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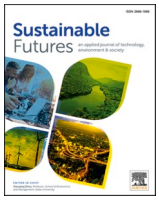

Promoting corporate sustainability: The effect of special economic zone policy on enterprises' digital transformation

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ABSTRACT

Digital transformation (DT) is the core driving force for enterprises aiming to achieve sustainable development in the future. This paper investigates the impact of Special Economic Zone (SEZ) policy on DT. Prior research focused on economic returns, leaving DT effects underexplored. Utilizing data from Chinese listed enterprises spanning 1990 to 2020, this study employs a difference-in-differences (DID) approach to compare enterprises located in different treated regions before and after the implementation of SEZ policies. Our findings indicate a significant increase of 1.342 in DT attributable to these policy effects, driven by SEZ initiatives that reduce operating costs, alleviate financial constraints, and promote innovations. This study sheds new light on the effective external solutions in promoting corporate sustainability in terms of digital transformation, and provides new insights into non-monetary return of government industrial policies.

1. Introduction

The digital economy has become a key driver for corporate growth and sustainable development in the rapidly evolving global economy [1]. Countries are now focusing on both economic growth and the sustainability of business operations, with digital governance and digital industrialization being important policy components for guiding companies towards greener and more sustainable transformation [2]. In 2022, the digital economy of 51 major economies reached USD 41.4 trillion, accounting for 46.1 % of GDP, with digitization making up 85.3 % of it, highlighting its significant role in promoting business sustainability. To strengthen digitization's role in economic development and align it with sustainable goals, many countries have launched industrial policies.A key question emerges: Can enterprises effectively drive their digital transformation (DT) through these sustainable development-oriented industrial policies? And to what extent can these policies have a positive and sustainable impact on DT?

Studying this issue is crucial for understanding the DT of enterprises. DT is not only crucial for enterprises to adapt to the current economic environment but also a catalyst for promoting cross-industry and social sustainable development [3]. Thus, enterprises' ability to embrace DT, which depends on policy implementation, has become a focus of current reform and development [4,5]. Under policy guidance, enterprises can have a clearer direction for sustainable development and develop their digital capabilities [6,7].

Since the digital economy's explosive growth in 2008 [8], digitization has become a new competitive frontier [9]. Many countries, like the US, Germany, the UK, and Australia, have implemented digital economy strategies, and China has issued policies for long-term business sustainability [10]. However, whether governments' industrial policies can effectively enhance enterprises' DT capabilities remains an open question worthy of in-depth discussion.

A review of the literature reveals that existing studies often concentrate on the impact of digital transformation DT n the economy and various other factors, while insufficient attention is given to the elements influencing DT itself. For instance, research has examined the effects of DT on aspects such as common prosperity within enterprises [11], labor productivity [12], total factor productivity [13], enterprise technological innovation [14], and other aspects. However, these studies primarily focus on the outcomes of DT rather than exploring the underlying factors that facilitate it. Notably absent from this body of research is an investigation into how industrial policies can enhance DT.

This study aims to provide evidence on the impact of industrial policies on the digital transformation DT of enterprises. To achieve this, the research will focus on two key tasks. First, it will control for non-policy factors that often influence enterprises' decisions regarding digital investment, as these can confound the effects of policy implementation. Second, it will identify environments where enterprises are

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exposed to exogenous positive policy shocks to discern the impact of these policies and determine whether their influence on DT arises from direct policy implementation or from aggregation effects triggered by such implementation. To address this issue, the paper categorizes all enterprises into three groups. The first group consists of enterprises located within districts and counties where industrial policies are actively implemented, considered primarily affected by these policies. The second group includes enterprises situated in prefecture-level cities where industrial policies are enforced but outside the specific districts and counties implementing them; these are regarded as influenced by aggregation effects. The remaining enterprises form a control group. By comparing and analyzing these categories, we can assess the magnitude of policy effects on enterprise DT.

The industrial policies associated with national Special Economic Zones (SEZs) provide preferential treatment and financial support to enterprises located within these zones, resulting in significant positive impacts on their economic development. These advantages enable enterprises to enhance their level of digitalization. Consequently, this study focuses on the industrial policies implemented in China's cities that established national-level SEZs from 1984 to 2018 as the primary framework for analysis. To rigorously measure and construct an index system for digital transformation DT, we employ a comprehensive textual analysis method. By estimating the degree of DT among enterprises within the SEZs, we aim to provide valuable insights to policymakers and contribute to advancing enterprises' digital transformation processes, thereby facilitating long-term sustainability in their operations and development.

This study finds that the establishment of SEZs effectively promotes the DT of local enterprises. Specifically, enterprises located within the SEZs that benefit from "policy rent" exhibit a significant improvement in their level of DT. In contrast, enterprises situated outside the districts and counties where SEZs are established—though influenced by "aggregation rent"—experience only minimal changes in their DT as a result of policy diffusion. This conclusion has been validated through robustness testing.

Heterogeneity analysis reveals that enterprises with varying ownership structures, regional affiliations, factor endowments, and sizes experience different degrees of DT following policy impacts. Mechanism research indicates that the policy shocks resulting from national-level SEZs enhance enterprises' DT through cost effects, financing mechanisms, and research and development innovations. Further analysis shows that when enterprises actively respond to these policies and improve their own DT, they create opportunities for business development. Specifically, enhancing DT enables enterprises to optimize cost management, increase profitability, boost production efficiency through automation and process optimization, and raise per capita income by expanding market reach and achieving global marketing capabilities. Additionally, improved DT enhances information transparency, allowing market participants to more accurately assess companies' financial statuses and reducing abnormal stock price fluctuations caused by information asymmetry. Thus, as enterprises progress due to policy implementation, they align with governmental objectives, fostering a win-win situation for both parties.

The marginal contributions of this study are as follows:

(1) Analytical Framework: Unlike previous studies focusing on the impact of SEZs on local economies [15], per capita income [16], or social welfare [17], this research provides an analytical understanding and quantification of DT. By employing text analysis to construct a set of scientific indicators for DT measurement, we gain deeper insights into its characteristics while providing valuable tools for future research.
(2) New Perspectives on Mechanisms: In contrast to mechanisms proposed by Zhuo et al. [18] and Li et al. [19], this study adopts a novel perspective revealing that policies aimed at reducing costs, alleviating financial constraints, and promoting innovation significantly enhance enterprise DT—offering policymakers a more comprehensive decision-making foundation.
(3) Regional Policy Analysis: Building upon research by Jiang et al. [20] and Ge et al. [21], this study emphasizes regionally oriented industrial policies' characteristics and effects. Given that regions differ in economic development levels, industrial structures, and resource endowments—which lead to diverse industrial policies—this research explores how such variations impact enterprise DT across different contexts. It serves as a reference for local governments aiming to formulate tailored industrial policies aligned with their unique circumstances.

2. Policy background and research hypothesis

2.1. Policy background

This paper examines the impact of national SEZ policies on the DT of listed companies. Within this policy framework, we can observe how the establishment of state-level SEZs functions as an industrial policy and plays a crucial role in regional economic development and the DT of these companies. From 1984 to 2018, China established 552 state-level SEZs across 293 prefecture-level cities, with a relatively even distribution in terms of timing and location. This uniformity aids in distinguishing the effects of national SEZ policies from time-fixed effects.

Establishing national SEZs aims to foster rapid regional economic growth and industrial upgrading [22]. Newly established national SEZs typically designate one to three industries as leading sectors. The government implements preferential policies tailored to these industries to promote their transformation and upgrading [23]. While enterprises within the SEZs not classified as leading industries also benefit from certain advantages, variations in industry focus lead to differing levels of support [24], resulting in disparate progress in DT among these enterprises.

Thus, this research focuses on the DT of listed companies while observing how the establishment of national SEZs influences this transformation. In this context, understanding the interplay between policy implementation and SEZ development is vital for advancing the DT of listed firms. The establishment of national-level SEZs along with corresponding industrial policies provides robust support for these companies' digital transformations while fostering positive interactions between policy frameworks and enterprise development.

