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The potential of blockchain technology in advancing sustainable energy: a study on the mediating role of specialization in the growth of Chinese hidden champions

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Innovation is a crucial factor for hidden champions to gain a competitive edge and foster organizational growth. This study focuses on Chinese-listed hidden champion firms between 2010 and 2019 and examines the impact of innovation heterogeneity on their growth. The study explores the impact of different types of innovation, including overall innovation, product innovation, and process innovation, and their interaction effects on the growth of hidden champions. The study also investigates the mediating role of the degree of specialization, which refers to the extent to which a firm focuses on a particular area of expertise. Furthermore, the potential of blockchain technology in advancing a sustainable energy future is becoming increasingly apparent. By enabling the creation of decentralized energy markets, blockchain can facilitate the integration of renewable energy sources, such as solar and wind power, into the grid. This can help to reduce carbon emissions and promote the transition to a low-carbon economy. The results of the study indicate that innovation, including overall innovation, product innovation, and process innovation, is significant for hidden champions' growth. Moreover, the study reveals that product innovation and process innovation have complementary effects on the growth of hidden champions. The degree of specialization also plays a mediating role between different types of innovation and hidden champions' growth. The results of this study provide empirical evidence to improve the growth of hidden champions from the perspective of enterprise innovation. By focusing on different types of innovation and understanding their complementary effects, firms can develop a more comprehensive innovation strategy that can enhance their growth potential. Moreover, the mediating role of degree of specialization highlights the importance of aligning innovation efforts with a firm's core competencies to achieve sustained growth. This study contributes to the literature on hidden champions by shedding light on their innovation strategies and their impact on firm growth.

KEYWORDS

hidden champions, innovation heterogeneity, enterprise growth, small and medium-sized enterprises, blockchain technology

1 Introduction

Blockchain technology has emerged as a transformative force across various industries, and its potential to revolutionize the sustainable energy sector is gaining significant attention. This study aims to explore the role of blockchain technology in advancing a sustainable energy future, specifically focusing on the mediating role of specialization in the growth of Chinese hidden champion firms (Dickinson, 2011; Din et al., 2013; Ali et al., 2014; Bao, 2016). Blockchain technology offers a decentralized and transparent platform that can enhance the efficiency, reliability, and security of energy systems. By leveraging smart contracts and distributed ledger technology, blockchain can facilitate peer-to-peer energy trading, enable the integration of renewable energy sources, and promote energy efficiency. These capabilities hold immense promise for achieving a sustainable energy future by reducing carbon emissions, increasing renewable energy adoption, and empowering energy consumers (Dundas and Richardson, 1982; Fontana and Nesta, 2009). Hidden champions are small and medium-sized enterprises (SMEs) with limited brand awareness but strong international market share and segment leadership (Henard and Szymanski, 2001; Hayton et al., 2002; Han et al., 2017). In recent years, China's economy has maintained a high level of sustainable development, and some rising hidden champions in China focusing on market segmentation have played a very important supporting role (Kunst and Marin, 1989; Hitt et al., 2000; Hsieh and Lin, 2016). These hidden champions have shown high vitality and have become the backbone of China's efforts to enhance the competitiveness of the global industrial chain and promote the modernization of the industrial chain. However, in order for China's economic transformation and upgrade to enter the phase of high-quality development, it is crucial to address the shortage of hidden champions in high-tech fields such as key basic materials, advanced basic processes, and industrial technology foundations (Lin and Tan, 1999; Li and Li, 2008; Lambertini and Mantovani, 2009; Lei and Wu, 2020; Ning et al., 2023). Moreover, the potential of blockchain technology in advancing a sustainable energy future is becoming increasingly apparent. By enabling the creation of decentralized energy markets, blockchain can facilitate the integration of renewable energy sources, such as solar and wind power, into the grid (Lin and Tan, 1999; Li and Li, 2008; Lei and Wu, 2020; Ning et al., 2023). This can help to reduce carbon emissions and promote the transition to a low-carbon economy. As a result, the growth of hidden champions in the sustainable energy sector is of particular importance for achieving China's economic development goals. This study focuses on Chinese-listed hidden champion firms between 2010 and 2019 and examines the impact of innovation heterogeneity on their growth. The study explores the impact of different types of innovation, including overall innovation, product innovation, and process innovation, and their interaction effects on the growth of hidden champions (Hamel and Prahalad, 1990; Foss, 1999; Nieto and Santamaría, 2007; Schumpeter, 2009; Mao and Xu, 2016; AlQershi et al., 2023; Zhang C. et al., 2023). The study also investigates the mediating role of the degree of specialization, which refers to the extent to which a firm focuses on a particular area of expertise. The results of this study provide empirical evidence to improve the growth of hidden champions from the perspective of enterprise innovation, with a particular focus on the potential of blockchain technology in advancing a sustainable energy future. Hidden champions are SMEs with limited brand awareness but strong international market share and segment leadership (Simon, 2009; Shen et al., 2020; Song et al., 2022). In recent years, China's economy has maintained a high level of sustainable development, and some rising hidden champions in China focusing on market segmentation have played a very important supporting role. These hidden champions have shown high vitality and have become the backbone of China's efforts to enhance the competitiveness of the global industrial chain and promote the modernization of the industrial chain. Even though Chinese hidden champions have achieved prominent development results, there remain numerous serious challenges, which is reflected in the shortage of several hidden champions, particularly in high-tech fields such as key basic materials, advanced basic processes, and industrial technology foundations. The growth of hidden champions can no longer meet China's economic transformation and upgrade requirements in order for the country to enter the phase of high-quality development (Voudouris et al., 2000; Zahra et al., 2005; Yu et al., 2015; Zeng and Yuan, 2016; Ahmadi Choukolaei et al., 2021; Mathiyazhagan et al., 2022; Goodarzian et al., 2023a).

Innovation is an important factor in promoting the growth of hidden champions. Product innovation can extend the value chain and production chain of hidden champions, enhance the added value of products, strengthen the barriers to entry, and help enterprises become industry leaders (Babaeinesami and Ghasemi, 2021; Goodarzian et al., 2021; Goodarzian et al., 2023b; Momenitabar et al., 2023). Process innovation can improve the efficiency of internal resource utilization, reduce costs, form a good innovation atmosphere, and continue the leadership position of hidden champions. Both product innovation and process innovation play an important role in the growth of hidden champions. The theory of business growth views internal variables as the source of growth and competitive advantage and highlights the impact of innovation on the growth of hidden champions. The resource-based theory states that valuable, scarce, and hard-to-replicate resources can bring sustainable competitive advantage to enterprises, and technology, with its specialization and competitive barriers, is a unique resource that drives the sustainable growth of hidden champions. However, due to the difficulties in data acquisition, empirical studies on innovation and the growth of hidden champions in the Chinese context are still scarce (Ahmadi and Ghasemi, 2022; Arabian et al., 2022; Barenji and Nejad, 2022; Goodarzian et al., 2023c). Therefore, our study aims to explore the relationship between innovation heterogeneity and the growth of hidden champions in China. To be specific, this paper empirically examines the impact of different types of innovation (including product innovation and process innovation) and their interaction effects on the growth of hidden champions. Findings are based on 150 Chinese-listed hidden champions, including 1,448 observations from 2010 to 2019. This paper aims to provide sufficient empirical evidence for the growth of hidden champions from the perspective of enterprise internal innovation (Ghadiri Nejad et al., 2018; Ghasemi et al., 2022; Golabi and Nejad, 2022). Firstly, it examines the impact of innovation heterogeneity on the growth of hidden champions, thereby expanding the existing body of literature on growth factors for hidden champions that primarily

focuses on core competence theory and innovation development theory. Secondly, it investigates how innovation heterogeneity influences the growth of hidden champions across different enterprise natures and enterprise life cycle scenarios, leveraging the benchmark regression results. The empirical findings offer valuable insights for hidden champions in formulating customized innovation development strategies and for policymakers in designing relevant public policies. Lastly, the study explores the mediating role of the degree of specialization in the relationship between innovation heterogeneity and the growth of Chinese hidden champions, elucidating the mechanism through which innovation heterogeneity impacts their growth. This article provides recommendations for enterprise growth based on the findings of a study. The paper is structured as follows: The first section provides a review of the relevant literature and presents the research hypotheses. The methodology section describes the empirical approach, including details on the sample, data sources, econometric model, and variable measurement. The analysis and results section presents a summary of the empirical findings. The discussion and conclusion section offers a comprehensive analysis of the key research findings, highlighting the theoretical contributions and practical implications. Additionally, limitations of the study are discussed, and potential directions for future research are suggested.

