functions. China has introduced various laws and regulations to promote digital technological innovation, including the *Network Security Law*, the *Data Security Law*, the *Anti-Unfair Competition Law*, the *E-Commerce Law*, and the *Regulations on the Administration of Blockchain Information Services*. The list of administrative law enforcement matters for 2022 by the Ministry of Industry and Information Technology includes a total of 296 matters. Among these, 38 matters pertain to network security, 15 are focused on data security, and 4 relate to the protection of personal information.

The system for disclosing information regarding administrative penalties has undergone continuous improvement. The Interim Provisions on Disclosure of Information on Administrative Penalties by Industry and Commerce Administration were introduced in August 2014, alongside the Interim Regulations on Disclosure of Enterprise Information, which took effect on October 1 of the same year. In July 2021, the State Administration for Market Supervision issued the *Provisions on Publication of Information on Administrative Punishments in Market Supervision*. By publicising enterprise information and information on administrative penalties, the main responsibility of enterprises is strengthened through the mechanisms of publicising, supervising, and restraining. This accelerates the transformation of the market supervision mode of the business administration department. It promotes the construction of the enterprise integrity system and plays a supervisory and restraining role in violation behaviours.

Administrative penalties in China are applied systematically and hierarchically, with distinct administrative bodies carrying out individual penalty functions and the central office of the same body and its dispatched agencies possessing diverse penalty prerogatives. For instance, the PBOC imposes administrative penalties for offences and violations discovered during law enforcement inspections conducted under the PBOC's name. Additionally, PBOC branches impose administrative penalties for offences and violations that occur within their jurisdictions. Over the first half of 2023, PBOC branches issued 82 fines to financial institutions for violating credit information regulations. The total amount of the fines imposed was 44.82168 million yuan. Due to differences in regulation and enforcement, the discretionary scale and enforcement of administrative penalties vary among regions in China, providing an optimal research scenario for analysing BDTI within the context of administrative penalties.

The information on administrative penalties imposed on enterprises published by the National Enterprise Information Publicity System includes such basic information as the name of the enterprise subject to administrative penalty, legal representative (person in charge), location, the number of the administrative penalty decision, the type of offence, the main facts of the offence, the basis for the penalty, the time of the penalty, the type of the penalty, the reason for the penalty, the content of the administrative penalty, the organ that imposes the administrative penalty, the date of penalty, the date of the announcement of the administrative penalty, and the deadline for the announcement of the administrative penalty, and so on. The penalties imposed on firms include non-compliance, safety, environmental pollution, traffic violations, illegal occupancy, labour-related offences, fire safety breaches, and others. This study applied all these areas of administrative penalties to the digital technology firms examined.

Hypothesis development. Administrative penalties are crucial enforcement mechanisms within formal systems encompassing laws, regulations, industrial policies and tax policies, which play a pivotal role within the institutional environment (Li, 2019). Consequently, administrative penalties contribute significantly to establishing clear institutional norms and guidelines. These penalties can significantly affect the efficiency of the system's enforcement, as well as its binding force and the dissemination of information related to the system's procedures. Fair and regulated market competition can decrease the duration and economic expenses entailed in the enterprise innovation process, encourage collaborative innovation between companies, and augment technological innovation within the sector (Yu et al., 2021). Digital technology has positive externalizations and spillover effects (Qi et al., 2022). The high threshold, high cost, and imitability of digital technological innovation (Firk et al., 2021) pose challenges for enterprises in achieving economic benefits from their innovation activities (Teece, 2018). Enforcing compliance can boost market players' confidence in the legal protection of BDTI results they plan to invest in, thereby enhancing their investment appetite and intensity. Implementing administrative penalties facilitates the formulation and spread of institutional norms within a region, thereby supporting innovation incentives, protection, synergies and disseminating BDTI.

Classical regulatory economic theory indicates that regulation and penalties levied on enterprises can create incentives. Such incentives result not only from the economic losses caused by penalties but also from the loss of social capital. Regulatory penalties are known for being reputational penalties, which listed firms and their executives face (Li et al., 2023). These penalties affect financing scale, financing costs, profits, and risk-taking behaviour (Zhu, 2020; Zhao and Gao, 2023). Government regulatory actions may also impact companies affiliated with penalised firms (Xin et al., 2019). In the immediate aftermath of the administrative penalty, the reprimanded company will encounter increased external scrutiny and more stringent regulatory measures. As a result, it will allocate additional resources towards improving its corporate governance and performance, in order to rehabilitate its reputation. Furthermore, the organisation will prioritise bolstering its technological innovation, thereby enhancing its proficiency in digital technology innovation and elevating its 'high-tech' profile. All of these factors contribute to enhancing the capabilities and effectiveness of digital technology for innovation purposes.

The concept of deterrence, first introduced by Becker (1968), has found wide application in economic analysis. Administrative penalties act as a deterrent, impacting the corporate governance, risk management, and investment behaviour of the penalised firms (Chu and Fang, 2021). This curtails ex-post violations by penalised firms, standardises digital technology innovation activities within the industry, and elevates the level of regional big data innovation. Companies operating in the same industry or region are indirectly discouraged by regulatory penalties and will modify their conduct related to violation matters (Xue et al., 2017). Firms also respond to information on the disclosure of administrative penalties. When government bodies enforce DTAP, they provide guidance to enterprises on 'how to lawfully adopt digital technology such as Big Data technology' and 'which applications are illegal'. This, in turn, helps market participants comprehend the legal framework and establish stable innovation prospects. DTAP can convey relevant policy signals, create penalty expectations, govern business conduct, and reinforce market discipline in the sector, thereby easing the implementation of innovation.

Based on the institutional normative, incentive and deterrent effect of DTAP, we propose H1.

H1: DTAP can facilitate BDTI.

The enhancement of the business environment, alongside an increase in long-term innovation investment by enterprises and the formation of orderly competition within the market—facilitated by the DTAP—all form an essential foundation for business model innovation in the digital economy. The implementation of administrative penalties can also serve to encourage the growth of new industries in the digital economy. BDTI has an industrial clustering effect, whereby enterprises and organisations located within the same geographic area promote the development of novel digital economy formats by sharing resources, facilitating information interoperability, creating market synergy and other economies of scale. A monopoly of a few large enterprises is not conducive to the technological innovation of the industry (Yu et al., 2021). It is imperative to avoid a 'winner-take-all' scenario, which prevents the survival and profitability of new innovation subjects, as well as the formation and expansion of new business forms in the digital economy. The increase in new digital economy business forms offers a wider range of application scenarios for BDTI, and these firms can collaborate and integrate deeply through informatisation. They can also develop new forms of business whilst completing their own transformation and upgrading. The industrial linkage effect and industrial fusion effect are expected to propel BDTI. Accordingly, we propose hypothesis 2:

H2: DTAP contributes to the development of new business forms, thus promoting BDTI.

Improving the business environment, increasing long-term innovation investment by enterprises, and forming an orderly and competitive pattern in the market, facilitated by DTAP, will accelerate industry digitisation. In China, governments across the board actively promote the growth of the digital economy and the digital industrial revolution. Therefore, DTAP is set to further promote industry digitisation. Concurrently, with stronger government management of digital technology, digital results shall receive better protection. This shall have an advantageous effect on enterprises by motivating them to increase their digital transformation efforts and promote the digitisation of the industry. Intellectual property rights (IPR) protection shall also release financing constraints (Ang et al., 2014; Wu and Tang, 2016), thereby enabling enterprises to expand their digitalisation investment. The digitisation and data mining of diverse elements, including labour, land, capital, technology, management, and knowledge, will generate fresh types of data productivity, as per Mei's (2022) findings, and propel industry digitisation. The latter can furnish ample data resources, elevating demand, and diversifying application scenarios for BDTI, thereby fuelling innovation. Accordingly, we propose hypothesis 3:

H3: DTAP contributes to the digitalisation of industries, thus promoting BDTI (Fig. 1).