Consequently, this study will further explore how SEZ policies influence the DT of listed companies along with identifying specific mechanisms and effects associated with these influences.

2.2. Research hypothesis

National SEZs serve as powerful engines for economic growth by attracting both domestic and foreign investments, fostering industrial clustering, and driving technological innovation. These factors facilitate their transformation and development [25,26]. Hence, the establishment of national SEZs influences enterprise DT through two unique effects: "Policy Effect" and "Cluster Effect". The "Policy Effect" encompasses a range of preferential policies and services provided directly by SEZs to enterprises. These initiatives can lower costs and risks associated with DT, encouraging enterprises to pursue transformation actively. On the other hand, as for the "Cluster Effect", its theoretical root is Marshall's industrial agglomeration theory. The formation of industrial clusters is mainly attributed to three factors: the availability of a specialized labor force, the development of supporting industries, and knowledge spillovers. For digital transformation, a specialized labor force can bring relevant knowledge and experience in technology. Industrial clusters usually have a network of supporting industries. In the context of digital transformation, these supporting industries can include digital infrastructure. In industrial clusters, knowledge and ideas spread more freely among enterprises. Knowledge about new technologies, business

models, and best practices in digital transformation can be disseminated [27]. However, due to the limitations of spillover effects, enterprises located outside special economic zones are less likely to be significantly affected by these policies. Therefore, we propose our first hypothesis:

H1. The establishment of national SEZs promotes the digital transformation of enterprises primarily through "Policy Effect", while "Cluster Effect" may be shown as less significant impact.

Policies implemented within national SEZs may incentivize enterprises to increase spending on marketing and brand promotion to enhance visibility and market share. This could involve higher advertising expenditures or expanding sales teams—efforts that help businesses better connect with target customers, generate sales leads, and create demand for DT [28]. Moreover, advanced management concepts prevalent in SEZs provide efficient services that help companies reduce operational costs while improving management efficiency—fostering favorable conditions for DT [29]. Finally, preferential loan policies and tax relief available within SEZs can alleviate financial burdens on enterprises. This support enables companies to invest more heavily in DT initiatives and enhances their core competitiveness. Henceforth, we propose our second hypothesis:

H2. Policies established within SEZs influence the digital transformation of enterprises through cost reduction effects.

As pivotal engines for economic advancement, national-level SEZs significantly contribute to growth by optimizing industrial layouts [30]. Firstly, these zones collaborate with financial institutions to offer preferential loan policies that optimize financing environments while reducing interest rates on loans. Lower interest rates allow enterprises to secure necessary funding at reduced costs—enabling them to allocate more resources toward DT efforts thereby enhancing their informatization levels and market competitiveness [31]. Secondly, national-level SEZs actively bridge connections between enterprises and financial institutions—broadening access to financing channels which provides additional loan support during the DT process. Therefore, we propose our third hypothesis:

H3. Policies established within SEZs promote digital transformation by relaxing financing constraints.

SEZs also function as vital platforms for regional economic development by attracting numerous enterprises along with capital while converging research-and-development resources [32]. First off, they encourage increased R&D investment among enterprises via policy support coupled with financial assistance—which reduces R&D costs while improving efficiency in this area. Such guidance motivates firms to allocate resources toward innovative endeavors potentially advancing their DT efforts [33,34]. Secondarily; these zones emphasize talent cultivation—providing ample access to skilled personnel who enhance R&D capabilities offering strong technical backing for digital transformations undertaken by firms. Furthermore, encouragement towards intellectual property protection strengthens patent applications safeguarding innovations—a factor conducive towards stimulating enterprise creativity thus promoting research into digital transformation technologies overall leading us towards our fourth hypothesis:

H4. Policies established within SEZs impacts enterprise digital transformation via R&D innovation mechanism.

The subsequent section will empirically test these hypotheses using benchmark regression analysis alongside robustness checks; heterogeneity analysis; mechanism discussions; followed by further examination leading up into actionable policy recommendations based upon research findings.

3. Research design

3.1. 3.1.Data

This paper primarily utilizes four databases for its analysis. The first dataset is derived from the "Announcement of the Audit and Approval Catalog of China's Development Zones" (2018 edition), which provides information on SEZs. The second dataset consists of annual report data from Chinese listed companies spanning from 1990 to 2020. This dataset includes details such as the publication dates of annual reports, listing times, geographical locations of enterprises, and their asset and liability information. The third dataset is sourced from the Industrial Enterprise Database covering the years 1990 to 2007. It contains financial status and geographical location data for enterprises across various prefecture-level cities. The fourth dataset comes from the "China City Statistical Yearbook", which spans from 1999 to 2020. By leveraging these datasets, we can gather insights into enterprise digitization developments alongside the establishment timelines of national-level SEZs in corresponding prefecture-level cities. These datasets will form the empirical foundation for this research.

The primary focus of this paper will be on enterprises mentioned in the annual reports of Chinese listed companies; however, data from the industrial enterprise database will serve as a supplementary resource. While using annual report data for empirical analysis has its limitations—most notably that not all enterprises within regions hosting national-level SEZs publish such reports—the industrial enterprise database compensates for this gap by including additional firms. Additionally, based on classifications of national prefecture-level cities, this paper will align the locations of national-level SEZs listed in the "Announcement of the Audit and Approval Catalog of China's Development Zones" with those where listed companies are situated. This alignment will help determine whether a company operates within a national-level SEZ and how it may be influenced by related industrial policies.

3.2. Variable definition

3.2.1. Explained variable

In this paper, the core explained variable is the DT of enterprises. Measuring the degree of DT poses one of the key challenges. Traditional single-dimensional measurement methods fall short in capturing the nuances of enterprise DT [35]. To address this, we employ a text analysis method using machine learning to develop a more comprehensive index for measuring the extent of DT, thereby providing a richer data environment for subsequent empirical analysis.

To construct the enterprise DT index, we utilize Python web scraping techniques as follows. Keyword Extraction: relevant keywords associated with DT are extracted from national documents focused on digital economy and digitalization themes. Supplementing Vocabulary: we enhance our vocabulary by searching for pertinent digital terms within the annual reports of listed companies. Classification: through the analysis of policy documents, these keywords are categorized into domains such as big data, cloud computing, blockchain, artificial intelligence, and various applications of digital technology. Frequency Analysis: using this specialized vocabulary, we count the frequency of identified keywords in the annual reports of listed companies. The logarithmically transformed sum of these word frequencies constitutes our index representing the degree of enterprise DT. A higher index value indicates a greater level of DT.

3.2.2. Explanatory variable

The core explanatory variable in this study is the interaction term (treat*post), which combines a dummy variable (treat) representing enterprises affected by national-level SEZ construction policies with a time variable (post). Addressing how to differentiate between treatment and control groups presents another significant challenge. We adopt the

DID approach that necessitates clear sample classification [36]. Specifically, samples impacted by the policy are designated as the treatment group while those unaffected serve as the control group.

Given that each city has different timelines for establishing national-level SEZs, we apply a staggered DID methodology. Listed companies situated in cities with established SEZs form our treatment group and are assigned treat=1, whereas other companies constitute the control group with treat=0. For firms located in cities with SEZs, post is set to 1 starting from their respective year of establishment onward; prior years receive a value of 0. Conversely, for firms based in cities without SEZs, post remains at 0.

The primary variable used in our analysis is then generated by multiplying treat by post. A detailed overview is provided in Fig. 1.

3.2.3. Control variables

Apart from policies will affect the DT of enterprises, there are other factors that will affect the latter. When selecting control variables, we referred to a wide range of literature with the aim of comprehensively controlling the factors that may affect the digital transformation of enterprises and ensuring the accuracy and reliability of the research results.