1.1 Innovation heterogeneity and hidden champions' growth

The innovation process can bring a new combination of factors to businesses, break the quantitative growth path of enterprises relying on thin margins, and help enterprises achieve growth through technological progress. Technology is a distinctive resource for sustainable growth because of its specialization and its obstacles to competition, according to the preservation of resources theory's concept of the value of the business. The core competence theory, which is developed on this premise, holds that core competence, which is valuable, scarce, irreplaceable, and difficult to imitate, determines the growth of an enterprise, and that enterprises rely on core competence to continuously develop markets, develop new products, and improve the quality of services in order to solve various business activities more efficiently than their competitors (Cao et al., 2020; Li et al., 2020; Ghadirinejad et al., 2021; Ghasemi et al., 2021; Yan et al., 2021; Ibeanu et al., 2023). They are capable of solving a variety of business issues more efficiently than their competitors and gaining competitive advantages for sustainable development. According to the notion of enterprise core competencies, core competencies such as technology and knowledge are the primary source of power for business growth and the most influential factor in enterprise growth. Din et al. (2013) have researched hidden champion firms in Germany, Sweden, and the United Kingdom and found that these firms generally prioritize innovation. In particular, hidden champions are typically anchored in niche markets that are disregarded by large enterprises and use a resource-focused strategy to concentrate their limited resources on in-depth R&D and deep processing of products to accomplish deep value creation. In-depth and sustained innovation in a field enables the enterprise to reserve significant capabilities in the sector and generate products that are highly specialized and cannot be replaced by other products in the same field, hence accelerating the enterprise's market dominance. Consequently, hidden champions acquire advanced core technology in their respective market segment through R&D innovation, subsequently forming a leading brand effect and gaining market share (Gao et al., 2020; Wang et al., 2021; Yan et al., 2021; Chen, 2022; Zhang J. et al., 2023; Chen et al., 2023; Yin and Song, 2023). Building upon the literature review, we now analyze the state of the art in the field. Despite the considerable progress made in understanding the relationship between innovation, specialization, and firm growth, several key knowledge gaps remain unaddressed. Specifically, the existing literature lacks a comprehensive examination of the impact of innovation heterogeneity, different types of innovation (product and process), and the degree of specialization on the growth of hidden champion firms. This knowledge gap presents an opportunity for our research to contribute to the field. Our paper aims to fill the identified knowledge gaps and make several novel contributions to the existing literature. Firstly, we propose an econometric model that allows for the quantification and analysis of the relationships between innovation heterogeneity, types of innovation, specialization, and firm growth among hidden champions. This methodological approach is novel in the context of hidden champion research and provides a robust framework for examining these relationships. This study seeks to make a valuable contribution to the existing literature by examining the correlation between innovation heterogeneity (covering overall, product, and process innovation) and the growth of Chinese hidden champions, an area that has been underexplored in previous research (Voudouris et al., 2000; Zahra et al., 2005; Simon, 2009; Yu et al., 2015; Zeng and Yuan, 2016; Shen et al., 2020; Song et al., 2022). Additionally, the study investigates the previously unexplored mediating role of specialization degree. Furthermore, the research focuses on the emerging field of blockchain technology and its potential to advance sustainable energy initiatives. The study aims to achieve several objectives, including analyzing the impact of different types of innovation and their combined effects on the growth of hidden champions, exploring how innovation influences growth across various firm characteristics and stages of the business lifecycle, examining the mediating role of specialization degree in the relationship between innovation and growth, providing empirical evidence to guide innovation strategies for hidden champions and inform policymaking to support their sustainable growth, and offering fresh insights into innovation strategies and the growth of hidden champions from a Chinese perspective. In summary, this study aims to empirically investigate the interplay between innovation heterogeneity, specialization, and the growth of hidden champions, with a particular emphasis on the potential of blockchain technology to facilitate the adoption of renewable energy solutions.

Hypothesis 1. Innovation has a significant positive effect on hidden champions' growth.

1.2 Product innovation and hidden champions' growth

Product innovation refers to the introduction of a consumer-unfamiliar product or the upgrading of an existing product with the ultimate goal of enhancing product differentiation. Product innovation is the linchpin of hidden champions' innovation capability, and retaining technological superiority is a crucial

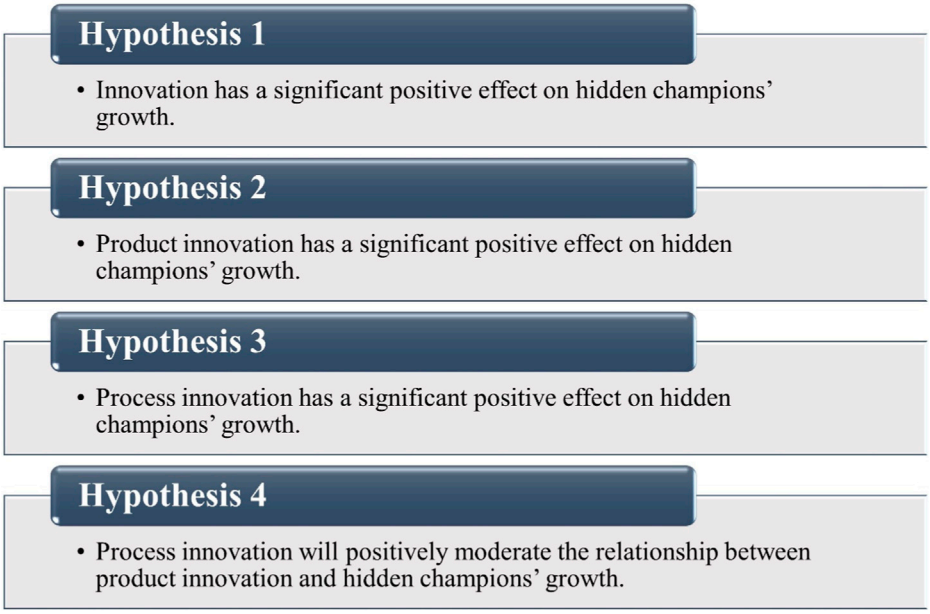

FIGURE 1
The four hypotheses on the relationship between innovation and hidden champions' growth in China.

condition for hidden champions to maintain a dominant position. Product innovation can successfully mitigate the challenges of insufficient resources, expertise, and capabilities during the establishment phase and improve the environment for the survival and rapid growth of hidden champions. In addition, product innovation can help hidden champions gain a dominant position and expand their market share by establishing specific technical standards within the sector. Moreover, product innovation can vertically extend the product and value chains of hidden champions and strengthen their specialization capabilities (Hayton et al., 2002; Zahra et al., 2005). These skills distinguish their products from those of competitors and boost their products' added value. These characteristics distinguish their products from those of competitors, increase their products' added value, and foster the growth of hidden champions. As such, the following hypothesis is proposed.

Hypothesis 2. Product innovation has a significant positive effect on hidden champions' growth.

Our study aims to bridge these research gaps and make several contributions to the existing literature. Firstly, we propose a comprehensive framework that considers the combined effects of innovation heterogeneity and specialization on the growth of hidden champion firms.

1.3 Process innovation and hidden champions' growth

Process innovation refers to the development of a new production process, including new processes, new equipment, and new organizational and managerial structures, which is represented in the continual improvement of existing technologies (Lin and Tan, 1999; Li and Li, 2008; Lambertini and Mantovani, 2009; Lei and Wu, 2020). Hidden champions reorganize and leverage internal resources to bring internal innovations to market and generate commercial value, which facilitates the quick commercialization of innovations. Moreover, process innovation fosters an inventive organizational environment that supports creativity and tolerates failure, which is beneficial for mobilizing the enthusiasm and initiative of R&D personnel and encouraging enterprise growth.