Models, variables, and data

Model. China is a geographically extensive and disparately developed nation (Chen et al., 2023). Each city possesses distinct elements that influence its big data technology innovation, which remain consistent over time. To control for this factor, we incorporate city-fixed effects into our analysis. Furthermore, China operates under a government-led economic system, where the central government annually implements programs to foster various technical innovations, such as big data technology innovation, throughout all cities. These policies have an impact on every city and undergo changes on an annual basis. To control for this factor, we incorporate year fixed effects into our analysis. We have designed the following bidirectional fixed effects for year

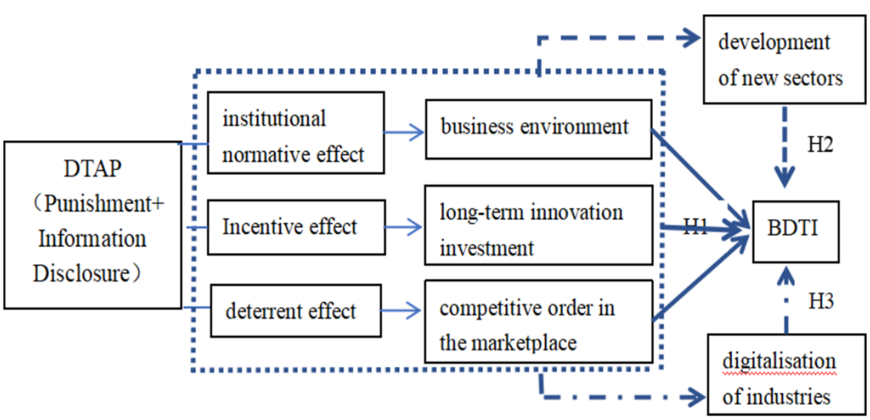

Fig. 1 A roadmap of the mechanisms by which DTAP affects BDTI. This figure shows the direct pathways and indirect channels through which DTAP affects BDTI.

Table 1 Variable description.

Type	Name	Symbol	Definition
Dependent variable	Big data technology innovation activity	*BDTI*	Number of Big data technology patent applications/total population, Lu, etc. (2021)
		rBDTI	Number of Big data technology patents granted/total population, Lu, etc. (2021)
Independent variable	Intensity of administrative penalties for digital technology	*DTAP*	*Admsanition/Total population*
		rDTAP	*Admsanctionmoney/Total population*
Mediating variable	Development of new business formats	*NBUS*	*Newbusiness/total population*, *Newbusiness* is the number of new business enterprises such as micro economy, Sharing economy, data circulation, online education, Internet medical, virtual industry, etc
	Industrial digitisation level	*IDIG*	Based on seven data items, including the number of traditional digital talent training universities and their majors, the number of emerging digital talent training universities and their majors, and the number of digital enterprises in the first, second, and third industries, factor analysis method is used to generate.
Control variable	Economic development	*PGDP*	Ln (real per capita GDP), based on 2008, Chen et al. (2022)
	economic growth rate	*GGDP*	GDP growth rate, Wang et al. (2022)
	Foreign investment	*FDI*	Foreign Investment/GDP, Chen et al. (2022)
	Industrial structure level	*INSR*	1 * proportion of Primary sector of the economy+2 * proportion of Secondary sector of the economy * 3 * proportion of Tertiary sector of the economy, Chen et al. (2020)
	Financial technology expenditure	*SCIP*	Financial Science and Technology Expenditure/GDP, Zhang et al. (2022)
	Urbanisation rate	*CITY*	Citypeople/People, Chen et al. (2022)
	population density	PDEN	Ln (total population/land area), Chen (2017)
	Financial development level	*FSIZ*	Loan balance/GDP, Chen et al. (2022)
	Financial efficiency	*FEFF*	Loans/Deposits, Chen et al. (2022)

and city, referring to Chen et al. (2022, 2023):

$$BDTI_{it} = \alpha_0 + \beta_1 * DTAP_{it} + \eta * X + \alpha_i + \lambda_t + \varepsilon_{it} \tag{1}$$

The formula uses '*i*' to represent the city and '*t*' to represent the year. α_i captures fixed effects for the city. λ_t represents the fixed effects for the year and is a random error term. $BDTI_{it}$ is the level of BDTI of the *i*th city in year *t*. $DTAP_{it}$ is the intensity of DTAP of the *i*th city in year *t*. β_1 is the coefficient of the $BDTI_{it}$. If β_1 is significant and positive, then DTAP can promote BDTI. Control variables are included in *X*.

To analyse the effect channels, we have designed the following model with reference to Chen et al. (2022, 2023).

$$BDTI_{it} = \alpha_0 + \beta_1 * DTAP_{it} + \eta * X + \alpha_i + \lambda_t + \varepsilon_{it} \tag{2}$$

$$MED_{it} = \alpha_0 + \beta_1 * DTAP_{it} + \eta * X + \alpha_i + \lambda_t + \varepsilon_{it} \tag{3}$$

$$BDTI_{it} = \alpha_0 + \beta_1 * DTAP_{it} + \phi * MED_{it} + \eta * X + \alpha_i + \lambda_t + \varepsilon_{it} \tag{4}$$

MED_{it} is the level of new business (*NBUS*) and digitisation (*IDIG*) of city *i* in year *t*. In Eqs. (2) to (4), X represents the same control variables as in Eq. (1).

The procedure for testing is as follows: Firstly, Eq. (2) is estimated. If β_1 is significant, this indicates a total effect and the analysis should continue. Otherwise, a masking effect is found. Secondly, Eq. (3) is estimated to determine the impact of DTAP on the intermediary variables. Thirdly, we estimate Eq. (4). If the β_1 in Eq. (3) and the ϕ in Eq. (4) are significant, then there is an intermediary effect. If the β_1 in Eq. (4) is significant, then the intermediary variable influences the intermediary effect. Otherwise, the intermediary variable has a full intermediary effect. Finally, If only one of β_1 in Eq. (3) and ϕ in Eq. (4) is significant, we must use the Sobel test for the intermediary effect.

Variables. Table 1 presents a summary of the variables based on the literature.

Dependent variable. A search was conducted on Patsnap (www.zhihuiya.com) for 'Big Data' in the titles and abstracts of patents, using data from the National Intellectual Property Administration of China, as previously done in studies (Lu et al., 2021). We then tallied the patent applications by enterprises and the number of patents granted for each city between 2008 and 2020. The *BDTI* is calculated by dividing the number of patent applications related to Big Data by the total population of the city. Similarly, the *rBDTI* is obtained by dividing the number of Big Data patent licenses by the total population of the city, which is another proxy variable for the level of BDTI.

Independent variable. The intensity of DTAP (*DTAP*) is the independent variable. In China, administrative bodies are authorised to impose administrative penalties within their jurisdiction. Digital technologies, including Artificial Intelligence, Augmented Reality, Big Data, Blockchain, Cloud Computing, Internet of Things, Metaverse, Quantum Computing, Virtual Reality, and 5 G, are defined as such. The data from Shanghai Da Zhi Hui Cai Hui Data Technology Co., Ltd was used to search for administrative penalties imposed on companies with these keywords in their names. We calculated the number and amount of administrative penalties in each city, and obtained *Admsanition* and *Admsanitionmoney*. *DTAP* and *rDTAP* are then calculated based on *Admsanition/total population* and *Admsanitionmoney/total population*, respectively, as proxy variables for the intensity of DTAP.

Mediating variables. The mediating variables in this study are the level of new business development (*NBUS*) and the level of industrial digitisation (*IDIG*).