(1) The selection of "labor" referred to the research of Yang et al. [37]. The scale and quality of an enterprise's labor force can have a significant impact on its production and operation activities, and thus may influence the decision-making and process of the enterprise's digital transformation. (2) "Degree of network infrastructure" referred to the research of Jia et al. [38]. Digitalization relies on the network environment, and the level of infrastructure affects the transformation ability. (3) "Industrial structure" drew on the research findings of Zheng et al. [39]. Different industries have different demands for digitalization, which affects the transformation speed. For example, technology-intensive industries are more proactive. (4) "Size of the enterprise" was the research of Shang et al. [40]. There is a complex relationship between enterprise size and digital transformation. Large enterprises usually have more abundant resources for digital transformation, but may also face transformation resistance due to their large organizational structures. Although small and medium-sized enterprises have relatively limited resources, they are flexible in decision-making and may be more agile in digital transformation. (5) "Economic environment" referred to the research of Luo et al. [41]. The quality of the regional economic environment can affect the enterprise's market demand, the difficulty of financing, and the innovation atmosphere, etc., and thus influence the motivation and ability of the enterprise's digital transformation. (6) "Competitiveness of the enterprise" was based on the research of Liu and Ananthachari [42]. When an enterprise has strong competitiveness, it may be more motivated to carry out digital transformation to maintain its competitive advantage. (7) "Enterprise return on assets" and (8) "Enterprise capital per capita" referred to the research of An and Yoon [43]. The financial situation and capital investment of an enterprise can affect its ability and willingness to digitalize. (9) "The duration of the enterprise" referred to the research of Li et al. [44]. Enterprises with different durations have different accumulated experiences, technologies, and resources, and their cognition and response capabilities to digital transformation also vary. (10) "Enterprise asset-liability ratio" and (11) "Enterprise cash flow ratio" variables referred to the research of Sun et al. [45]. These two variables reflect the financial risk and capital liquidity of the enterprise. An excessively high asset-liability ratio may limit the enterprise's financing ability and thus affect the investment in digital transformation. The cash flow ratio affects the capital support and project progress during the enterprise's digital transformation process.

The main variables and measures are detailed in Table 1.

3.3. Model setting

This paper adopts the method of DID to measure the influence of the establishment of national SEZ on the DT of enterprises. According to the data of this paper, from 1984 to 2018, a total of 552 state-level SEZs were set up in 293 prefecture-level cities in China, which provides us with a good quasi-natural experiment. The enterprises in the prefecture-level cities located in the SEZ are the treatment group of this paper, while the other enterprises not located in the SEZ are all the control

Table 1
Main variable names and measures.

Variable classes	Variable name	Measurement method
Explained variable	Enterprise Digital Transformation (lnDigita)	The value of the number of word frequency statistics
Core explanatory variables	SEZ Establishment (Treat*Post)	The group dummy variables are multiplied by the policy implementation dummy variable
Control variable	Labor (lnlabour)	The number of workers
	Degree of network infrastructure (lninfras)	The international Internet users
	Industrial Structure (Indus)	The proportion of the primary industry, secondary and tertiary industries
	Economic environment (lnecon)	The value of the regional GDP
	Size of the enterprise (lnsize)	The value of the total assets of the enterprise
	Competitive tiveness of enterprises (lncompete)	The value of the total profit of the enterprise
	The Life Time of the Enterprise (Age)	The time of the annual report minus the time of listing
	Return on assets of enterprises (Roe)	The total profits of the enterprise are divided by the total assets of the enterprise
	Debt-to-asset ratio of the enterprise (Cdr)	The total liabilities of the enterprise are divided by the total assets of the enterprise
	Cash flow ratio of the enterprise (Cfr)	The current assets of the enterprise are divided by the current liabilities of the enterprise
	Per capita capital of the enterprise (Per-cap)	The total amount of capital owned by the enterprise per person

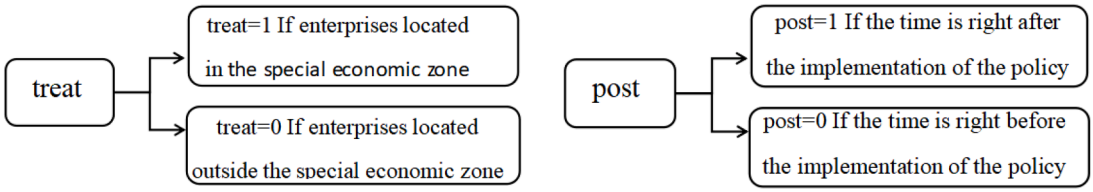

Fig. 1. Assignment of the dummy variable.

group. Due to the different establishment time of the SEZ, this paper expresses the time grouping variables by Post according to the establishment time of the SEZ. This paper constructs the following measurement model to measure the impact of the policy of setting up a national SEZ on the DT of enterprises:

$$Digita_{ict} = \beta_0 + \beta_1 Treat_i \times Post_{it} + \boldsymbol{X}_{it}'\boldsymbol{\beta} + \gamma_c + \tau_t + \varepsilon_{it} \quad (1)$$

In model (1), $Digita_{it}$ is the explained variable, indicating the degree of DT of enterprise i in the annual t. $Treat_i$ is a grouping variable, and the enterprise i is assigned 1 if it is a treatment group and 0 if it is a control group. $Post_{it}$ is a virtual variable, indicating whether the enterprise i establishes a national SEZ in the annual t, and takes 1 if any, and 0 if not. $Treat_i \times Post_{it}$ is the core explanatory variable, which represents the impact on the explained variables to explore the impact of the policy of establishing the SEZ on the DT of enterprises. The $\boldsymbol{X}_{it}'$ represents the control variable. This paper follows the design requirements of the DID with multiple periods, and controls time fixed effect τ_t and industry fixed effect γ_c. Extreme values will cause the data analysis results to be unreliable. To address this problem, we have unified the observations of variables, and then winsorize all continuous variables at 1 %. Descriptive statistics of variables are shown in Table 2.

4. Empirical results

4.1. Benchmark results

Table 3 shows the benchmark regression results of "policy effect" and "cluster effect" on DT, and the empirical results that control both industry fixed effect and time fixed effect. The results of column (1) show that the coefficient of DT is significantly positive without the addition of control variables. The results of column (2) show that the DT is significant at the estimated level of 1 %, indicating that the "policy effect" generated by the policy of SEZ can effectively and significantly promote the DT of enterprises. The results of column (3) is to test the "cluster effect" where firms are located outside the SEZ but within the city. The regression result is positive but not significant, which means the "cluster effect" of SEZ policy does not have a significant impact on the DT of the enterprise. Benchmark results validate H1 (Fig. 2).

The establishment of national SEZs has played a positive role in promoting the DT of enterprises through the "policy effect". Preferential policies and supporting measures provide the impetus and support for enterprise transformation, and help to promote the upgrading and development of regional economy.

Although the "cluster effect" contributes to the formation of a good industrial ecology to some extent, it has a relatively limited role in promoting the DT of enterprises. Enterprise digital transformation requires substantial capital investment and advanced technological support. Although the spillover of knowledge and information in industrial clusters brings certain benefits, it cannot directly provide enterprises with the funds and cutting-edge technologies needed for digital transformation. Moreover, there may be obstacles to the spillover of knowledge and information in industrial clusters. The effectiveness of knowledge and information spillover depends on factors such as the enterprises' absorptive capacity and technological compatibility. Against the backdrop of the rapid development of digital technologies, some enterprises may lack the ability to absorb and apply the spilled knowledge and information.

In the process of promoting the DT of enterprises, we should pay more attention to the role of policy guidance and support, and formulate targeted transformation policies based on the actual situation of enterprises and the market demand of enterprises.

Table 2
Descriptive statistics of the variables.