Figure 1 illustrates a graphical depiction of the four hypotheses that put forth various associations between innovation and the growth of hidden champions in China. This conceptual framework acts as a valuable tool for comprehending the potential dynamics within this context, providing a visual guide for researchers and readers to navigate the different theoretical perspectives and hypotheses proposed in the study.

The following hypothesis is thus proposed.

Hypothesis 3. Process innovation has a significant positive effect on hidden champions' growth.

Furthermore, process innovation can accelerate the flow of information and knowledge exchange within hidden champions, which is conducive to the improvement of enterprises' overall innovation efficiency and aids hidden champions in accumulating technical knowledge for product innovation (Hitt et al., 2000). In other words, process innovation can broaden the technological foundation of hidden champions, thereby enhancing existing technological capabilities and facilitating the creation of new goods. Continuous process innovation can raise the level of product innovation and technological heterogeneity, resulting in the manufacture of new goods with distinctive value or considerable advances, particularly for hidden champions in leadership positions (Kunst and Marin, 1989; Lin and Tan, 1999; Li and Li, 2008;

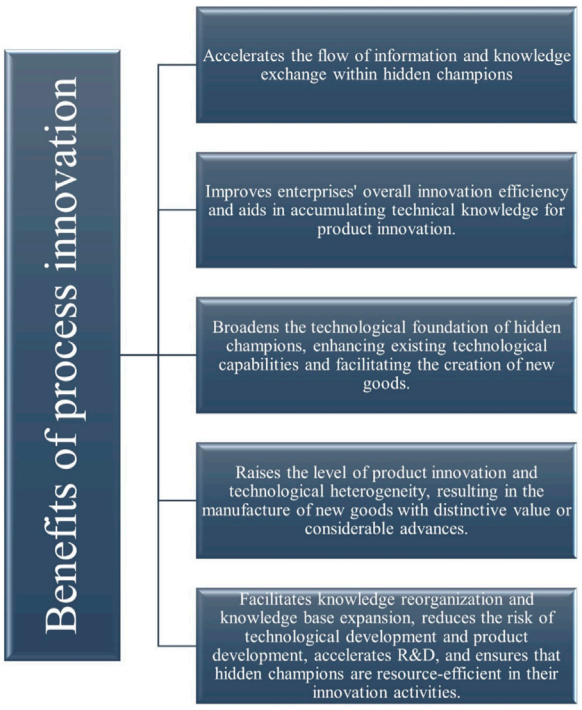

FIGURE 2
Benefits of process innovation.

Lambertini and Mantovani, 2009; Hsieh and Lin, 2016; Lei and Wu, 2020; Zhang C. et al., 2023; Ning et al., 2023). In addition, process innovation can facilitate the hidden champions' knowledge reorganization and knowledge base expansion, reduce the risk of technological development and product development, accelerate R&D, and ensure that the hidden champions are resource-efficient in their innovation activities. This would ensure that hidden champions are able to carry out innovation activities efficiently with little resources, thereby supporting their growth. Accordingly, the following hypothesis is proposed.

Hypothesis 4. Process innovation will positively moderate the relationship between product innovation and hidden champions' growth.

Figure 2 shows a comprehensive overview of the benefits derived from process innovation. It highlights the multifaceted advantages organizations can gain, including operational efficiency, improved quality control, enhanced flexibility, a culture of innovation, and environmental sustainability. By visually representing these benefits, Figure 2 shows a clear and concise understanding of the positive impacts that process innovation can have on organizations across various sectors and industries. The benefits showcased in Figure 2 encompass a range of positive outcomes that organizations can expect to achieve through process innovation. Firstly, process innovation can enhance operational efficiency, leading to cost reductions and improved resource utilization. By streamlining workflows, eliminating bottlenecks, and implementing more effective and efficient processes, organizations can optimize their operations, minimize waste, and achieve higher productivity levels.

1.4 The mediation role of degree of specialization

Hidden champions are rooted in niche markets with high growth potential and the ability to rapidly take a leadership position that cannot be readily duplicated or replaced by other businesses. Hidden champions opt to specialize and concentrate their limited resources on the areas they value the most, producing profound value creation through "focus" and establishing market leadership. By implementing innovation activities such as product innovation and process innovation, hidden champions continuously improve their specialization, increase the depth of their R&D and processing, and establish a distinct competitive advantage. This is one of the pillar strategies for the continuous growth of hidden champions. This research proposes that the level of specialization influences the relationship between innovation heterogeneity and the growth of hidden champions. First, innovation is the source of growth for hidden champions in terms of overall innovation, and hidden champions establish their core technology leadership in the industry through continuous innovation, enhance their specialization, and then grow rapidly to become market segment leaders (Hayton et al., 2002; Fontana and Nesta, 2009; Han et al., 2017). Second, specific to the different types of innovation, product innovation is reflected in the creation of new products and the upgrading and iteration of existing products, and the in-depth and persistent exploration of a field makes the products produced by enterprises unique and incomparable to other products in the same field, which deepens the specialization of hidden champions and enables them to compete more effectively. This enhances the specialization of hidden champions and enables them to achieve a larger proportion of the international market and better international competitive advantages. Process innovation is reflected in the continuous improvement and refinement of the production process and technology, which increases the technological level and the added value of the products, making the products produced by the enterprises more adaptable to the needs of the niche market and more irreplaceable, thereby contributing to the improvement of the degree of specialization of the hidden champions and the further enhancement of their production efficiency (Kunst and Marin, 1989; Lin and Tan, 1999; Li and Li, 2008; Lambertini and Mantovani, 2009; Lei and Wu, 2020; Ning et al., 2023), which is crucial to the creation of hidden champions. In conclusion, innovation activities (including product innovation and process innovation) can extend the product and value chains vertically, and increase the specialization and growth of hidden champions. Therefore, the following hypotheses are proposed.

Hypothesis 5a. the degree of specialization mediates the relation between innovation and hidden champions' growth.

Hypothesis 5b. the degree of specialization mediates the relation between product innovation and hidden champions' growth.

Hypothesis 5c. the degree of specialization mediates the relation between process innovation and hidden champions' growth.

2 Research methodology

2.1 Sample and data sources

For this study, we focused on identifying hidden champions among publicly listed companies on the Shanghai and Shenzhen stock markets. To gather a comprehensive and systematic dataset, we utilized various sources, including the Ministry of Industry and Information Technology of China, the China Federation of Industrial Economics, Investor's Business Daily's list of hidden champions, and other industry research reports. We selected hidden champion firms listed in China between 2010 and 2019 as our initial sample. To ensure data accuracy and integrity, we set the starting year as 2010, considering that some of the selected hidden champions were listed in that year. Data on innovation were obtained from the Chinese Innovation Research Database (CIRD) on the Chinese Research Data Services (CNRDS), while the remaining economic data were sourced from the CSMAR and Wind databases. To assure the validity of the empirical findings, the initial sample is screened in the following manner: (1) removing ST and *ST companies; (2) excluding enterprises with missing innovation data and important variables; and (3) avoiding the influence of outliers by tailing (winsorize) continuous variables at the 1% and 99% quartiles. Our final sample consisted of 150 hidden champions and 1,448 observations across 10 years of panel data (2010–2019).

2.2 Econometric model construction

In order to test the impact of innovation on the growth of hidden champions, the following regression model was constructed.

$$Growth = \beta_0 + \beta_1 L.Innova + \beta Controls + \vartheta_j + \vartheta_t + \varepsilon \quad (1)$$

In this model, *Growth* is the explanatory variable for the growth of hidden champions. *Innova* represents the overall innovation level of hidden champions. β_1 is the estimated coefficient of overall innovation, if it is positive, it means that the overall innovation at the end of the previous period positively affects the growth of hidden champions between the two periods. *Controls* represent enterprise-level control variables. The controls include enterprise productivity (Lntfp), enterprise size (Size), enterprise age (Age), the second power of enterprise age (Age*Age), capital intensity (Capital), employee wages (Wage), *etc.*, υ_j and υ_t denote industry and time fixed effects, respectively. ε is the residual term.