We developed a list of keywords, such as "digital governance," "digital transformation," "data circulation," "industrial platform," "Internet health care," "micro economy," "multi-point practice," "online education," "online office," "sharing," and "virtual industry," based on "*opinions on Accelerating the Development of New Consumption with New Business Forms and Models*." In order to obtain *Newbusiness*, we counted the number of businesses whose scope of business contains these keywords. Next, *NBUS* is computed using the ratio of *Newbusiness* to the entire population as a proxy variable for the development level of new businesses.

Industry digitisation relies heavily on digital talent, with firms constituting the bulk of this activity. The number of colleges and universities developing traditional digital talents, the number of specialisations developing traditional digital talents, the number of colleges and universities cultivating emerging digital talents, the number of specialisations cultivating emerging digital talents, and the number of digital enterprises in the primary, secondary, and tertiary sectors of the economy are the seven data items that we selected based on the available data. A factor analysis was employed to determine the extent of industrial digitalisation in different cities from 2008 to 2020. The KMO and Bartlett's spherical tests were run as preliminaries before the analysis was carried out. The KMO-test showed that KMO = 0.682, which is greater than 0.6. The chi-squared statistic of Bartlett's test was 42532.726, with a p-value of less than 0.0001. The 7 data items met the prerequisite conditions for factor analysis. Using the factor analysis method, we measured the industry digitisation index *Indigital* for each city and then calculated the *IDIG* at (*Indigital*-Min)/(MAX-Min) * 10 as the proxy variable for the level of industrial digitisation.

Control variables. Consistent with previous studies (Chen et al., 2022; Zhang et al., 2022), The variables shown in Table 1 were controlled for.

Data

Data sources. A digital economy has emerged as a result of the economy's adoption of big data and other digital technologies following the global financial crisis of 2008 (Chen et al., 2022; Chen, 2023). China's BDTI has also entered the stage of commercial application. China is a vast country with unbalanced development, it was chosen by Chinese scholars to study the country's problems at an urban level. Therefore, Chinese city data collected from the *China City Statistical Yearbook* is selected for analysis in this paper. The data are processed as follows: (1) removal of missing samples and (2) linear interpolation applied to foreign direct investment in 2020, as it is no longer reported in the *China City Statistical Yearbook*. A total of 3 350 urban observations were obtained. The data on Big Data technology patents were obtained from Patsnap (www.zhihuiya.com), which acquired them from the National Intellectual Property Administration of China, with a more convenient collection method. Administrative penalty data were obtained from Shanghai Da Zhi Hui Cai Hui Data Technology Co., Ltd (www.qyyjt.cn), whose data comes from administrative organs. The number of entrepreneurial systems in each city was obtained from Bailu Thinktank (www.bailuzhiku.com) using "entrepreneurship" as the keyword, and its data was obtained from city governments. The data for calculating the Digital Product Manufacturing Development Index, Digital Product Service Development Index, Digital Technology Application Development Index and Digital Factor-Driven Industry Development Index were obtained from Shanghai Da Zhi Hui Cai Hui Data Technology Co., Ltd. Other data were extracted from the *China City Statistical Yearbook*. We account for the influence of outliers by taking the natural logarithm and winsorising at the top and bottom 1% for other continuous variables.

Table 2 Summary statistics.

Variables	Obs	Mean	Std. dev.	Min	Max
BDTI	3350	0.5398	1.8656	0.0000	14.3056
rBDTI	3350	0.1193	0.4054	0.0000	3.0844
DTAP	3350	0.5110	1.8234	0.0000	16.9715
rDTAP	3350	0.4359	2.3927	0.0000	22.7273
NBUS	3350	0.9871	2.0561	0.0000	17.9769
IDIG	3350	0.5417	1.1197	0.0000	10.0000
PGDP	3350	5.8932	0.7323	3.5688	8.4008
GGDP	3350	9.5900	4.3050	−4.6000	20.3000
FDI	3350	0.1798	0.1744	0.0000	1.0918
INDS	3350	2.2746	0.1422	1.8312	2.6431
SCIP	3350	1.8351	8.5633	0.0001	57.5403
CITY	3350	0.3633	0.2370	0.0618	1.0000
POP	3350	5.9091	0.6592	2.9226	8.1362
FSIZ	3350	7.1071	30.3022	0.0021	190.3869
FEFF	3350	0.6595	0.1779	0.2890	1.1945

Summary statistics. As shown in Table 2, the average of *BDTI* in Chinese cities is 0.5398, the minimum is 0.0000, and the maximum is 14.3056. The mean value of DTAP intensity is 0.5110, with a minimum of 0 and a maximum of 16.9715. These numerical gaps are consistent with the unbalanced character of China's regional development.

Results

Correlation matrix. Table 3 provides the correlation matrix of the main variables. First, the correlation coefficient between *DTAP* and *BDTI* is 0.4040, $p < 0.0001$, which is significantly positive at the 1% level. Second, the correlation coefficient between the *DTAP* and *NBUS* is 0.4860, $p < 0.0001$. The correlation coefficient between the latter and *BDTI* is 0.3896, $p < 0.0001$. Both correlations are significantly positive at the 1% level. Third, the correlation coefficient between the *DTAP* and *IDIG* is 0.2553, $p < 0.0001$. The correlation coefficient between the latter and *BDTI* is 0.6475, $p < 0.0001$. Both are significantly positive at the 1% level.

Univariate analysis. Figure 2 displays the scatter plot and univariate regression line for *BDTI* with *DTAP* and *rDTAP*, as well as for *rBDTI* with *DTAP* and *rDTAP*. The R^2 in the four figures is at least 10.2% and at most 16.3%. There is an obvious linear relationship between DTAP and BDTI. With an increase in DTAP, the level of BDTI has improved.

Table 3 Correlation matrix of main variables.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
(1) *BDTI*	1.0000					
(2) *rBDTI*	0.9477*** (0.0000)	1.0000				
(3) *DTAP*	0.4040*** (0.0000)	0.392*** (0.0000)	1.0000			
(4) *rDTAP*	0.3275*** (0.0000)	0.3192*** (0.0000)	0.5770*** (0.0000)	1.0000		
(5) *NBUS*	0.3896*** (0.0000)	0.3927*** (0.0000)	0.4860*** (0.0000)	0.3304*** (0.0000)	1.0000	
(6) *IDIG*	0.6475*** (0.0000)	0.6708*** (0.0000)	0.2553 *** (0.0000)	0.1912*** (0.0001)	0.2127*** (0.0000)	1.0000