Variable	Observations	Mean	Std	Min	Max
lnDigita	17,077	1.798	1.335	0	4.990
lnlabour	41,921	7.582	0.968	4.522	8.4761
lninfras	41,532	4.740	1.451	0.494	7.130
lndus1	42,202	0.060	0.066	0.0004	0.306
lndus2	42,202	0.167	0.099	0.013	0.59
lndus3	42,202	0.201	0.069	0.028	0.286
lnecon	42,378	7.766	0.796	4.977	8.680
lnsize	48,192	21.489	1.282	18.763	25.727
lncompete	40,544	18.320	1.580	14.091	22.680
Age	45,411	13.347	6.575	1	29
Roe	47,789	0.032	0.078	−0.385	0.234
Cdr	48,186	0.395	0.235	0.007	1.269
Cfr	47,561	3.071	5.958	0.091	46.586
Per-cap	43,092	14.342	1.350	11.312	18.409

Table 3
Benchmark regression results.

Variable	(1) Baseline	(2) Policy effect	(3) Cluster effect
	lnDigita		
Treat × Post	1.275***	1.342***	1.767
	(3.78)	(3.43)	(1.07)
Control variable	N	Y	Y
Time fixed effect	Y	Y	Y
Industry fixed effect	Y	Y	Y
N	13,712	10,567	5186
Adj − R^2	0.1083	0.1275	0.2841

Note: t in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4.2. Robustness test

4.2.1. Parallel trend test

The parallel trend is assumed to be the premise of the use of double difference in the empirical paper. In order to observe the parallel trend of this paper, this paper sets a virtual variable every year in the year before the implementation of the SEZ, and then multiply the virtual variables with the virtual variables set by the experimental group, and regresses the transfer to the degree of DT of the enterprise [46]. The regression model is as follows:

$$Digita_{ict} = \sum_{t=1}^{6} \beta_{-t} D_{i,-t} + \sum_{t=1}^{6} \beta_t D_{i,t} + \boldsymbol{X}_{it}'\boldsymbol{\beta} + \gamma_c + \tau_t + \varepsilon_{it} \quad (2)$$

Among them, β represents the coefficient, $D_{i,-t}$ represents the multiplication of the timing variable before the experiment and the treatment variable established by the treatment group. Namely, $D_{i,-t}$ means that the enterprises in the city of treatment are in t years before the policy. Similarly, $D_{i,t}$ means that the enterprises in the treated city are in t years after the policy. $\boldsymbol{X}_{it}'$ represents control variables. γ_c and τ_t represent industry fixed effects and time fixed effects.

As shown in Fig. 3, the coefficient of the core explanatory variable $D_{i,-t}$ was not significant, indicating that the degree of DT of the enterprises in the treatment group was not significantly different from the control group in six years before the policy, that is, the parallel trend test passed. After the implementation of SEZ policy, the graph shows the "inverted-U" type that the effect firstly rises and then declines, which is in line with the common changing trend of a policy effect.

On the other hand, it can also be understood as a robustness test, that is, if the estimation of $D_{i,-t}$ is significantly positive, it means that the DT of the enterprise is not driven by SEZ after the policy, but by other factors; if $D_{i,-t}$ is not significant, it proves that the DT of the enterprise is affected by SEZ policy exactly.

4.2.2. The placebo test

(1) Randomly generate treatment group. According to the previous proof, the treatment and control groups met the parallel trend test. However, due to the limited number of samples, the experimental results will still be affected by the non-randomness and

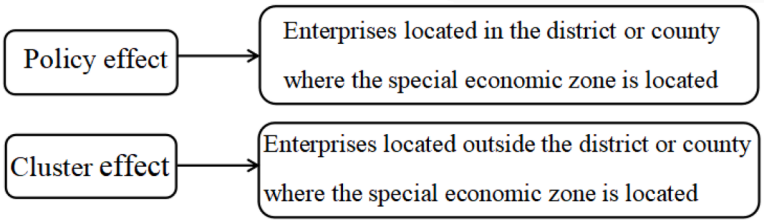

Fig. 2. Classification of enterprises subject to policy effect and cluster effect.

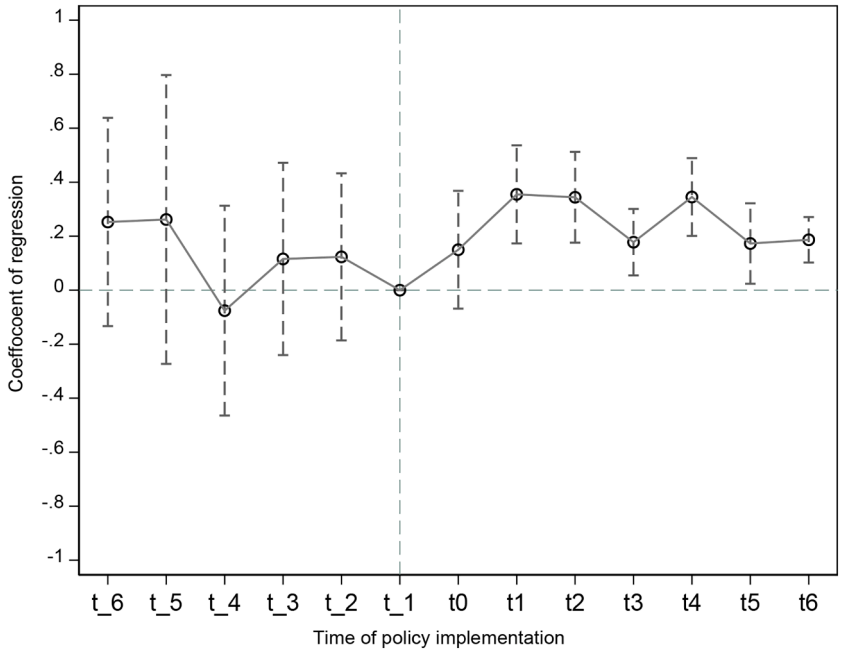

Fig. 3. Parallel trend test.

regional heterogeneity of the impact of the policy implementation. In order to exclude the influence of these uncertain factors, this paper refers to the method of Qian et al. [47] to construct virtual treatment group, randomly selected individuals as treatment group, and repeated 500 times to observe whether the coefficient of "pseudo policy virtual variable" is significant.

In Fig. 4, the estimated coefficients of randomly selected samples from the full sample follow a normal distribution and are concentrated around zero. This rules out the contingency of the estimation results. To ensure the robustness of the placebo test across different industries, we conducted an industry-stratified test. Based on the significant differences in digital transformation requirements, resource dependencies, and technology applications among industries, we stratified the sample into three major industry categories: technology-intensive, capital--intensive, and labor-intensive industries. For each industry subset, we performed 500 placebo tests. By randomly assigning treatment groups, we simulated the random occurrence of policy shocks to examine the contingency of policy effects in different industries. By comparing the distribution characteristics of the placebo coefficients in different industry groups, we observed that the coefficients in each industry were normally distributed and centered around zero, with no systematic bias. This proves that the policy effects were not caused by industry-specific random shocks.

Our research conclusions remain robust in the face of industry heterogeneity. The actual policy effects are significantly different from the results of the placebo test, indicating that the degree of enterprises' digital transformation (DT) is not caused by other policies or random factors. This further validates the robustness of our research conclusions.

(2) Counterfactual test. To exclude other possible explanatory factors and verify the robustness and veracity of the policy, the counterfactual test was conducted twice. First, this paper eliminates the enterprises in SEZ from 1990 to 2000, and at this time, all the enterprises are not affected by SEZ. If the enterprises in this part of the data are affected by the development zone policy in 2000–2010, it is assumed that these enterprises were affected by the policy in 1990–2000, and the regression results are shown in Table 4, columns (1)-(2). Second, the data from 1990 to 2000 are still selected to eliminate the enterprises affected by the policies of SEZ. At this time, all the enterprises are not affected by the development zone policy. The system randomly assumes that some enterprises are affected by the development zone, and the regression results are shown in Table 4, columns (3)-(4). The regression results at this time are not significantly inconsistent with the actual situation. This proves that the results of the digital transformation of enterprises are indeed caused by SEZ policy and enhances the credibility of this study.