The following regression model was constructed to test the impact of different innovation types and their interactions on the growth of hidden champions.

$$Growth = \beta_0 + \beta_1 L.Um + \beta_2 L.Pt + \beta_3 L.Um^{*} L.Pt + \beta Controls + \vartheta_j + \vartheta_t + \varepsilon \quad (2)$$

In this model, *Growth* is the explanatory variable for the growth of hidden champions. *Um* represents the process innovation of hidden champions, *Pt* represents the product innovation of hidden champions and is the explanatory variable. *Um*Pt* represents the interaction effect between product innovation and process innovation, and β_3 represents the coefficient of the interaction effect.

If it is positive, it indicates that process innovation positively regulates the relationship between product innovation and the growth of hidden champions, and *vice versa*, it is negative. In light of the fact that the impact of innovation on enterprise growth has a certain lag, this article treats total innovation and various forms of innovation with a lag, partially resolving the reverse causality issue.

2.3 Variable measurement

2.3.1 Dependent variable hidden champions' growth

Growth reflects the characteristics of an enterprise's current economic behavior or business activities that make it potentially more valuable in the future and is characterized by continuity, dynamism, and profitability. Therefore, based on the theory of enterprise growth and taking into account the characteristics of hidden champions, nine indicators are selected, including return on assets, net profit margin of total assets, return on net assets, cost profit margin, current ratio, quick ratio, gearing ratio, asset growth rate, and total asset growth rate, and the principal component analysis and mutation level method are applied to measure the growth rate of hidden champions. To measure the growth of hidden champions, we use principal component analysis and the mutation level method.

2.3.2 Independent variables innovation of hidden champions (Innova)

The number of patents is both the main form of enterprise innovation results and an intuitive indicator of enterprise innovation ability. Given that the number of granted patents is affected by various factors such as approval time and the government-enterprise relationship, this paper selects the number of patent applications as a proxy variable for enterprise innovation.

2.3.3 Process innovation (Um) and technological innovation (Pt)

Enterprise innovation can be categorized into two distinct types: process innovation and product innovation. Process innovation involves leveraging past experience to enhance existing products or technologies, often through utility model patents and design patents. On the other hand, product innovation focuses on developing new products or processes with significant novel functionalities through research and development (R&D) activities, typically resulting in invention patents. The number of patents serves as a primary measure of an enterprise's innovation accomplishments and provides an intuitive indicator of its innovation capabilities. However, it's important to note that the number of patents granted can be influenced by various factors, including approval timelines and government-enterprise relationships. To address these complexities, this article employs the number of invention patent applications as a proxy variable for product innovation, while the number of utility model and design patent applications serves as a proxy variable for process innovation.

2.3.4 Mediating variable degree of specialization (Divhhi)

Highly specialized is an important feature of hidden champions. Focusing on the niche market enables hidden champions to reserve far more resources and capabilities in this field than their competitors, thus promoting the growth of hidden champions. According to previous research, this paper used the Divhhi to measure the degree of specialization of hidden champions. The Divhhi can be calculated as follows:

$$Divhhi = \sum_{i=1}^{n} w_i^2$$

where w_i is the proportion of the category i main business revenue in the total business revenue of the hidden champion firm, with a higher value representing a greater degree of specialization of the hidden champion.

2.3.5 Control variables

Drawing on previous research, we selected enterprise productivity, enterprise size, enterprise age, capital intensity, and employee wage as control variables.

Productivity (Lntfp) The higher the productivity of an enterprise, the stronger its growth capability. Here, the LP method is used to calculate firm productivity.

Size (Size) The size of the enterprise in the previous period often has an impact on the growth of the enterprise in the subsequent period, the larger the size of the enterprise, the lower the subsequent growth. Use enterprise sales revenue as a measure of firm size.

Age (Age) and the square of age (Age*Age) Generally, with the growth of age, hidden champions' growth will show a decreasing trend, which is reflected in the primary term coefficient of the enterprise age in the empirical process; meanwhile, if there is a U-shaped or inverted U-shaped relationship between hidden champions' growth rate and the enterprise age, it will be reflected in the secondary term coefficient of enterprise age in the empirical results. Age is calculated by adding 1 to the logarithm of the number of years of establishment.

Capital intensity (Capital) The higher the capital intensity of the enterprise, the more external resources the enterprise can obtain, which helps to expand production. The ratio of the net value of fixed assets to the number of employees is used to measure the capital intensity of the enterprise.

Employee Wage (Wage) Generally speaking, the higher the wages of employees, the faster the growth of the enterprise. The ratio of wages payable to the number of employees is used to measure this. Table 1 shows the definition and measurement of variables.

2.4 Analysis and results

2.4.1 Correlation analysis

Table 2 reports the descriptive statistics and correlation coefficients of each variable. There is no significant multicollinearity problem because the correlation coefficients between the independent variables and the dependent variable are smaller than the critical criterion of 0.7. In addition, we adopted the variance inflation factor (VIF) to test for multicollinearity, and the results showed that the VIF values of all control variables and independent variables ranged from 1 to 5, indicating that multicollinearity was not an issue in this study. The mean value of firm growth is 0.870, indicating that the overall growth effect of China's hidden champions is not satisfactory. The mean value of overall innovation, process innovation, and product innovation is between 1 and 2, which indicates that there is still a lot of room for improvement in the innovation level of China's hidden champions. There are positive correlations between different types of innovation and the degree of specialization, and there is a positive correlation between the degree of specialization and firm growth, which provides preliminary evidence for the research hypothesis validation and further causality identification.

2.4.2 Regression results

The full-sample regression estimation was performed based on the baseline model of Eqs 1, 2. The model contains the interaction term between process innovation and product innovation, and the relevant variables are centralized in the research. The results of the full-sample benchmark regression analysis are shown in Table 3. Model 1 tests the effect of overall innovation on the growth of hidden champions. Models 2 and 3 test the effects of process innovation and product innovation on the growth of hidden champions, respectively. Model 4 regresses process innovation and product innovation simultaneously to test the effect of both on the growth of hidden champions. Model 5 regresses the effect of both process innovation and product innovation on the growth of hidden champions, adding the interaction term of product innovation and process innovation to Model 4 to test the interaction effect of both on the growth of hidden champions.

Model 1. shows that innovation ($\beta = 0.037$, $p < 0.01$) significantly and positively affects the growth of hidden champions, indicating that, basised on controlling other influencing factors, innovation has a positive impact on hidden champions' growth. In other words, innovation helps hidden champions grow. Therefore, Hypothesis 1 is confirmed.

Model 2. shows that process innovation ($\beta = 0.029$, $p < 0.05$) significantly and positively affects the growth of hidden champions, indicating that process innovation has a positive impact on hidden champions' growth after controlling for other influencing factors. Hence, the empirical result supports Hypothesis 2.

Model 3. shows that product innovation ($\beta = 0.047$, $p < 0.01$) significantly and positively affects the growth of hidden champions, indicating that product innovation has a positive impact on hidden champions' growth after controlling for other influencing factors. Hence, the empirical result supports Hypothesis 3.

In Model 4, we add the product innovation variable on the basis of Model 2. When the two variables are regressed simultaneously, product innovation still plays a significant role in promoting hidden champions' growth ($\beta = 0.046$, $p < 0.05$), whereas the effect of process innovation on hidden champions' growth is no longer significant ($\beta = 0.003$, $p > 0.1$).

We include the interaction of product innovation and process innovation in Model 5. The regression results show that there is no

TABLE 1 Definition and measurement of variables.

Type	Name	Symbol	Definition
Dependent variable	Enterprise growth	Growth	Calculated by principal component analysis
Independent variables	Innovation	Innova	The number of patent applications plus one is taken as a logarithm
	Process innovation	Um	Number of invention patent applications plus 1 to take the logarithm
	Product innovation	Pt	The number of utility model and design patent applications plus one is taken as a logarithm
Mediating variable	Degree of specialization	Divhhi	The proportion of the main business revenue in the firm's total business revenue
Control variables	Enterprise productivity	Lntfp	LP Method Calculation
	Enterprise size	Size	The number of employees in a company is taken as a logarithm
	Enterprise age	Age	The number of years of enterprise establishment plus 1 and then take the logarithm
	Square of enterprise age	Age*Age	
	Capital intensity	Capital	Net value of fixed assets of the enterprise divided by the number of employees
	Employee wages	Wage	Enterprise payroll payable divided by the number of employees

TABLE 2 Descriptive statistics and correlations.