***$p < 0.01$.

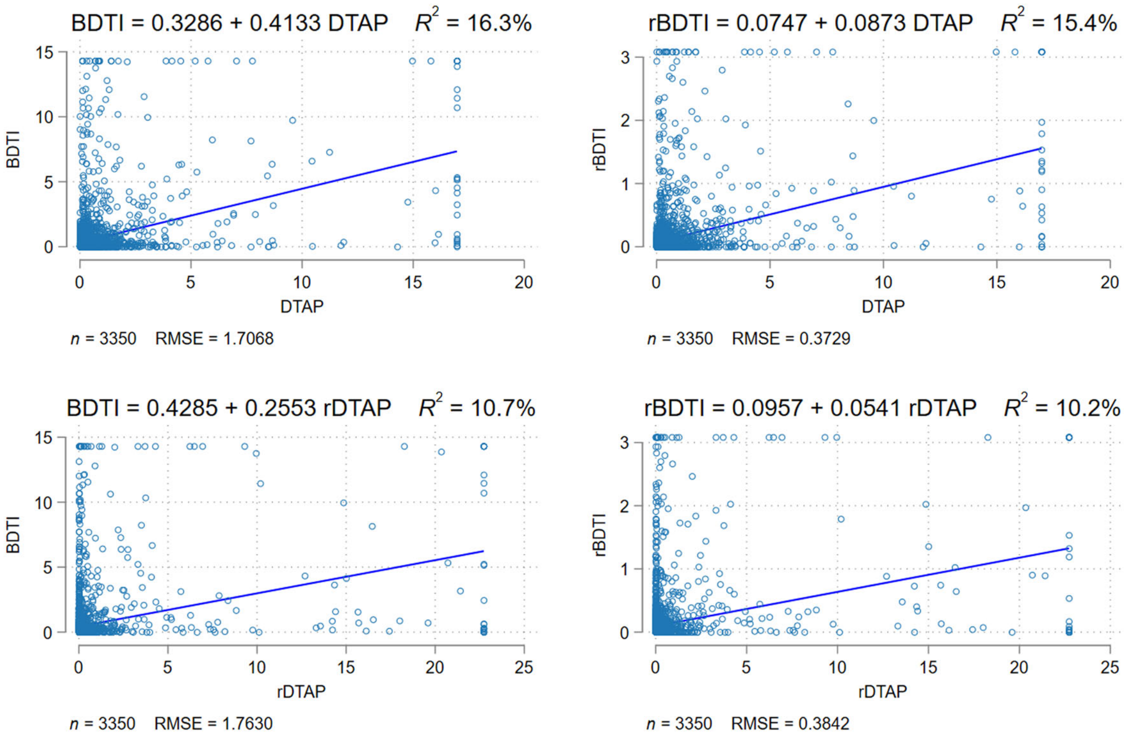

Fig. 2 Relationship between BDTI and DTAP in China. The figure displays the scatter plot and univariate regression line for BDTI with DTAP and rDTAP, as well as for rBDTI with DTAP and rDTAP. It is evident that there is a linear relationship between DTAP and BDTI.

Table 4 FE estimation results of Eq. (1).

Variables	(1) *BDTI*	(2) *rBDTI*	(3) *BDTI*	(4) *rBDTI*
DTAP	0.3059*** (0.0348)	0.0645*** (0.0077)	0.1938*** (0.0336)	0.0358*** (0.0071)
PGDP			−0.8645*** (0.2673)	−0.1812*** (0.0684)
GGDP			0.0385*** (0.0064)	0.0054*** (0.0014)
FDI			−0.7048*** (0.2035)	−0.1553*** (0.0456)
INDS			−4.6692*** (1.0755)	−0.9977*** (0.2487)
SCIP			0.0095** (0.0046)	0.0052*** (0.0012)
PDEN			1.1774** (0.5194)	0.3566** (0.1520)
CITY			1.9601** (0.9708)	0.5342** (0.2181)
FSIZ			0.0006 (0.0025)	0.0021*** (0.0006)
FEFF			0.8546*** (0.2556)	0.2242*** (0.0545)
Constant	0.3835*** (0.0229)	0.0863*** (0.0050)	17.5052*** (2.3708)	4.0626*** (0.6835)
City/Year	√	√	√	√
Obs.	3350	3350	3350	3350
R^2	0.1462	0.1310	0.2894	0.3654
N	281	281	281	281

Robust standard errors are in parentheses.
***$p < 0.01$, **$p < 0.05$.

Multivariate regression. Equation (1) was estimated using a fixed-effects(FE), and the results are shown in columns (1) and (2) of Table 4. We re-estimate Eq. (1) with all control variables added, and the results are shown in columns (3) and (4). As shown in columns (1) to (4) of Table 4, the coefficients of DTAP are significantly positive at the 1% level. These results indicate that Hypothesis 1 is valid.

Robustness checks

Endogeneity. The results show that DTAP affects BDTI. By contrast, BDTI may also violate the application process, resulting in digital technology administrative penalties. There may be a bidirectional causal relationship between DTAP and BDTI. More importantly, *DTAP* is obtained by constructing a keyword search administrative penalty decision form, which inevitably leads to a bias in keyword searches, resulting in measurement errors and endogeneity.

To this end, we follow Laeven and Levine (2007, 2009) to calculate the mean value of *DTAP* of in the same year other cities and obtain the *ivDTAP* as an instrumental variable estimation. The *DTAP* in all cities was affected by measurement errors. Therefore, *ivDTAP* is related to *DTAP*, and *ivDTAP* meets the 'correlation' condition. It is challenging for the *DTAP* in other cities to influence the BDTI in this city, thus *ivDTAP* satisfies the "exogenous" requirements. This study re-estimates Eq. (1) using

Table 5 Robustness.

Variables	(1) BDTI	(2) rBDTI	(3) BDTI	(4) rBDTI
Panel A				
DTAP	0.1560***	0.0309***	0.1453**	0.0294**
	(0.0584)	(0.0119)	(0.0592)	(0.0123)
City/Year/Control	√	√	√	√
Obs.	3350	3350	3019	3019
R^2	0.2875	0.3648	0.2987	0.3398
N	281	281	275	275
Panel B				
rDTAP	0.0812***	0.0139***		
	(0.0186)	(0.0038)		
DTAP			0.2087***	0.0390***
			(0.0132)	(0.0028)
City/Year/Control	√	√	√	√
Obs.	3350	3350	3350	3350
R^2	0.2574	0.3417	–	–
N	281	281	281	281
Panel C				
DTAP	0.1797***	0.0330***	0.1187***	0.0242***
	(0.0316)	(0.0068)	(0.0298)	(0.0065)
POLY	0.4603***	0.0927***		
	(0.0347)	(0.0080)		
City/Year/Control	√	√	√	√
Obs.	3350	3350	1974	1974
R^2	0.3533	0.4176	0.2413	0.3526
N	281	281	270	270
Panel D				
DTAP	0.2106***	0.0395***	0.2661***	0.0530***
	(0.0388)	(0.0079)	(0.0152)	(0.0033)
City/Year/Control	√	√	√	√
Obs.	3350	3350	3350	3350
R^2	0.3334	0.3570	0.3599	0.3764
N	281	281	281	281

Note: All instrumental variable estimations pass the validity test. Under the MLE, there is no R^2. ***$p < 0.01$, **$p < 0.05$.

the instrumental variable estimation method (IV), with *ivDTAP* serving as the instrumental variable. The weak instrumental variable estimation hypothesis is rejected and *ivDTAP* is a legitimate instrumental variable, according to the Cragg-Donald F-statistic for the test of weak instrumental variable estimation, which is 2175.396, significantly bigger than the crucial value of 16.38 at 10% error.

Equation (1) was re-estimated using the instrumental variable method(IV). The results are reported in columns (1) and (2) of Panel A of Table 5. All control variables were lagged for one period, and Eq. (1) was re-estimated using IV. The results are reported in columns (3) and (4) of Panel A in Table 5. The coefficients are positive at the significance level of 1 or 5%. The conclusion that hypothesis H1 holds is robust.

Alternative measure of the DTAP. Replace *DTAP* with *rDTAP*, with *BDTI* and *rBDTI* as dependent variables, and use FE to re-estimate Eq. (1). The results reported in Columns (1) and (2) of Panel B in Table 5 indicate that hypothesis H1 is robust.

Alternative estimation method. We use the Maximum Likelihood Estimation (MLE) method to re-estimate Eq. (1). The results reported in Columns (3) and (4) of Panel B in Table 5 indicate that hypothesis H1 is robust.

Adding control variables. It is necessary to test for the possibility that entrepreneurship policies in each region may influence BDTI. We take the natural logarithm of the number of policies containing the keyword "entrepreneurship" in each city plus one to obtain variable 'POLY'. After controlling for this variable we re-estimate Eq. (1) using the FE. The results shown in columns (1) and (2) of Panel C in Table 5 confirm the robustness of hypothesis H1.

Excluding pre-2012 samples. After the eighteenth National Congress of the Communist Party of China in 2012, China listed the digital economy as a national strategy and achieved rapid development of the digital economy. Equation (1) was re-estimated using FE after excluding the pre-2012 sample. The results shown in columns (3) and (4) of Panel C in Table 5 confirm the robustness of hypothesis H1.