4.2.3. *Analysis of the bacon decomposition*

As is known above, the time of the establishment of SEZs is inconsistent, so that the time of policy impact on enterprises is inconsistent. The existence of this situation will have impacts on the DID coefficient estimation. In Goodman-Bacon [48] cases, this policy effect is actually a weighted average of the four 2 × 2 DD estimators. After doing the

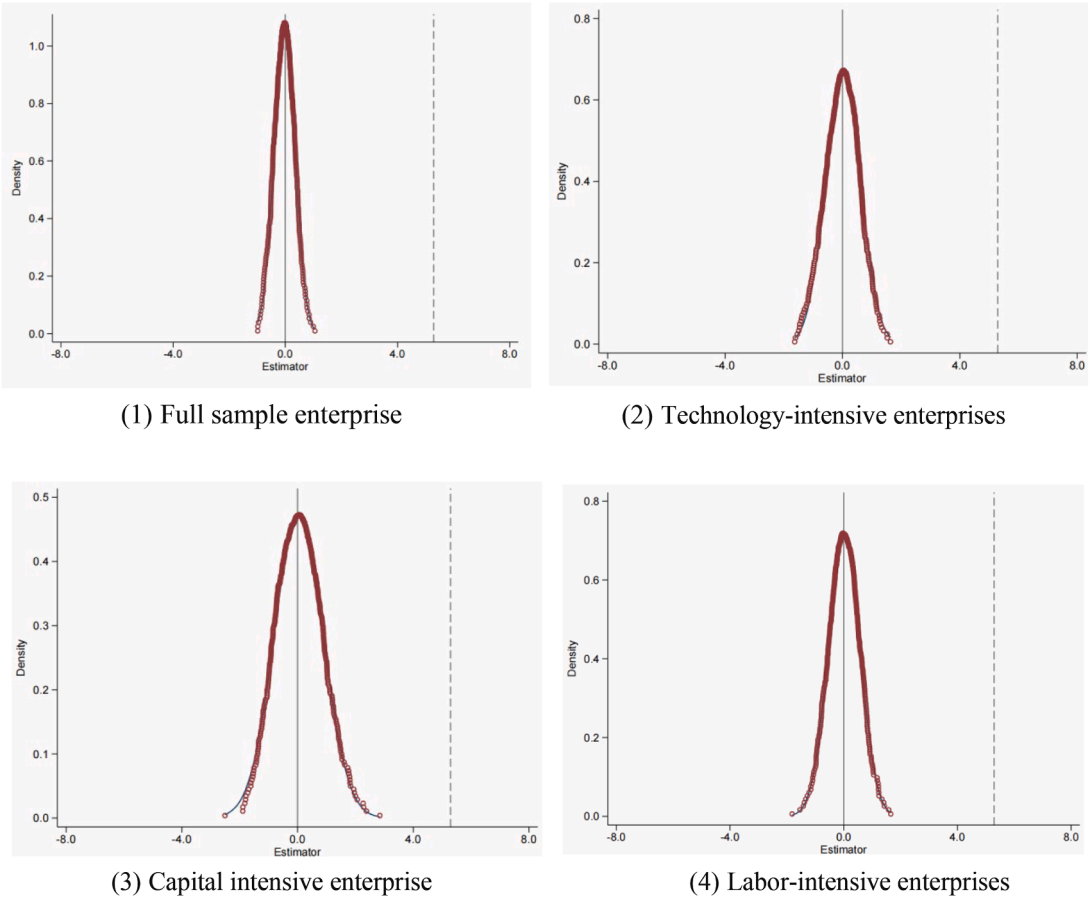

Fig. 4. Placebo test.

Table 4
Counterfactual test.

Variable	(1) Baseline	(2) Policy effect	(3) Baseline	(4) Policy effect
	lnDigita			
Treat × Post	2.862	3.389	2.073	2.019
	(2.690)	(2.864)	(1.398)	(1.670)
Control variable	N	Y	Y	Y
Time fixed effect	Y	Y	Y	Y
Industry fixed effect	Y	Y	Y	Y
N	268	226	825	679
Adj $-R^2$	0.0269	0.0813	0.2099	0.1206

traditional two-way fixed effect (TWFE), the result is decomposed into the weighted average of each part, so as to understand the influence of the estimator of each part on the overall result.

Fig. 5 utilizes the Bacon decomposition to draw a scatter plot of the four 2 × 2 DD subsample coefficients and their weights. Different weights can quantify the contribution of different groups or time points to the effects of policy change. By time-weighted averaging, we found that temporal variation contributed 0.3 % to the overall DD coefficient, indicating that time-varying effects lead to estimation bias. Meanwhile the DD of Earlier vs Later is opposite to the total DD, explaining the source of the overall bias. Comparing the total DD estimator in Fig. 5 with the DD estimator of 0.144 in the previous benchmark regression, we found that the estimation results of TWFE were indeed biased. But the overall gap was small and the robustness test was met. According to Fig. 5, the weight of group (3) (4) has a large proportion, indicating that the estimated coefficient of group (3) (4) has a large contribution to the total estimated coefficient. Moreover, their estimator of DD is positive, which proves that the (3) and (4) group suffered a large positive impact during the policy implementation. This facilitates understanding the actual impact of policy changes on economic or social outcomes and provides targeted recommendations for policy making.

4.2.4. *Change the measure of enterprise digitalization*

Although this paper uses a relatively forward-looking text analysis method to construct indicators for enterprise digitalization, there may still be other deficiencies. Therefore, this paper will attempt to measure the digitalization level of enterprises in three other ways. The first method: The vocabulary related to enterprise digital transformation can be roughly divided into five categories: artificial intelligence technology, blockchain technology, cloud computing technology, big data technology, and digital technology application. Considering that different digital indicators have different degrees of influence on enterprise digital transformation, based on expert scoring and existing literature, different weights are assigned to these five types of digital indicators to form a new digital indicator, Digita 1. The second method: Referring to the approach of Zhao et al. [49], the frequencies of 99 digital-related words in four dimensions, namely digital technology application, Internet business models, intelligent manufacturing, and modern information systems, are counted to generate a new digital indicator, Digita 2. The third method: Referring to the approach of Zhen et al. [50], the frequencies of 139 digital-related words under categories such as technology classification, organizational empowerment, and digital applications are counted to generate a new digital indicator, Digita 3.

As verified by multi-dimensional indicators, the results are shown in Table 5. This paper uses three different methods to measure the

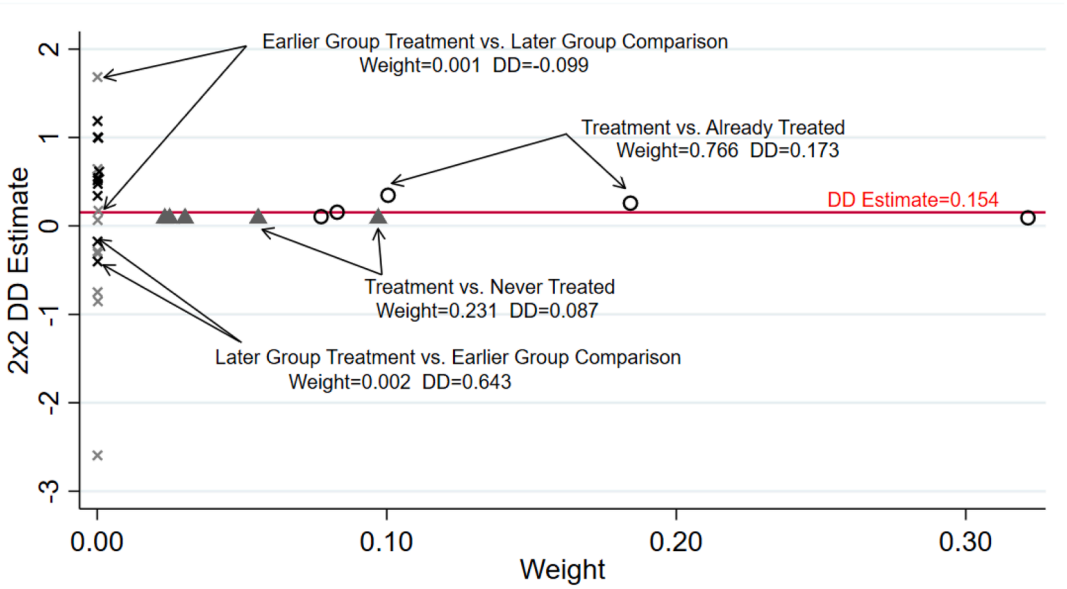

Fig. 5. The Bacon decomposition.