Variables	1	2	3	4	5	6	7	8	9	10
1.Growth	1									
2.Innova	−0.077***	1								
3.Um	−0.094***	0.882***	1							
4.Pt	−0.057**	0.838***	0.564***	1						
5.Divhhi	0.104***	0.075**	0.076**	0.092***	1					
6.Lntfp	−0.344***	0.082***	0.053*	0.108***	−0.067**	1				
7.Age	0.394***	0.036	0.031	0.070**	−0.124***	0.328***	1			
8.Size	−0.422***	0.150***	0.119***	0.165***	−0.064**	0.958***	0.432***	1		
9.Capital	0.367***	−0.092***	−0.085***	−0.045	−0.038	−0.539***	−0.050*	−0.509***	1	
10.Wage	−0.112***	0.017	−0.052*	0.142***	−0.046	0.241***	0.526***	0.282***	0.070***	1
Mean	0.870	1.875	1.349	1.232	0.793	3.371	2.707	20.838	2.421	11.387
SD	0.060	1.480	1.386	1.225	0.239	0.556	0.312	0.988	1.355	0.460

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

significant change in the coefficient and significance level of product innovation on hidden champions' growth ($\beta = 0.058$, $p < 0.05$), and the effect of process innovation on hidden champions' growth is insignificant ($\beta = -0.020$, $p > 0.1$). Furthermore, the interaction of product innovation and process innovation has a significant and positive effect on the growth of hidden champions ($\beta = 0.034$, $p < 0.05$). Considering the interaction term in the regression increases the effect of product innovation on hidden champions' growth, which indicates that process innovation positively moderates the relationship between product innovation and hidden champions' growth, thus the two types of innovation have an interaction effect on the growth of hidden champions. From the perspective of control variables, enterprise's productivity, capital intensity, and employee wages present significant positive impacts on hidden champions' growth, indicating that the higher the enterprise productivity, capital intensity, and employee wages, the higher the growth of hidden champions. The higher the enterprise productivity, capital intensity, and employee wages, the higher the growth of hidden champions. Enterprise age has a significant negative influence on the growth of hidden champions, and the square of enterprise age has a significant positive influence on the growth of hidden champions, indicating that the relationship between enterprise age and the growth of hidden champions is U-shaped. With the growing age of enterprises, the growth of hidden champions first declines and then rises. The significant negative correlation between enterprise size and the growth of hidden champions shows that the expansion of enterprise size is not conducive to the growth of hidden champions. Therefore, the growth of hidden champions should pay more attention to the improvement of quality, such as productivity, rather than blindly pursuing scale expansion.

TABLE 3 Baseline regression results.

Variables	Growth				
	Model 1	Model 2	Model 3	Model 4	Model 5
L.Innova	0.037***				
	(2.83)				
Um_{t-1}		0.029**		0.003	−0.020
		(2.23)		(0.16)	(−1.07)
Pt_{t-1}			0.047***	0.046**	0.058**
			(3.00)	(2.10)	(2.48)
Um_{t-1} * Pt_{t-1}					0.034**
					(1.99)
Lntfp	0.208***	0.193***	0.201***	0.203***	0.154**
	(3.55)	(3.24)	(3.51)	(3.44)	(2.50)
Age	−2.980***	−2.978***	−2.969***	−2.971***	−2.873***
	(−7.34)	(−7.33)	(−7.33)	(−7.31)	(−7.02)
Age*Age	0.754***	0.749***	0.749***	0.749***	0.719***
	(6.75)	(6.71)	(6.73)	(6.71)	(6.40)
Size	−0.251***	−0.241***	−0.250***	−0.251***	−0.223***
	(−7.47)	(−7.13)	(−7.59)	(−7.45)	(−6.48)
Capital	0.220***	0.219***	0.217***	0.217***	0.215***
	(6.97)	(6.91)	(6.91)	(6.84)	(6.81)
Wage	0.195***	0.199***	0.179***	0.181***	0.071**
	(3.85)	(3.89)	(3.51)	(3.42)	(2.15)
Constant	4.330***	4.158***	4.532***	4.531***	6.729***
	(4.57)	(4.42)	(4.70)	(4.69)	(8.29)
OwnshipD	Yes	Yes	Yes	Yes	Yes
IndustryD	Yes	Yes	Yes	Yes	Yes
YearD	Yes	Yes	Yes	Yes	Yes
N	1,338	1,338	1,338	1,338	1,338
Adj-R^2	0.439	0.438	0.440	0.439	0.437
F value	10.825***	10.672***	10.986***	10.812***	10.063***

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

2.4.3 Robustness test

2.4.3.1 Endogenous processing

In the above regressions, the independent variables are treated with a one-period lag to eliminate the estimation bias caused by reverse causality as much as possible. However, even so, endogeneity biases such as missing variables are still present in the empirical regressions. For this reason, the two-stage least squares (IV-2SLS) method is used to test the regression results. Following the approach of Song et al. (Song et al., 2022), two lags of overall innovation, process innovation, and product innovation are used as instrumental variables, because in principle, two lags of total innovation, process innovation, and product innovation do not have an impact on the growth of hidden champions in the current period. The results are shown in Table 4, and the results and significance of key variables are consistent with Table 3.

2.4.3.2 Replacement of independent variables

To test the robustness of the findings, we changed the measurement of the independent variables, and the total number of patents (L.Innova-A), process innovation (Um_{t-1} - A) and product innovation (Pt_{t-1} - A) granted were used as substitution variables for innovation. Table 3 was re-regressed on this basis, and the regression results are shown in Table 5. The

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TABLE 4 Regression results of endogeneity test.

Variables	Growth			
	2SLS1	2SLS2	2SLS3	2SLS4
L.Innova	0.035**			
	(2.04)			
Um_{t-1}		0.030*		−0.012
		(1.65)		(−0.40)
Pt_{t-1}			0.047**	0.062**
			(2.45)	(2.13)
Control	Yes	Yes	Yes	Yes
Constant	4.757***	4.381***	4.981***	4.650***
	(4.30)	(4.23)	(4.48)	(4.17)
OwnshipD	Yes	Yes	Yes	Yes
IndustryD	Yes	Yes	Yes	Yes
YearD	Yes	Yes	Yes	Yes
Kleibergen-Paap rk LM statistic	265.049 (0.00)	204.145 (0.00)	305.844 (0.00)	204.406 (0.00)
Kleibergen-Paap rk	913.780	721.822	1,244.457	191.900
Wald F statistic	{16.38}	{16.38}	{16.38}	{7.03}
N	1,188	1,188	1,188	1,188
Centered R2	0.405	0.402	0.406	0.407
Uncentered R2	0.420	0.417	0.421	0.422
Phase I Return				
IV1	0.708***	--	--	--
	(30.37)			--
IV2	--	0.673***	--	--
		(25.83)		--
IV3	--	--	0.752*** (35.50)	--
Control	Yes	Yes	Yes	--
Constant	−2.737*	−2.210*	−2.865**	--
	(−1.95)	(−1.71)	(−2.46)	--
OwnshipD	Yes	Yes	Yes	--
IndustryD	Yes	Yes	Yes	--
YearD	Yes	Yes	Yes	--
N	1,188	1,188	1,188	--
Adj-R^2	0.620	0.634	0.616	--
F value		10.453***	10.928***	

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$, values in parentheses are *p*-values. The {} values are the *Stock – Yogo* critical value at the 10% level of the weak identification test.

regression results are generally consistent with Table 4, indicating that the regression results presented in this paper are robust.

2.4.3.3 Replacement of dependent variable

Next, we changed the measurement of the dependent variable and chose Tobin Q as the substitution variable for the growth of

TABLE 5 Regression results for replacement of independent variables.