Changing estimation model. Equation (1) was re-estimated using RE and Pool-OLS.The results are presented in columns (1) to (4) of Panel D in Table 5. The conclusion that hypothesis H1 holds is robust.

Mechanism verification

The *NBUS* and *IDIG* are the mediating variables required for mechanism testing. Figure 3 depicts the relationship between *DTAP*, *NBUS*, and *BDTI*. There was a significant positive correlation between *DTAP* and *NBUS*. There was a significant positive correlation between *NBUS* and *BDTI*.

Figure 4 shows the relationship between *DTAP*, *IDIG*, and *BDTI*. There was a significant positive correlation between *DTAP* and *IDIG*. The latter is significantly positively correlated with *BDTI*.

We tested the mechanism of action using a multivariate regression. When estimating Eq. (3), for the same reason as in the section 'Endogeneity', DTAP may have endogeneity. When considering *NBUS* as the intermediary variable in Eq. (4), *BDTI* can provide the technological impetus for *NBUS* such that a two-way causal relationship forms between *BDTI* and *NBUS*. Therefore, the NBUS is endogenous. Similarly, when using the *IDIG* as the intermediary variable to estimate Eq. (4), BDTI can provide a new technological impetus for *IDIG*, forming a two-way causal relationship between BDTI and *IDIG*. As in the section 'Robustness checks', we calculate the average of the *NBUS* and *IDIG* in the same year in other cities to obtain ivNBUS and ivIDIG as instrumental variables.

New business channels. With *BDTI* as the dependent variable and *ivDTAP* as the instrumental variable, we use the IV to re-estimate Eq. (2). With *NBUS* as the intermediary variable and *ivDTAP* as the instrumental variable, we use the IV to re-estimate Eq. (3). With *BDTI* as the dependent variable, and *ivDTAP* and *ivNBUS* as the instrumental variables, we use the IV to re-estimate Eq. (4). Table 6 Panel A provides the results.

As shown in column (1) of Panel A in Table 6, the coefficient of the *DTAP* is significant at the 1% level, indicating an overall effect. The coefficient of *DTAP* in column (2) is significant at the 5% level, and the coefficient of the *NBUS* in column (3) is significant at the 1% level, indicating an intermediary effect. Based on the symbols and *DTAP* and *NBUS* in Columns (2) and (3), DTAP promotes BDTI by promoting the development of new businesses. Therefore, hypothesis H2 holds.

We replace the independent and dependent variables with *rDTAP* and *rBDTI* and use IV to re-estimate Eqs. (2)–(4), resulting in Table 6 Panel B and C. Here, we find that DTAP

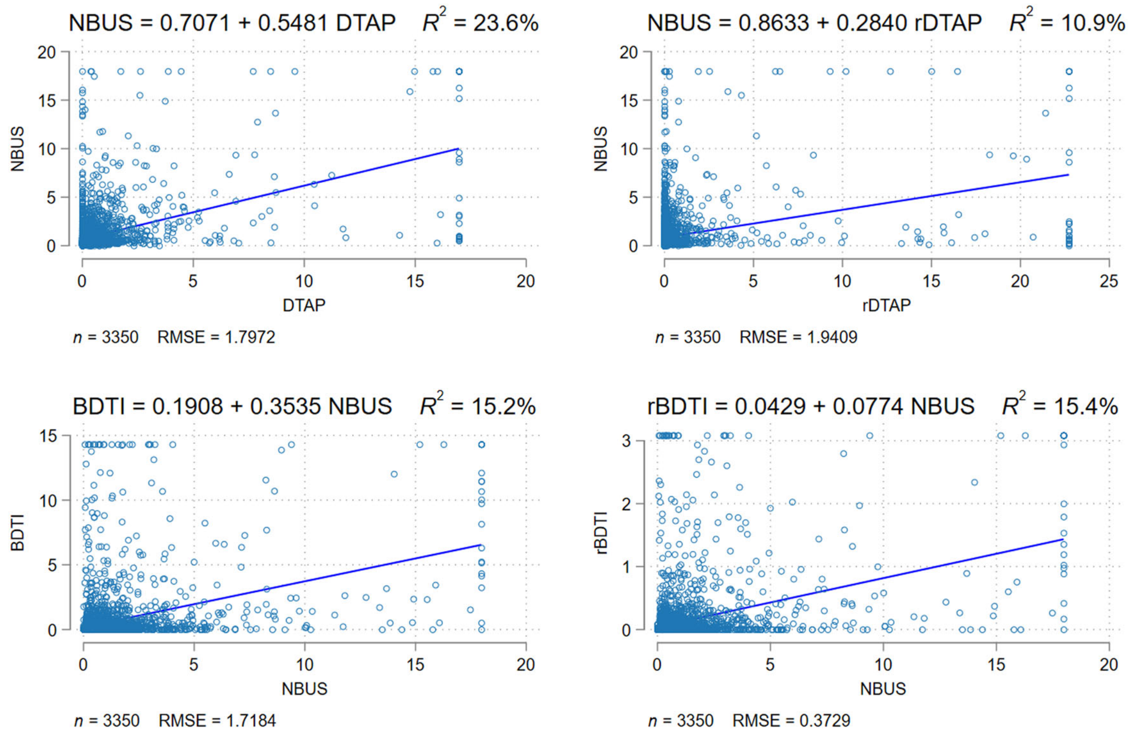

Fig. 3 Relationship between DTAP, the level of development of new businesses, and BDTI in China. This figure shows that there was a significant positive correlation between DTAP and NBUS. A significant positive correlation was observed between NBUS and BDTI.

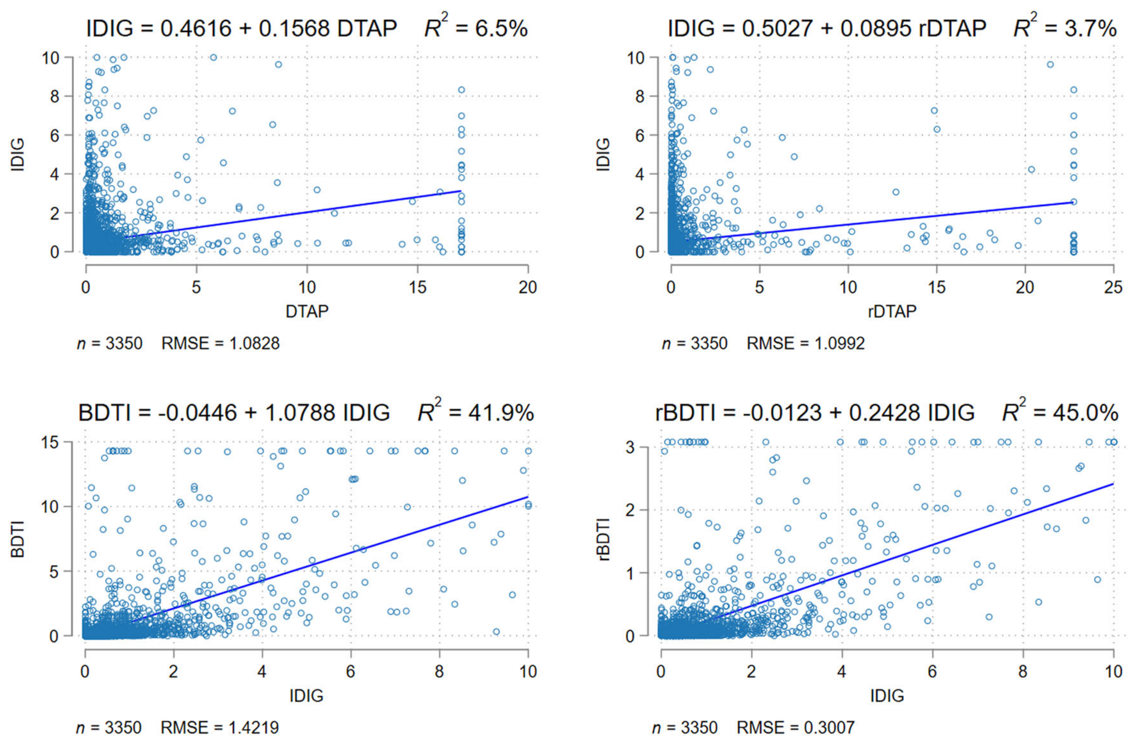

Fig. 4 Relationship between DTAP, level of industry digitisation, and BDTI in China. This figure shows that there was a significant positive correlation between DTAP and IDIG. A significant positive correlation was observed between IDIG and BDTI.

promotes BDTI by promoting the development of new business. Therefore, the results support hypothesis H2.