Table 5
Robustness test of changing the explained variables.

Variable	(1) Digita 1	(2) Digita 2	(3) Digita 3
Treat × Post	0.257***	0.09***	0.079***
	(3.57)	(5.77)	(4.50)
Control variable	Y	Y	Y
Time fixed effect	Y	Y	Y
Industry fixed effect	Y	Y	Y
N	10,567	17,681	17,681
Adj − R^2	0.1458	0.3936	0.2878

digitalization level of enterprises, constructing the indicators Digita 1, Digita 2, and Digita 3 respectively. Different indicator construction methods depict enterprise digitalization from multiple perspectives, covering different technology fields, application dimensions, and analytical approaches. However, under these three different measurement methods, the estimated coefficients of the core explanatory variable are all significantly positive. This result verifies the positive correlation between the establishment of national and development zones and enterprise digital transformation from different aspects. Even if the measurement method of the explained variable is changed, this significance remains stable, which enhances the reliability and persuasiveness of the results.

4.2.5. Eliminate interference from other major events

The DT of enterprises may also be affected by other major events, such as the financial crisis and the China-US trade friction. Therefore, in order to exclude the influence of major events, this paper takes the proportion of import and export to GDP in prefecture-level cities as the trade dependence, and constructs two new control variables. (1) According to the time of the financial crisis, the post before 2008 is 1, and the post after 2008 is 0. Multiply the time virtual variable post and trade dependence to obtain the interaction term to control the financial crisis; (2) Assign the post to 0 according to the time after 2018. Similarly, multiplied with the trade dependence, to get the interactive item to control the trade friction between China and the United States. In Table 6, the regression results are robust, which means the impact of the SEZ policy on the DT of enterprises will not change due to the financial crisis and the China-US trade friction.

Table 6
Robustness test of the reduced sample.

Variable	(1) Baseline	(2) Policy effect	(3) Cluster effect
	lnDigita		
Treat × Post	1.094***	1.195***	1.967
	(3.21)	(3.05)	(1.19)
Control 2008 finance crisis	1.343	−5.503	−10.572*
	(0.30)	(−1.06)	(−1.67)
Control China-US trade friction	1.173***	2.095***	1.040
	(3.97)	(2.94)	(1.04)
Control variable	N	Y	Y
Time fixed effect	Y	Y	Y
Industry fixed effect	Y	Y	Y
N	13,530	10,567	5186
Adj − R^2	0.1085	0.1277	0.2839

5. Heterogeneity

5.1. Heterogeneity of enterprise

5.1.1. Heterogeneity of enterprise ownership

Different ownership of enterprises leads to different resources, credit and economic goals of enterprises, which may also lead to differences in

Table 7
Analysis of the heterogeneity of enterprise ownership.

Variable	(1) State-owned enterprises	(2) Private enterprises	(3) Sino-foreign joint ventures	(4) Wholly foreign-owned enterprises
	lnDigita			
Treat × Post	3.843***	1.449**	0.711	3.418
	(3.79)	(2.44)	(0.45)	(0.35)
Control variable	Y	Y	Y	Y
Time fixed effect	Y	Y	Y	Y
Industry fixed effect	Y	Y	Y	Y
N	1639	4414	724	63
Adj − R^2	0.1513	0.1298	0.1024	0.0831

the digital development of enterprises. In Table 7, the (1)-(2) show that the establishment of state-level SEZs has an obvious positive effect on the DT of both state-owned enterprises and private enterprises, and has a stronger impact on state-owned enterprises. It is mainly because the management structure and business model of state-owned enterprises are more secure and more stable, while the overall resource support of private enterprises is lower than state-owned enterprises. So the degree of DT is lower than state-owned enterprises under the impact of policies.

The results of columns (3)-(4) in Table 7 show that although Sino-foreign joint ventures and wholly foreign-owned enterprises are positively impacted by the policies, the transformation of the degree of DT is not significant. On the one hand, foreign enterprises have an independent development path, so the acceptance of domestic policies is lower than that of domestic enterprises. On the other hand, the impact of the SEZ on Sino-foreign joint ventures and wholly foreign-owned enterprises may lag behind.

5.1.2. The regional heterogeneity of the enterprise

Due to the complex terrain and different economic development priorities in China, the level of digital development differs across regions [51]. In Table 8, the coefficients of DT of enterprises in the eastern, central and western regions are significantly positive, with the digital coefficient in the west being higher than in the eastern and central regions. The possible reason is that the eastern region has always been China's economic center of gravity due to historical reasons and geographical advantages. However, with the rapid development of the economy, the pressure of resources and environment in the eastern region gradually increases, and the economic growth rate may gradually slow down, so the degree of DT will also slow down at the current level. Thanks to its advantages of convenient transportation, complete infrastructure and talent gathering, the central region has made remarkable progress in economic development and the DT of enterprises in recent years. In the western region, with the in-depth implementation of the national "Western Development" strategy, a large number of policies, technologies and talents have been introduced into the region, providing great development opportunities for local enterprises. This also makes the DT of enterprises in the western region grow significantly at the current level.

5.1.3. Industry heterogeneity of the enterprise

There are obvious differences between different industries, which also lead to the different degree of demand for digitalization among them [52]. In Table 9, the coefficients of the digital index of labor-intensive, capital-intensive and technology-intensive enterprises are all significantly positive, indicating that policies have effectively promoted their DT. Among them, technology-intensive enterprises have a high demand for automation and digitalization, so they respond more strongly to policy influences. At the same time, with the penetration of digital technology revolution into various industries, capital-intensive enterprises rely on stable funds to support their business analysis activities and gradually integrate digital integration. However, the degree of DT of them will be significantly higher than labor-intensive enterprises. The production and operation of labor-intensive enterprises mainly rely on manpower, and the demand for digitalization is slightly lower.

Table 8
Analysis of regional heterogeneity of enterprises.

Variable	(1) East	(2) Middle	(3) West
	lnDigita		
Treat × Post	0.951**	1.845*	3.023**
	(2.11)	(1.81)	(2.24)
Control variable	Y	Y	Y
Time fixed effect	Y	Y	Y
Industry fixed effect	Y	Y	Y
N	8047	1613	905
Adj − R^2	0.1228	0.2840	0.1389

Table 9
Analysis of Industry heterogeneity of enterprises.

Variable	(1) Labor-intensive enterprises	(2) Capital-intensive enterprises	(3) Technology-intensive enterprises
	lnDigita		
Treat × Post	1.237**	1.732*	1.493**
	(2.04)	(1.80)	(2.37)
Control variable	Y	Y	Y
Time fixed effect	Y	Y	Y
Industry fixed effect	Y	Y	Y
N	4117	2240	4014
Adj − R^2	0.1943	0.0916	0.1342

5.1.4. Heterogeneity of enterprise scale

The size of an enterprise often influences its level of digitization. In this study, we categorize enterprises into three groups based on revenue scale and employee count. Table 10 reveals that small and medium-sized enterprises exhibit significantly higher levels of DT compared to their larger counterparts. A possible explanation is that large enterprises tend to have established development models and market advantages, which expose them to less competitive pressure. As a result, they may adopt more conservative approaches to growth, potentially hindering their internal digital reforms.