Variables	Growth				
	(1)	(2)	(3)	(4)	(5)
L.Innova-A	0.029**				
	(2.04)				
Um_{t-1} - A		0.029**		0.022	−0.003
		(2.03)		(1.45)	(−0.16)
Pt_{t-1} - A			0.051**	0.047**	0.047**
			(2.15)	(2.02)	(1.96)
Um_{t-1} - A* Pt_{t-1} - A					0.018**
					(2.45)
Lntfp	0.771***	0.194***	0.172***	0.144**	0.198***
	(5.76)	(3.24)	(3.00)	(2.31)	(3.31)
Age	−0.679***	−2.983***	−2.912***	−2.853***	−2.902***
	(−7.13)	(−7.33)	(−7.22)	(−6.93)	(−7.19)
Age*Age	−2.806***	0.750***	0.719***	0.710***	0.717***
	(-6.81)	(6.70)	(6.51)	(6.28)	(6.45)
Size	0.729***	−0.240***	−0.234***	−0.211***	−0.260***
	(6.44)	(−7.22)	(−7.16)	(−6.14)	(−7.42)
Capital	0.249***	0.219***	0.213***	0.217***	0.212***
	(7.56)	(6.91)	(6.71)	(6.66)	(6.74)
Wage	0.072**	0.198***	0.188***	0.058*	0.177***
	(2.26)	(3.87)	(3.63)	(1.79)	(3.42)
Constant	10.451***	4.154***	4.236***	6.413***	4.798***
	(8.97)	(4.41)	(4.36)	(8.09)	(4.73)
OwnshipD	Yes	Yes	Yes	Yes	Yes
IndustryD	Yes	Yes	Yes	Yes	Yes
YearD	Yes	Yes	Yes	Yes	Yes
N	1,338	1,338	1,338	1,338	1,338
Adj-R^2	0.448	0.438	0.438	0.434	0.440
F value	10.092***	10.711***	10.809***	9.843***	10.687***

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$, values in parentheses are *p*-values.

TABLE 6 Regression results for replacing the dependent variables.

Variables	Growth				
	(1)	(2)	(3)	(4)	(5)
L.Innova	0.081***				
	(3.93)				
Um_{t-1}		0.052**		−0.028	−0.046
		(2.41)		(−1.01)	(−1.58)
Pt_{t-1}			0.122***	0.139***	0.130***
			(4.53)	(4.04)	(3.78)
Um_{t-1} * Pt_{t-1}					0.060**
					(2.29)
Lntfp	0.465***	0.416**	0.459***	0.441**	0.410**
	(2.71)	(2.45)	(2.68)	(2.57)	(2.42)
Age	1.575***	1.578***	1.597***	1.611***	1.637***
	(4.72)	(4.72)	(4.78)	(4.79)	(4.92)
Age*Age	−0.270**	−0.282**	−0.279**	−0.285***	−0.304***
	(−2.48)	(−2.56)	(−2.57)	(−2.60)	(−2.82)
Size	−0.934***	−0.886***	−0.941***	−0.925***	−0.918***
	(−7.17)	(−6.82)	(−7.20)	(−7.06)	(−7.08)
Capital	−0.227***	−0.228***	−0.234***	−0.236***	−0.243***
	(−7.06)	(−7.10)	(−7.22)	(−7.28)	(−7.47)
Wage	0.212**	0.226***	0.175**	0.166**	0.144*
	(2.57)	(2.74)	(2.12)	(2.01)	(1.75)
Constant	14.763***	14.068***	15.403***	15.329***	15.753***
	(8.22)	(7.81)	(8.53)	(8.47)	(8.61)
OwnshipD	Yes	Yes	Yes	Yes	Yes
IndustryD	Yes	Yes	Yes	Yes	Yes
YearD	Yes	Yes	Yes	Yes	Yes
N	1,338	1,338	1,338	1,338	1,338
Adj-R^2	0.444	0.440	0.449	0.449	0.451
F value	18.101***	17.967***	18.272***	17.894***	17.543***

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$, values in parentheses are *p*-values.

hidden champions. The regression results are shown in Table 6, which are basically consistent with Table 3, indicating that the regression results are robust.

2.4.4 Heterogeneity analysis

The promoting effect of innovation on the growth of hidden champions may vary based on the nature of the enterprise, the concentration of the industry, and its life cycle. In this study, we examine the effects of various enterprise types (state-owned and non-state-owned), industry concentrations (high and low), and enterprise life cycles (start-up, growth, and maturity). The global energy landscape is currently experiencing a significant transformation due to the increasing demand for sustainable and renewable energy sources. Blockchain technology, known for its decentralized and transparent nature, has the ability to revolutionize the energy sector by introducing greater efficiency, transparency, and trust in energy transactions and operations. This study focuses on examining the role of blockchain technology in advancing a sustainable energy future, particularly in relation to Chinese hidden champions. Blockchain technology offers enhanced transparency and efficiency in energy transactions by providing a decentralized and immutable ledger of transactions. This transparency can

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TABLE 7 Heterogeneity of firm nature regression results.

Variables	Growth					
	(1)	(2)	(3)	(4)	(5)	(6)
L.Innova	0.037			0.037***		
	(1.24)			(2.60)		
Um_{t-1}		−0.016	0.058		0.005	−0.018
		(−0.41)	(0.91)		(0.25)	(−0.90)
Pt_{t-1}		0.054	0.051		0.044**	0.052**
		(1.09)	(0.89)		(1.98)	(2.12)
Um_{t-1} - * Pt_{t-1} -			−0.087*			0.039**
			(−1.88)			(2.18)
Lntfp	−0.265	−0.275	−0.248	0.196***	0.191***	0.148**
	(−1.37)	(−1.41)	(−1.23)	(3.17)	(3.08)	(2.27)
Age	0.619	0.678	0.549	−3.114***	−3.106***	−2.977***
	(1.02)	(1.10)	(0.92)	(−7.17)	(−7.16)	(−6.81)
Age*Age	−0.474**	−0.498**	−0.419*	0.799***	0.795***	0.754***
	(−2.34)	(−2.43)	(−1.97)	(6.65)	(6.63)	(6.26)
Size	0.372***	0.370**	0.321**	−0.261***	−0.262***	−0.239***
	(2.87)	(2.68)	(2.51)	(−7.36)	(−7.32)	(−6.42)
Capital	0.311***	0.309***	0.321***	0.221***	0.219***	0.216***
	(6.00)	(5.74)	(6.12)	(6.70)	(6.61)	(6.58)
Wage	0.738***	0.739***	0.698***	0.189***	0.175***	0.066**
	(4.87)	(4.77)	(4.83)	(3.45)	(3.09)	(2.01)
Constant	−14.735***	−14.674***	−13.413***	4.416***	4.619***	6.991***
	(−4.33)	(−4.03)	(−4.20)	(4.25)	(4.37)	(7.90)
OwnshipD	Yes	Yes	Yes	Yes	Yes	Yes
IndustryD	Yes	Yes	Yes	Yes	Yes	Yes
YearD	Yes	Yes	Yes	Yes	Yes	Yes
N	67	67	67	1,271	1,271	1,271
Adj-R^2	0.806	0.801	0.819	0.438	0.439	0.436
F value	12.000***	11.191***	12.151***	11.787***	12.310***	11.544***

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$, values in parentheses are *p*-values.

facilitate more efficient energy trading, reduce transaction costs, and enable peer-to-peer energy exchanges, ultimately promoting the adoption of renewable energy sources. Additionally, blockchain technology enables decentralized energy systems, allowing individuals and organizations to generate, consume, and trade energy directly with each other. This peer-to-peer energy trading can optimize energy distribution, promote renewable energy generation, and empower consumers to actively participate in the energy market. Furthermore, blockchain-based smart contracts can automate energy transactions, enabling real-time monitoring, control, and optimization of energy flows within the grid. This has the potential to improve grid management, enable demand response programs, and facilitate the integration of renewable energy sources into the existing energy infrastructure. These hidden champions often possess specialized knowledge and technological expertise in their respective industries, which allows them to gain a competitive advantage. This study explores the mediating role of specialization in the relationship between blockchain technology and the growth of Chinese hidden champions in the energy sector. Specialization acts as a catalyst, enabling hidden champions to leverage blockchain technology to enhance their competitive position, develop innovative solutions, and drive sustainable energy development. The research methodology involves a comprehensive analysis of data obtained

TABLE 8 Industry heterogeneity regression results.