Industry digitisation channels. With *BDTI* as the dependent variable and *ivDTAP* as the instrumental variable, we use the IV to re-estimate Eq. (2). With *IDIG* as the intermediary variable and *ivDTAP* as the instrumental variable, we use the IV to re-estimate Eq. (3). With *BDTI* as the dependent variable, and *ivDTAP* and *ivIDIG* as the instrumental variables, we use the IV to re-estimate Eq. (4). The results are reported in Table 7 Panel A. Here, DTAP

Table 6 Estimation results for new business development channels.

Panel A

Variables	**(1) *BDTI***	**(2) *NBUS***	**(3) *BDTI***
DTAP	0.1560***	0.1502**	0.1198**
	(0.0584)	(0.0641)	(0.0510)
NBUS			0.2407***
			(0.0528)
City/Year/ Control	√	√	√
Obs.	3350	3350	3350
R^2	0.2875	0.1839	0.2929
N	281	281	281

Panel B

Variables	**(1) *BDTI***	**(2) *NBUS***	**(3) *BDTI***
rDTAP	0.1553**	0.1495**	0.1234**
	(0.0662)	(0.0695)	(0.0616)
NBUS			0.2135***
			(0.0702)
City/Year/ Control	√	√	√
Obs.	3350	3350	3350
R^2	0.2425	0.1505	0.2707
N	281	281	281

Panel C

Variables	**(1) *rBDTI***	**(2) *NBUS***	**(3) *rBDTI***
DTAP	0.0309***	0.1502**	0.0228**
	(0.0119)	(0.0641)	(0.0097)
NBUS			0.0543***
			(0.0111)
City/Year/ Control	√	√	√
Observations	3350	3350	3350
R-squared	0.3648	0.1839	0.3732
N	281	281	281

Note: All Instrumental variables estimation pass the validity test.
***$p < 0.01$, **$p < 0.05$.

Table 7 Estimation results for industrial digital channels.

Panel A

Variables	**(1) *BDTI***	**(2) *IDIG***	**(3) *BDTI***
DTAP	0.1560***	0.0463**	0.1058**
	(0.0584)	(0.0191)	(0.0462)
IDIG			1.0843***
			(0.0729)
City/Year/ Control	√	√	√
Obs.	3350	3350	3350
R^2	0.2875	0.4053	0.5309
N	281	281	281

Panel B

Variables	**(1) *BDTI***	**(2) *IDIG***	**(3) *BDTI***
rDTAP	0.1553**	0.0461**	0.1055**
	(0.0662)	(0.0204)	(0.0517)
IDIG			1.0807***
			(0.0753)
City/Year/ Control	√	√	√
Obs.	3350	3350	3350
R^2	0.2425	0.3994	0.5056
N	281	281	281

Panel C

Variables	**(1) *rBDTI***	**(2) *IDIG***	**(3) *rBDTI***
DTAP	0.0309***	0.0463**	0.0196**
	(0.0119)	(0.0191)	(0.0094)
IDIG			0.2440***
			(0.0138)
City/Year/ Control	√	√	√
Obs.	3350	3350	3350
R^2	0.3648	0.4053	0.6135
N	281	281	281

Note: All Instrumental variables estimation pass the validity test.
***$p < 0.01$, **$p < 0.05$.

promotes BDTI by promoting industry digitalisation. Therefore, H3 holds.

Replaced the independent and dependent variables with *rDTAP* and *rBDTI*, we use the IV to re-estimate Eqs. (2)–(4). As shown in Panels B and C of Table 7, we find that DTAP promotes BDTI by promoting industry digitalisation. Therefore, the results supporting H3 are robust.

Regional heterogeneity

First-tier and non-first-tier cities. The results above indicate that DTAP can promote BDTI. Policy interventions have heterogeneous effects on different market players (Li et al., 2023). China's first-tier cities include Beijing, Shanghai, Guangzhou, and Shenzhen. These four cities are economically developed, possess abundant financial resources, are strong in innovation and entrepreneurial activity, and have rapidly developed new business forms and industrial digitalisation. Therefore, DTAP's role in promoting BDTI may hold more significance in first-tier cities.

To test this hypothesis, we utilise *BDTI* and *rBDTI* as dependent variables and *DTAP* as an independent variable. We re-estimated Eq. (1) with a variable coefficient individual fixed effects model. The findings are presented in Columns (1) and (2) of Panel A in Table 8. We substitute the *DTAP* with *rDTAP* and re-estimate Eq. (1). The results are shown in Columns (3) and (4) of Panel A in Table 8. The *DTAP* coefficient exhibits a significant positive correlation at the 1% level in both first-tier and non-first-tier cities. Therefore, *DTAP* is able to promote *BDTI*. The coefficient of *DTAP* is notably larger in first-tier cities, indicating that the role of DTAP in promoting BDTI is more significant in such areas.

Development of the digital factor-driven industry. Digital factor-driven industry is closely related to big data technology innovation. Administrative penalties provide the institutional guarantee for big data technology innovation, while the digital factor-driven industry serves as its foundation. The development of the digital factor-driven industry varies across different regions of China, and the role of DTAP in promoting BDTI may differ accordingly. The development of digital factor-driven industry provides valuable technological support and application scenarios for BDTI. DTAP plays a significant role in promoting BDTI.

Table 8 Heterogeneity between first-tier and non-first-tier cities.

Variables	(1) *BDTI*	(2) *rBDTI*	(3) *BDTI*	(4) *rBDTI*
Panel A				
DTAP (Non-First tier)	0.1476***	0.0296***		
	(0.0336)	(0.0071)		
DTAP (First tier)	0.4199***	0.0662***		
	(0.0900)	(0.0210)		
rDTAP (Non-First tier)			0.0422***	0.0073**
			(0.0153)	(0.0031)
rDTAP (First tier)			0.2571***	0.0439***
			(0.0533)	(0.0123)
City FE	√	√	√	√
Year FE	√	√	√	√
Control	√	√	√	√
Observations	3350	3350	3350	3350
R-squared	0.3044	0.3709	0.2768	0.3531
N	281	281	281	281
Panel B				
DTAP (Low)	0.4760	0.0999		
	(0.3201)	(0.0682)		
DTAP (High)	0.1865***	0.0340***		
	(0.0335)	(0.0071)		
rDTAP (Low)			0.0139	0.0007
			(0.0214)	(0.0049)
rDTAP (High)			0.0982***	0.0172***
			(0.0217)	(0.0044)
City FE	√	√	√	√
Year FE	√	√	√	√
Control	√	√	√	√
Observations	3126	3126	3126	3126
R-squared	0.3013	0.3768	0.2661	0.3489
N	279	279	279	279
Panel C				
DTAP (Low)	0.2168***	0.0445***		
	(0.0461)	(0.0101)		
DTAP (High)	0.1794***	0.0303***		
	(0.0418)	(0.0086)		
rDTAP(Low)			0.1072***	0.0223***
			(0.0277)	(0.0059)
rDTAP (High)			0.0644***	0.0085*
			(0.0242)	(0.0047)
City FE	√	√	√	√
Year FE	√	√	√	√
Control	√	√	√	√
Observations	3350	3350	3350	3350
R-squared	0.2900	0.3673	0.2589	0.3448
N	281	281	281	281

Note: In calculating penalty densities, some of the data were omitted due to the fact that some cities had a denominator of zero for individual years, resulting in a reduced number of observations in Panel B.
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Regions with a less developed digital factor-driven industry have a weaker economic and technological foundation for BDTI. This may lead to unregulated behaviours, but also provides more space for innovation. Therefore, the role of DTAP in promoting BDTI may be more significant.