In contrast, small and medium-sized enterprises face greater market pressures than large firms. It may prompt them to leverage DT more actively in pursuit of new development opportunities. Additionally, the management structures of smaller enterprises are typically simpler, allowing for greater flexibility and agility in their transformation efforts. With access to their own capital and supportive policies, these smaller entities demonstrate enhanced execution capabilities when it comes to implementing DT initiatives. Consequently, their degree of transformation surpasses that of medium-sized enterprises.

This dynamic illustrates how varying levels of competitive pressure and organizational structure can influence the pace and extent of digital transformation across different enterprise sizes.

5.2. Heterogeneity of SEZ

5.2.1. Type heterogeneity of SEZ

Different types of SEZs lead to different policy environment, infrastructure, industrial structure and enterprise types. These factors promote different digitalization of enterprises. Therefore, this paper divides

Table 10
Analysis of enterprise size heterogeneity.

Variable	Divided by revenue scale			Divided by number of employees		
	(1) Large	(2) Medium	(3) Small	(4) Large	(5) Medium	(6) Small
	lnDigita					
Treat × Post	0.880	1.223*	1.790**	−0.167	1.702**	1.792***
	(1.46)	(1.92)	(2.07)	(−0.22)	(2.40)	(3.00)
Control variable	Y	Y	Y	Y	Y	Y
Time fixed effect	Y	Y	Y	Y	Y	Y
Industry fixed effect	Y	Y	Y	Y	Y	Y
N	4658	3632	2241	2816	3345	4406
Adj − R^2	0.2395	0.2908	0.1025	0.1197	0.1150	0.1330

the SEZs into three categories for comparative analysis.

In Table 11, the established large enterprises in economic and technological development zone (ETDZ) occupy a dominant position in the manufacturing sector. They are large but have too cumbersome production models, and most of them are sunset industries. So their desire for digital transformation is not strong. For example, in water, electricity and other industries, the demand for digital transformation is low, and the domestic market is gradually becoming saturated. Their need to increase production is not urgent, resulting in a relatively low upgrading of their digital transformation.

In contrast, the enterprises in the high-tech development zone (HTDZ) are relatively small but efficient and flexible, and most of them are emerging high-tech enterprises. These companies keep up with the pace of technology development, and the degree of DT is very obvious. They are rapidly adopting the most advanced technology and management methods to continuously enhance the competitiveness of the industrial chain.

Enterprises in the special customs supervision area (SCSA) are mainly involved in export processing and OEM, and these enterprises have frequent trade contacts with foreign countries. This frequent communication makes the enterprise management concepts in the region advanced and fosters a strong sense of transformation and upgrading. Therefore, the level of DT in these enterprises is also very high. They actively adopt advanced digital technologies to improve the overall production efficiency and quality, thereby maintaining competitiveness in the international market.

5.2.2. Heterogeneity of the SEZ period

In order to test whether the performance of the early established SEZ is different from the later ones, the following model was constructed according to the estimation method of Wang [53]:

$$Digita_{it} = \alpha_0 + \alpha_1 S_{iPt} + \sum_{q=2}^{3} \alpha_2 G_i^q S_{iPt} + X_{it}' \alpha_3 + \gamma_c + \tau_t + \varepsilon_{it} \quad (3)$$

If the enterprise is located in 1999–2008 established SEZ, G_i^2 assigned a value of 1 otherwise it is 0. G_i^3 for 1 means that the location of the enterprise in the SEZ was established from 2009 to 2018, but not established for 0. Businesses within the SEZ established in 1984–1999 were set up as the reference group S_{iPt} for the model. All other controls are as previously defined.

Table 12 illustrates that SEZs established from 1999 to 2008 did not have a significant impact on enterprise DT. This lack of effect can be attributed to the limited popularity and application of digital technology during this time. Although these SEZs offered policy support and resources to enterprises, their relatively small number diminished their overall influence on promoting DT.

As time progressed, digital technologies became more prevalent, suggesting that the SEZs established between 1999 and 2008 may have laid an early groundwork for subsequent transformations by providing initial experiences and frameworks. By contrast, during the period from 2009 to 2018, there was a marked increase in the adoption of digital technologies within SEZs. At this stage, government support intensified, with more resources allocated specifically to foster enterprise DT.

Table 11
Analysis of the type heterogeneity of SEZ.

Variable	(1) HTDZ lnDigita	(2) ETDZ	(3) SCSA
Treat × Post	1.867***	0.136	1.066**
	(3.17)	(0.27)	(1.99)
Control variable	Y	Y	Y
Time fixed effect	Y	Y	Y
Industry fixed effect	Y	Y	Y
N	10,567	10,553	10,567
Adj $-$ R^2	0.1274	0.2593	0.1269

Table 12
Analysis of the heterogeneity in the SEZ period.

Variable	lnDigita
SEZ	1.093***
	(2.64)
SEZ × G2(1999–2008)	0.466
	(0.30)
SEZ × G3(2009–2018)	1.767**
	(2.00)
Control variable	Y
Time fixed effect	Y
Industry fixed effect	Y
N	10,567
Adj $-$ R^2	0.1277

Consequently, from 2009 to 2018, the innovative potential of newly established SEZs played a significantly greater role in advancing enterprise DT compared to earlier periods. This shift highlights how evolving technological landscapes and enhanced governmental backing contribute synergistically to driving digital transformation within enterprises situated in these economic zones (Fig. 6).

6. Mechanism

The above empirical analysis shows that the policy of SEZs can promote the DT of enterprises to a certain extent, and the impact of policies on the DT of enterprises is heterogeneous at different levels. Building on this evidence, this section further examines whether the establishment of SEZs influences enterprise DT through the cost effect, financing support, and R&D and innovation.

6.1. Cost effect

In order to test whether the policies of SEZs can have an impact on the DT of enterprises by reducing costs, the paper constructs the following model:

$$Cost_{it} = \alpha_0 + \alpha_1 Treat_i \times Post_{it} + \boldsymbol{X}_{it}' \alpha + \gamma_c + \tau_t + \varepsilon_{it} \quad (4)$$

Among them, $Cost_{it}$ serves as the index of enterprise cost and expense. This paper borrows the practice of Shi et al. [54] measures the cost of enterprises through the sales rate (Selc), enterprise financial rate (Finc) and enterprise management rate (Magc). The results of the mechanism test are shown in Table 13.

Table 13 reveals that while SEZ policies increase sales costs for enterprises, they concurrently reduce financial and management costs. These findings align with our hypothesis H2.

The establishment of SEZs affects enterprise DT by lowering financial expense ratios and management expense ratios. One possible explanation is that SEZs encourage enterprises to invest more heavily in market promotion and brand development. Such investments facilitate better customer engagement, leading to increased sales opportunities and fulfilling market demand.

Additionally, these policies may offer enterprises more favorable loan conditions, lower financing thresholds, or tax incentives, thereby alleviating their financial burdens. This reduction in financial costs enables companies to allocate more resources toward their DT initiatives. Moreover, policies associated with SEZs may prompt enterprises to adopt advanced management practices and concepts that enhance operational efficiency. As a result, reduced management costs free up additional resources and energy for pursuing DT objectives, ultimately fostering successful implementation processes.