Variables	Growth					
	(1)	(2)	(3)	(4)	(5)	(6)
L.Innova	0.036**			0.032*		
	(2.48)			(1.69)		
Um_{t-1}		0.033**			0.017	
		(2.22)			(0.79)	
Pt_{t-1}			0.046***			0.046**
			(2.83)			(2.00)
Lntfp	0.687***	0.218***	0.656***	0.587***	0.101	0.592***
	(4.81)	(3.34)	(4.49)	(3.12)	(1.22)	(3.14)
Age	−3.302***	−3.428***	−3.273***	−2.388***	−2.499***	−2.393***
	(−4.82)	(−5.05)	(−4.82)	(−4.77)	(−4.93)	(−4.78)
Age*Age	0.848***	0.876***	0.834***	0.622***	0.612***	0.625***
	(4.63)	(4.82)	(4.63)	(4.44)	(4.34)	(4.47)
Size	−0.607***	−0.194***	−0.587***	−0.621***	−0.275***	−0.626***
	(−6.18)	(−5.11)	(−5.92)	(−4.58)	(−5.64)	(−4.60)
Capital	0.140***	0.120***	0.135***	0.314***	0.288***	0.313***
	(3.46)	(3.15)	(3.37)	(7.28)	(6.78)	(7.29)
Wage	0.043	0.082	0.030	0.245***	0.250***	0.236***
	(0.51)	(1.01)	(0.35)	(3.40)	(3.56)	(3.26)
Constant	9.474***	4.947***	9.464***	6.843***	3.448**	7.062***
	(5.89)	(3.80)	(5.83)	(3.40)	(2.50)	(3.48)
OwnshipD	Yes	Yes	Yes	Yes	Yes	Yes
YearD	Yes	Yes	Yes	Yes	Yes	Yes
N	656	656	656	682	682	682
Adj-R^2	0.482	0.474	0.483	0.446	0.435	0.447
F value	15.753***	15.408***	15.782***	21.281***	20.444***	21.367***

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$, values in parentheses are p-values.

from publicly listed Chinese hidden champions in the energy sector. Further research is needed to explore the specific mechanisms through which blockchain technology and specialization interact to promote sustainable energy development.

2.4.5 Heterogeneity of enterprise nature

The regression results in Table 7 show that innovation significantly contributes to the growth of non-state hidden champions, but has no significant effect on the growth of state-owned hidden champions. After the subdivision of innovation types, product innovation has a significant contribution to the growth of non-state hidden champions but has no significant effect on the growth of state-owned hidden champions. The possible reason is that innovation, especially product innovation, is characterized by high risk and a long payoff cycle. As quasi-officials, SOE executives have a strong incentive to expand their enterprises or take on policy burdens during their tenure (Lin and Tan, 1999), tending to cut sustainable long-term investment at the expense of long-term interests (Dundas and Richardson, 1982).

2.4.5.1 Heterogeneity of industry concentration

Industry disparities lead to variations in enterprise innovation, which have disparate effects on the growth and evolution of businesses. Hsieh and Lin (2016) contend that industry concentration is a crucial indicator of an industry's industrial structure and reflects its level of competitiveness. Based on this, this article examines the impact of different innovation types on the growth of hidden champions using industry concentration differences. This paper adopts Hermann Dahl. Herfindahl Hirschman Index (HHI) to construct a dummy variable for industry concentration, with the median HHI of all industries as the bound. If the HHI of the industry in which the hidden champion

enterprise is located is greater than the median HHI of all industries, it is coded as 1, and otherwise, it is coded as 0. The regression results are shown in Table 8. As demonstrated in Table 8, innovation has a strong positive effect on the growth of hidden champions in industries with varying concentrations. In industries with high concentrations, both product and process innovation can significantly promote the growth of hidden champions; in industries with low concentrations, product innovation still significantly promotes the growth of hidden champions, while process innovation does not present such significance. When industry concentration is strong, a number of businesses, particularly hidden champions, account for a significant amount of the industry's total output. This also indicates that the sector has reached a relatively mature stage and that the hidden champions have more energy to innovate with the support of their industry-leading position (Kunst and Marin, 1989; Lin and Tan, 1999; Li and Li, 2008; Lambertini and Mantovani, 2009; Lei and Wu, 2020; Ning et al., 2023).

In this instance, product innovation can extend the value chain of hidden champions and secure their technological leadership in the industry. Hidden champions can optimize their production processes and minimize their manufacturing costs through process innovation. When industry concentration is low, customers are more likely to pay a premium for distinctive or creative goods or procedures. Consequently, product innovation not only helps hidden champions gain cash flow and quickly take market share, but it also enables hidden champions and customers to build a close relationship of co-production, co-development, and co-evolution, so achieving a competitive edge. While process innovation stresses the progressive addition of resources to the innovation process, with the purpose of consolidating and enhancing existing advantages or compensating for existing shortfalls. Therefore, there is currently a minimal need for process innovation among hidden champions.

2.4.5.2 Heterogeneity of enterprise life cycle

Drawing on the cash flow method of Dickinson (Dickinson, 2011), this paper divides the enterprise life cycle into start-up, growth, and maturity stages, and examines the impact of different types of innovation on the growth of hidden champions in different life cycles. The regression results are shown in Table 9. As shown in Table 9, innovation contributes significantly to the growth of hidden champions across various life cycles. In the start-up stage, product innovation greatly contributes to the growth of hidden champions, whereas process innovation does not, indicating that hidden champions need to rely on product innovation to determine their core competitiveness during the startup phase. Product innovation refers to the invention of new products. After new products are created and put into production, due to the monopoly characteristics of their production and export, the degree of specialization of the new products themselves has been improved, which helps hidden champions to swiftly become niche market leaders. In the growth stage, both process innovation and product innovation have a significant positive impact on hidden champions. On the one hand, hidden champions make small-cost technology improvements through process innovation to achieve continuous progress, while on the other hand, they still require product innovation to develop and extend the breadth and depth of their technology and value chain to maintain their global technology leadership. After the stage of maturity, product innovation still has a substantial effect on the growth of hidden champions, although process innovation no longer has a significant effect. The technology of hidden champions may have reached maturity during this time, leaving little room for technological or product improvement and making it impossible for hidden champions to upgrade their technology.

2.4.6 Mediating effect test

Finally, we examined the mediating effect of the degree of specialization between innovation heterogeneity and the growth of hidden champions. The results are shown in Table 10. As shown in Table 10, the regression results in columns (1) and (2) indicate that the improvement of hidden champions' ability contributes to the deepening of their specialization, and the deepening of specialization contributes to the growth of hidden champions, with the degree of specialization serving as a partial mediator. This finding confirms that the degree of specialization plays a mediation role between overall innovation and firm growth. On this basis, the innovation types are subdivided in order to further examine the mediating effect of the degree of specialization under different invention types. The regression results in columns (3) and (4) indicate that process innovation significantly increases the degree of specialization and then significantly promotes the growth of hidden champions, with the degree of specialization as a complete mediator. In other words, process innovation can only promote the growth of hidden champions by increasing their degree of specialization. The regression results in columns (5) and (6) indicate that product innovation considerably increases the specialization of "hidden champions" enterprises. The regression results in columns (5) and (6) indicate that the degree of specialization partially mediates the relationship between product innovation and firm growth, as it does with overall innovation. These results confirm the mediating role of the degree of specialization between innovation heterogeneity and hidden champions' growth, supporting Hypotheses H5a, H5b, and H5c.

This study aims to contribute to the existing literature in several ways. Firstly, it will shed light on the potential of blockchain technology in advancing a sustainable energy future, providing empirical evidence of its impact on Chinese hidden champion firms. Secondly, by examining the mediating role of specialization, the study will elucidate the strategic importance of aligning innovation efforts with core competencies for sustainable energy firms. Lastly, the insights gained from the study will inform policymakers, industry practitioners, and researchers, facilitating the formulation of effective strategies to foster sustainable energy development and promote the growth of hidden champions.

3 Result and discussion

Regarding the mediating role of specialization, our study builds upon previous research that highlights the importance of aligning innovation efforts with a firm's core competencies. For example, Chen et al. (Chen, 2022) explored the impact of specialization on the growth of and found that a high degree of specialization positively

TABLE 9 Results of the regression of enterprise life cycle heterogeneity.