Indicators were constructed to measure the development level of digital factor-driven industry for each city. Data on the number of enterprises and their registered capital in each city were collected using keywords from Shanghai Da Zhi Hui Cai Hui Data Technology Co., Ltd. A total of 12, 10, 10, and 14 data points were obtained. The factor analysis method is used to create the *City Digital Product Manufacturing Development Index, Digital Product Service Industry Development Index, Digital Technology Application Industry Development Index*, and *Digital Factor-Driven Industry Development Index*. The development level of the digital factor-driven industry is measured by the digital factor-driven industry development index divided by the sum of the development indices of the digital product manufacturing industry, digital product service industry, digital technology application industry, and digital factor-driven industry. Using Florackis and Sainani's (2018) typology, cities with a relative development level of digital factor-driven industry above the median for each year are classified as high-level cities, while those below are classified as low-level cities. Referring to the section 'First-tier and non-first-tier cities', we re-estimated Eq. (1) using variable coefficients and individual fixed effects. The results are shown in Panel C of Table 8. DTAP plays a significant role in promoting innovation in both high and low-level cities, with a greater impact in low-level cities.

Discussion

Innovation policies, regulatory quality, and legal rules confer positive effects on innovation capabilities (Samara et al., 2012; Chadee and Roxas, 2013). The development of regional innovation is influenced by various factors, including innovation input, innovation environment, and innovation demand, among others (Sun et al., 2022). Our study shows that DTAP can facilitate BDTI, consistent with prior studies on the drivers of BDTI.

Mature formal systems, higher marketisation, and relatively transparent institutional arrangements characterise improved institutional environments. Our study demonstrates that DTAP is an effective enforcement mechanism that promotes the formulation and circulation of institutional regulations. This finding is consistent with Lu and Dang's (2015) research, which highlights the pivotal role of the institutional environment in influencing firms' technological innovation. Digital technological innovations are characterised by high thresholds, costs, and imitability (Firk et al., 2021). Improving the innovation environment can effectively boost entrepreneurship (Yang and Hou, 2023) and enhance the efficiency of regional innovation (Li et al., 2018), which is consistent with the findings of this study. Administrative penalties as a disciplinary measure can adversely affect an enterprise's reputation, financing capacity, and competitiveness in product performance (Li et al., 2023). Fair and efficient collaborations with government agencies can benefit enterprises by improving predictability and reducing uncertainty in business activities, ultimately promoting innovation.

Our study shows that the DTAP supports the growth of new businesses and the digitalisation of industries, which is consistent with prior studies on the factors that influencing the development of the digital economy. Strengthening administrative supervision of digital technology can send positive policy signals. This will attract a concentration of innovation factors, leading to improved scalability and efficiency of innovation activities. Competition within an industry can potentially enhance its technological progress. This can expand market capacity, drive industry growth, and increase the likelihood of the emergence of innovative firms (Yang and Hou, 2023). Specific policies, such as strengthening IPR protection, can enhance enterprises' innovation capacity (Wu and Tang, 2016) and ease financing constraints (Ang et al., 2014). This, in turn, encourages enterprises to increase their investment in digital transformation, and drive the digitalisation of industries.

Implications and policy suggestions

This study offers a preliminary insight into the effect of DTAP on BDTI, providing new evidence for promoting BDTI in China. DTAP is an important enforcement mechanism to deter non-compliance activities and can promote BDTI, thus favouring

China's digital economy development. China's exploration of Big Data technology provides valuable insights for countries worldwide. The study offers the following policy suggestions.

First, the administrative environment is a significant factor in regional disparities in digital technology innovation. It is imperative for the government to reinforce intellectual property rights (IPR) and other soft environment systems to safeguard the interests of enterprises. This will enable them to benefit from digital technological innovation outcomes and advance digital innovation. In the process of BDTI, local governments should not overlook the importance of constructing a favourable business environment. They should also prioritise improving the enforcement mechanism for administrative penalties to enhance the level of BDTI. For instance, they can encourage the creation of industrial data standards, safeguard of industrial data and personal information, enhance data safety inspections, supervision, and enforcement, increase penalties, and combat unfair competition and illegal behaviour.

Second, new businesses in the digital economy and industrial digitisation are important paths for the DTAP to promote BDTI. Beijing, Shanghai, Guangzhou, and Shenzhen are the most vibrant areas for digital technology innovation in China, exhibiting a greater facilitating effect of administrative penalties on BDTI. Relying solely on administrative penalties is insufficient for promoting digital technological innovation. It is necessary to combine administrative means with industrial policies and financial incentives and to perform the government's service and regulatory functions to form a good pattern of 'double-wheel drive' between technological and institutional innovation.

Finally, accelerating the development of the digital economy is crucial to reducing the global digital divide and fostering inclusive development. Major countries in the world are actively introducing policies and plans to promote digital technological innovation. Developing countries still have relatively underdeveloped digital infrastructure. When formulating digital technology development plans, governments should focus on strengthening the institutional environment. Developed countries are actively implementing policies and initiatives to encourage innovation in digital technology. By improving the institutional environment for digital innovation, these nations can focus on nurturing new business structures within the digital economy and advancing industrial digitisation.

Limitations and prospects

The study acknowledges limitations and identifies the need for further research on various aspects of DTAP. One such aspect is the differing impact of DTAP on various digital technologies and their respective diffusion mechanisms. For example, Artificial Intelligence (AI) has the potential to promote social equality (Bao and Huang, 2023) and can complement Big Data technologies. Future research could investigate the mechanisms by which different digital technologies are affected. Another factor to consider is country-specific heterogeneity in the impact of DTAP on BDTI. This study utilised data from Chinese cities. However, the level of economic and social progress, institutional environment, and degree of BDTI vary by country. Additionally, the administrative penalty system is diverse, which affects the role of enforcement mechanisms. Therefore, future analyses should consider the heterogeneity across the region. The types of administrative penalties are heterogeneous (Yu et al., 2023), and further research is needed to differentiate the impact of different administrative penalties on big data technology innovation.

Data availability

The data that support the findings of this study have been enclosed as supplementary files.

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References

Acemoglu D, Restrepo P (2018) The race between man and machine: implications of technology for growth, factor shares, and employment. Am Econ Rev 108(6):1488–1542

Ang J, Cheng Y, Wu C (2014) Does enforcement of intellectual property rights matter in China? Evidence from financing and investment choices in the high tech industry. Rev Econ Stat 96:332–348

Bao Z, Huang D (2023) Can artificial intelligence improve gender equality? Evidence from a natural experiment. Soc Sci Electron Publ. https://doi.org/10.2139/ssrn.4202239

Becker GS (1968) Crime and punishment: an economic approach. J Polit Econ 76(2):169–217

Chadee D, Roxas B (2013) Institutional environment, innovation capacity and firm performance in Russia. Crit Perspect Int Bus 9(1/2):19–39

Chen X, Teng L, Chen W, et al. (2022) How does finTech affect the development of the digital economy? Evidence from China. North Am J Econ Financ 61. https://doi.org/10.1016/j.najef.2022.101697

Chen X, Zhang H, Cheng X (2023) Taoism and digital inclusive finance. Heliyon 9(4):e14965

Chen X (2023) Information moderation principle on the regulatory sandbox. Econ Change Restruct 56(1):111–128