6.2. Financing mechanism

From the perspective of transmission mechanism, subsidies, tax reduction and interest rate cuts in the policies can effectively expand the

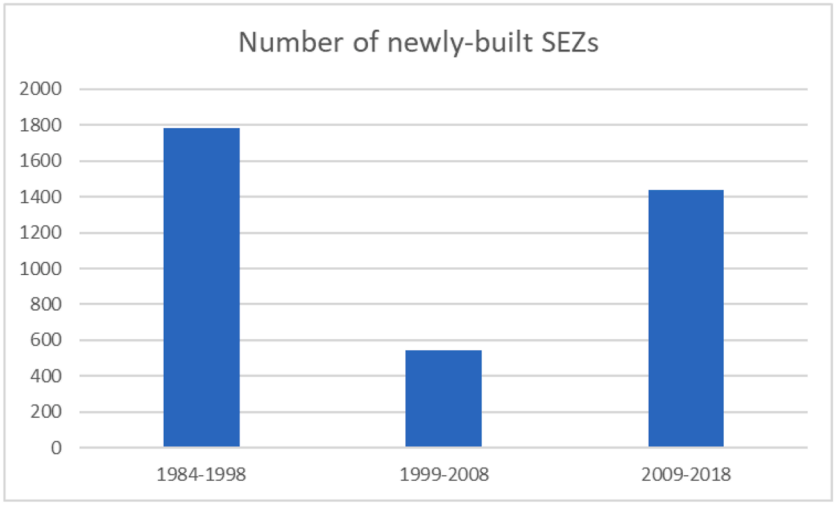

Fig. 6. Number of newly-built SEZs.

Table 13
Analysis of Cost-effect mechanism.

Variable	(1) Selc	(2) Finc	(3) Magc
Treat × Post	0.0053***	−3.813*	−1.623**
	(3.39)	(−1.92)	(−1.82)
Control variable	Y	Y	Y
Time fixed effect	Y	Y	Y
Industry fixed effect	Y	Y	Y
N	16,643	30,286	17,234
Adj − R^2	0.2504	0.0009	0.0141

cash flow of enterprises, and reduce the level of financial expenses and leverage ratio. This can ease the financing constraints to some extent. Enterprises can further promote the digital transformation of enterprises with the support of funds.

To examine the existence of this financing mechanism, we construct model (4), where the explained variables include the corporate bank loan ratio (Loan), interest rate (IR), SA index, and FC index. The SA index, based on Hadlock and Pierce [55], is constructed using two stable variables—enterprise size and age—which exhibit strong exogenous characteristics over time. The FC index is measured following Fama and French [56] as a weighted average of the investment cash flow ratio and cash flow asset ratio.

$$Constraint_{it} = \alpha_0 + \alpha_1 Treat_i \times Post_{it} + \boldsymbol{X}_{it}^{'}\boldsymbol{\alpha} + \gamma_c + \tau_t + \varepsilon_{it} \quad (5)$$

In Table 14, the estimated coefficient for the corporate bank Loan is significantly positive, indicating that the SEZ policy has led to a notable increase in enterprise loans. This suggests that the financing mechanism has eased for these enterprises, making it easier for them to secure financial support. This effect may be attributed to preferential loan provisions within SEZ policies; enterprises located in these zones often have access to central government loan discounts, thereby enhancing their financing capabilities.

Furthermore, the regression coefficient for IR is significantly negative, implying that financial support stemming from these policies has contributed to a decline in enterprise loan interest rates. This reduction helps alleviate some of the financing difficulties faced by enterprises. The favorable conditions provided by SEZs allow companies to benefit from lower interest rates and tax incentives, resulting in a downward trend in borrowing costs.

Both coefficients for the SA index and FC index are significantly negative as well, proveing that SEZ policies have reduced financing constraints for enterprises. These findings also validate Hypothesis H3.

6.3. R&D and innovation

The establishment of SEZs can attract all kinds of high-tech talents, enterprises and other resources. The collision of various talents' ideas and enterprise resources will further promote the innovation and development of the region, thus further promoting the DT of enterprises in the region. In order to further verify the existence of research innovation mechanism, on the basis of the model (3), we use RdssR (R&D), RdpR (proportion of researchers), and Digi-Pat (digital economy patent application) as the explained variables. The model is as follows:

$$Innovate_{it} = \alpha_0 + \alpha_1 Treat_i \times Post_{it} + \boldsymbol{X}_{it}^{'}\boldsymbol{\alpha} + \gamma_c + \tau_t + \varepsilon_{it} \quad (6)$$

In Table 15, the coefficients of all the core explanatory variables are significantly positive, which indicates that the policies established by the national SEZs can promote enterprises to increase their investment in R&D and the recruitment of R&D personnel, thus promoting the DT of enterprises themselves. The possible reason is that the implementation of the policy encourages the development of enterprises, also attracts the inflow of a large number of talents. Thus, the enterprise increases the R&D investment for its own development to promote innovation, and the innovation needs talents, and further promotes the enterprise to increase the participation of R&D personnel. Through the enhancement

Table 14
Analysis of financing mechanism.

Variable	(1) Loan	(2) IR	(3) SA	(4) FC
Treat × Post	0.099**	−0.060**	−0.018***	−0.009***
	(2.01)	(−2.43)	(−6.51)	(−3.49)
Control variable	Y	Y	Y	Y
Time fixed effect	Y	Y	Y	Y
Industry fixed effect	Y	Y	Y	Y
N	17,327	3260	17,327	14,663
Adj − R^2	0.0469	0.1252	0.6435	0.7417

Table 15
Analysis of R&D and innovation mechanism.

Variable	(1) RdssR	(2) RdpR	(3) Digi-Pat
Treat × Post	0.309***	0.846***	0.093***
	(3.57)	(3.15)	(2.85)
Control variable	Y	Y	Y
Time fixed effect	Y	Y	Y
Industry fixed effect	Y	Y	Y
N	11,330	7443	4933
Adj − R^2	0.3682	0.4420	0.3108

of the R&D and innovation ability of enterprises, the pursuit of advanced digital technology is also stronger, which makes the degree of DT of enterprises is higher.

7. Conclusion and policy implications

7.1. Research conclusions

The significance of this study lies in revealing how external policies effectively support and enhance the sustainability of enterprises during their digital transformation process.

On one hand, the creation of national SEZs not only provides a solid foundation for enterprises' DT but is also crucial for achieving sustainable development and long-term competitive advantages. Furthermore, SEZs offer a range of preferential policies, human resource training, and financial and technical support, effectively assisting enterprises in overcoming the various challenges encountered during the transformation process, thereby ensuring their sustainable operations and development in the fiercely competitive market.

On the other hand, SEZs inject robust momentum into enterprises' internal DT by optimizing resource allocation, reducing development costs, expanding financing channels, enhancing independent research and development capabilities, and stimulating innovation vitality. These positive effects not only accelerate the pace of enterprises' DT but also further underscore the irreplaceable role of national SEZs in promoting domestic enterprises' DT and sustainable development.

7.2. Policy implications

As the digital economy increasingly emerges as the core driver of global economic growth, industrial policies play a pivotal role in facilitating enterprises' DT. The findings of this study indicate that resolute governmental support and targeted policies are not only crucial for the digital transformation within SEZs but also profoundly impact the sustainability of business operations and the long-term sustainability of business development. Governments should actively promote in-depth research on DT, exploring how new technologies drive this transformation and foster sustainable technological advancements. Simultaneously, they must establish comprehensive data protection and privacy regulations to ensure the sustainability of information security. Through these initiatives, governments can better understand potential barriers and provide tailored solutions. These policies help create an environment within SEZs that is conducive to enterprises undergoing digital transformation efficiently and sustainably. In summary, proactive governmental support coupled with targeted policies is indispensable for advancing the digital transformation process within SEZs and achieving sustainable development goals. Governments should significantly strengthen the support system by promoting technology adoption initiatives, investing in necessary infrastructure, encouraging collaboration, and actively addressing challenges, enabling enterprises to maintain a thriving posture in the midst of ongoing digital changes and achieve sustainable business growth.

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CRediT authorship contribution statement

Zeyang Bian: Writing – review & editing, Validation, Supervision, Project administration, Funding acquisition, Conceptualization. **Ning Wang:** Writing – original draft, Visualization, Software, Resources, Methodology, Investigation, Formal analysis, Data curation.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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