Chen X, Zhang H, Wu Y (2020) How does the digital economy affect the level of industrial structure? Secur Mark Her 07:20–29

Chen G (2017) Entrepreneurship in cities: an empirical study of the impact of city size on entrepreneurship. Soc Sci J 04:83–93

Chu J, Fang J (2021) Punish one,teach a hundred? A study on the failure of the indirect deterrence effects of regulatory punishments. Account Res 01:44–54

Ciarli T, Kenney M, Massini S, Piscitello L (2021) Digital technologies, innovation, and skills: emerging trajectories and challenges. Res Policy 50(7):104289

Farboodi M, Mihet R, Philippon T, Veldkamp L (2019) Big data and firm dynamics. AEA Papers and Proceedings. pp. 38–42. https://doi.org/10.1257/pandp.20191001

Florackis C, Sainani S (2018) How do chief financial officers influence corporate cash policies? J Corp Financ 52:168–191

Firk S, Gehrke Y, Hanelt A, Wolff M (2021) Top management team characteristics and digital innovation: exploring digital knowledge and TMT interfaces. Long Range Plan 55(3):102166

Han Q, Wang Z (2022) Research on the correlation evaluation of scientific and technological innovation and digital economy development in National digital economy innovation and development pilot zone. Sci Manag Res 40(01):74–78

Hanelt A, Firk S, Hildebrandt B, Kolbe LM (2021) Digital M&A, digital innovation, and firm performance: an empirical investigation. Eur J Inf Syst 30(1):3–26

Huang B, Li H, Liu J et al. (2023) Digital technology innovation and the high-quality development of Chinese enterprises: evidence from enterprise's digital Patents. Econ Res J 58(03):97–115

Huang D, Bao Z (2020) Gender differences in reaction to enforcement mechanisms: a large-scale natural field experiment. Monash Economics Working Papers

Jiang W, Chen X, Peng M, Zhou L (2023) Digital regulatory policies, externality governance and technological innovation: a dual perspective of digital investment and incomplete contracts. China Ind Econ 07:66–87

Kohli R, Melville NP (2019) Digital innovation: a review and synthesis. Inf Syst J 29(1):200–223

Laeven L, Levine R (2007) Is there a diversification discount in financial conglomerates? J Financ Econ 85(2):331–367

Laeven L, Levine R (2009) Bank governance, regulation and risk taking. J Financ Econ 93(2):259–275

Lambrecht A, Tucker CE (2015) Can big data protect a firm from competition?. SSRN Working Paper. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2705530

Li H (2019) On the guarantee of the administrative rule of law for the optimization of the business environment. Chongqing Soc Sci 291(2):17–25

Li J, Li S, Zhu P et al. (2023) Punishment announcement, corporate performance and executive turnover: an explanation from the perspective of corporate reputation. Econ Theory Bus Manag 43(04):53–68

Li Z, Yang S, Lu J (2018) Can government participation improve regional innovation efficiency? Econ Rev 06:3–14+27

Lin R, Xie Z, Hao Y et al. (2020) Improving high-tech enterprise innovation in big data environment: a combinative view of internal and external governance. Int J Inf Manag 50:575–585

Lu T, Dang Y (2015) Investor protection, administrative environment and technological innovation: cross-country empirical evidence. J World Econ 38(10):99–124
Lu J, Yang S, Ma C (2021) Fiscal decentralization, financial decentralization, and technological innovation. South China J Econ 06:36–50
Mei H (2022) Big data and the digital economy. Qiushi 2:28–34
Pan M, Xu C (2023) Do M&As of Digital economy enterprises promote innovation in China? Study Pract 04:52–63
Peng W, Han D, Yin Y et al. (2022) Spatial evolution and integrated development of digital economy in Beijing-Tianjin-Hebei region. Econ Geogr 42(05):136–143+232
Qi Y, Du B, Ye S (2022) Intellectual property rights and technology standards synergistically driving digital industry innovation: mechanism and pathways. China Ind Econ 08:5–24
Rehman MHU, Chang V, Batool A, Wah TY (2016) Big data reduction framework for value creation in sustainable enterprises. Int J Inf Manag 36(6):917–928
Samara E, Georgiadis P, Bakouros I (2012) The impact of innovation policies on the performance of national innovation systems: a system dynamics analysis. Technovation 32(11):624–638
Sun J, Li J (2022) Big data applications, financing constraints and firms' innovation efficiency. Securit Mark Her 11:13–23
Sun Y, Fan J, Liu H et al. (2022) Spatial and temporal pattern of digital technology innovation and its influencing factors in the Yangtze River Delta. Econ Geogr 42(02):124–133
Svahn F, Mathiassen L, Lindgren R (2017) Embracing digital innovation in incumbent firms: how Volvo cars managed competing concerns. MIS Q 41(1):239–253
Teece DJ (2018) Profiting from innovation in the digital economy: enabling technologies, standards, and licensing models in the wireless world. Res Policy 47(8):1367–1387
Wang Y, Lu Y (2022) A review of digital economy research at home and abroad based on bibliometric analysis. J China Univ Min Technol (Soc Sci) 24(06):71–86
Wang Z, Li M, Liao L et al. (2022) Aging populations and regional entrepreneurship:a study using entrepreneurship data from Qixinbao. J Financ Res 02:80–97
Wu C, Tang D (2016) Intellectual property rights enforcement, corporate innovation and operating performance: evidence from China's listed companies. Econ Res J 51(11):125–139
Xin Y, Teng F, Gu X (2019) Information and performance transfer effects of fraud regulation in business group. J Manag Sci 23(01):125–142
Xu L, Hou L, Cheng G (2022) Innovation effect of national big data comprehensive pilot zone. Sci Technol Prog Policy 39(20):101–111
Xue J, Ru Y, Dou C (2017) Punishing one threatens a hundred?–the deterrent effect of exposure mechanism on top-executive excess perquisites. Account Res 05:68–74+97
Yang C (2022) How artificial intelligence technology affects productivity and employment: firm-level evidence from Taiwan. Res Policy 51(6):104536
Yang Z, Hou Y (2023) Exploring the mystery of firm survival: the comprehensive role of firm innovativeness, core capabilities and industry innovation environment. Bus Manag J 45(03):63–86
Yu C, Yang G, Du M (2021) Industrial policy and technological innovation of China's digital economy industries. Stat Res 38(01):51–64
Yu Y, Xia L, Duan S (2023) Market regulation and enterprise growth: empirical analysis based on administrative penalties data. China Ind Econ 08:118–136
Yuan C, Xiao T, Geng C et al. (2021) Digital transformation and division of labor between enterprises: vertical specialization or vertical integration. China Ind Econ 09:137–155
Yue L, Yin Y, Huang C (2023) Research on the impact of low-carbon city pilot on urban digital technology innovation. J Ind Technol Econ 42(05):30–37
Zhao J, Gao Y (2023) Financial penalty and bank risk: based on penalizing both banks and responsible persons, and different types of penalty. J Financ Econ 49(02):154–168
Zhang H, Xiong C, Chen X et al. (2022) The Influence of financial investment of science and technology on the development of digital economy. Financ Econ 05:135–148
Zhang J, Long J, Chen F (2022) Big data capability, knowledge-based dynamic capability, and business model innovation: moderating effect of innovation legitimacy. Econ Manag 36(05):19–28
Zhang Y, Lu Y, Li L (2021) Effects of big data on firm value in China: evidence from textual analysis of Chinese listed firms' annual reports. Econ Res J 56(12):42–59
Zhou R, Hong X, Lin X (2022) Foreign direct investment of China and digital economy innovation of "the Belt and Road" countries. J Shanxi Univ Financ Econ 44(06):70–83
Zhu P (2020) Negative reputation and corporate financing: empirical studies on listed companies. Financ Trade Econ 41(04):50–65

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The authors declare no competing interests.

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Additional information

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