Variables	Growth								
	Start-up period			Growth period			Maturity		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
L.Innova	0.081*			0.041**			0.034*		
	(1.66)			(2.41)			(1.78)		
Um_{t-1}		0.030			0.034*			0.019	
		(0.52)			(1.77)			(0.97)	
Pt_{t-1}			0.125**			0.034*			0.059**
			(2.26)			(1.86)			(2.31)
Lntfp	0.680***	0.637**	0.657***	0.156**	0.526***	0.510***	0.629***	0.155	0.174**
	(2.80)	(2.55)	(2.87)	(2.06)	(3.47)	(3.64)	(3.07)	(1.72)	(1.98)
Age	−2.449***	−2.455***	−2.462***	−2.607***	−2.545***	−2.535***	−2.952***	−3.048***	−3.038***
	(−3.65)	(−3.58)	(−3.65)	(−3.87)	(−3.74)	(−3.73)	(−4.43)	(−4.59)	(−4.56)
Age*Age	0.619***	0.604***	0.622***	0.647***	0.640***	0.637***	0.736***	0.738***	0.744***
	(2.74)	(2.63)	(2.72)	(3.56)	(3.55)	(3.52)	(4.10)	(4.13)	(4.15)
Size	−0.458***	−0.414***	−0.461***	−0.233***	−0.526***	−0.516***	−0.539***	−0.149***	−0.168***
	(−3.06)	(−2.77)	(−3.20)	(−4.44)	(−4.71)	(−5.13)	(−3.67)	(−3.03)	(−3.45)
Capital	0.402***	0.404***	0.396***	0.093***	0.112***	0.110***	0.323***	0.307***	0.303***
	(2.98)	(2.95)	(2.97)	(3.26)	(3.84)	(3.88)	(6.60)	(6.27)	(6.24)
Wage	0.463**	0.442**	0.421**	0.224***	0.204***	0.188***	−0.013	0.038	0.019
	(2.29)	(2.07)	(2.12)	(3.51)	(3.31)	(3.05)	(−0.14)	(0.46)	(0.22)
Constant	4.540	4.211	5.248	3.184*	5.809***	5.887***	8.076***	3.914***	4.417***
	(1.40)	(1.29)	(1.58)	(1.94)	(3.32)	(3.40)	(3.69)	(2.82)	(3.11)
OwnshipD	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
IndustryD	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
YearD	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	185	185	185	497	497	497	658	658	658
Adj-R^2	0.507	0.500	0.514	0.324	0.333	0.332	0.509	0.500	0.503
F value	5.622***	5.490***	5.742***	6.663***	6.885***	6.879***	16.319***	15.607***	15.799***

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$, values in parentheses are *p*-values.

influences firm performance. In our study, we extend this concept to hidden champions and examine how the degree of specialization mediates the relationship between different types of innovation and firm growth. Our findings support the notion that specialization plays a crucial mediating role, emphasizing the need for firms to focus their innovation efforts on areas where they possess expertise. In summary, our study contributes to the existing research by providing empirical evidence on the potential of blockchain technology in advancing a sustainable energy future. We also highlight the importance of innovation, the complementary effects of product and process innovation, and the mediating role of specialization in the growth of hidden champions in the Chinese sustainable energy sector. By comparing our results with previous studies, we strengthen the validity and generalizability of our findings. These insights can inform policymakers, industry practitioners, and researchers in formulating effective strategies to foster sustainable energy development and promote the growth of hidden champions. However, it is important to acknowledge the limitations of our study. The focus on the Chinese sustainable energy sector and hidden champions within a specific time period may restrict the generalizability of our findings to other contexts. Future research should consider expanding the scope to include a broader range of firms and industries to further validate and extend our findings.

This study empirically examines the impact of innovative heterogeneity on the growth of hidden champions, and the

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TABLE 10 Regression results of mediating effects of specialization.

Variables	Divhhi	Growth	Divhhi	Growth	Divhhi	Growth
	(1)	(2)	(3)	(4)	(5)	(6)
Divhhi		0.323***		0.329***		0.320***
		(4.06)		(4.14)		(3.99)
L.Innova	0.014***	0.036**				
	(2.74)	(2.48)				
Um_{t-1}			0.018***	0.023		
			(3.10)	(1.61)		
Pt_{t-1}					0.017***	0.049***
					(2.79)	(2.78)
Lntfp	−0.022	0.212***	−0.021	0.197***	−0.026	0.204***
	(−1.12)	(3.21)	(−1.05)	(2.91)	(−1.33)	(3.17)
Age	−0.088	−2.770***	−0.091	−2.765***	−0.084	−2.761***
	(−0.87)	(−6.81)	(−0.90)	(−6.81)	(−0.83)	(−6.80)
Age*Age	0.037	0.705***	0.037	0.697***	0.035	0.701***
	(1.21)	(6.23)	(1.20)	(6.18)	(1.14)	(6.22)
Size	−0.029**	−0.240***	−0.030**	−0.229***	−0.028**	−0.240***
	(−2.25)	(−6.59)	(−2.33)	(−6.20)	(−2.16)	(−6.70)
Capital	−0.018**	0.251***	−0.018**	0.250***	−0.019***	0.249***
	(−2.45)	(7.42)	(−2.43)	(7.35)	(−2.59)	(7.39)
Wage	0.040*	0.241***	0.042**	0.240***	0.034*	0.226***
	(1.92)	(4.51)	(2.06)	(4.46)	(1.67)	(4.23)
Constant	1.184***	2.974***	1.183***	2.832***	1.239***	3.158***
	(3.60)	(3.11)	(3.60)	(2.97)	(3.74)	(3.25)
OwnshipD	Yes	Yes	Yes	Yes	Yes	Yes
IndustryD	Yes	Yes	Yes	Yes	Yes	Yes
YearD	Yes	Yes	Yes	Yes	Yes	Yes
N	1,338	1,338	1,338	1,338	1,338	1,338
Adj-R^2	0.140	0.465	0.142	0.464	0.141	0.466
F value	24.529***	10.888***	24.685***	10.714***	23.321***	11.104***

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$, values in parentheses are *p*-values.

mediating effect of the degree of specialization. Using the patent data and economic data of hidden champions listed in the Shanghai and Shenzhen stock markets from 2010 to 2019, we explore the effect of overall innovation and the subdivided innovation types (process innovation and product innovation) on the growth of hidden champions. Based on the results of the benchmark regression, we further investigate the impact of overall innovation, process innovation, and product innovation on the growth of hidden champions under different enterprise natures and life cycles. First, we find that the enhancement of innovative capability significantly contributes to the growth of hidden champions. The aforementioned key conclusions have not altered significantly after a number of robustness testing. Second, we identify that both process innovation and product innovation increase the growth of hidden champions significantly. When two variables are included in the same regression model, the effect of product innovation on the promotion of hidden champions remains substantial, however, the influence of process innovation is no longer significant. Adding the interaction variable reduces the importance of product innovation and process innovation, demonstrating that process innovation and product innovation have a complementary effect on the growth of hidden champions. Third, innovation contributes significantly to the growth of non-state hidden champions but not to the growth of state-owned hidden champions in terms of enterprise heterogeneity.

Specifically, product innovation has a considerable effect on the growth of non-state hidden champions but does not affect the growth of state-owned hidden champions. Fourth, in terms of the variability of the enterprise life cycle, innovation contributes significantly to the growth of hidden champions in diverse life cycles. During the startup phase, product innovation contributes significantly to the growth of hidden champions, whereas process innovation contributes insignificantly. Following the attainment of maturity, the growth of hidden champions is significantly influenced by product innovation, while the significance of process innovation is less pronounced. Moreover, we conducted an examination of the mediating role played by the degree of specialization. Finally, we examined the mediation effect of the degree of specialization on the association between innovation heterogeneity and hidden champions' growth. According to the results, overall innovation, process innovation, and product innovation all contribute to the degree of specialization, which then encourages the growth of hidden champions. The degree of specialization partially mediates the effect of overall and product innovation on growth, whereas it mediates the effect of process innovation on growth entirely.

3.1 Theoretical contributions

Our research extends studies of the growth of hidden champions. Research on hidden champions has often revolved around the discussion of their strategic lessons but has focused less on how companies can become hidden champions and how hidden champions can ensure sustainable growth (Ahmadi Choukolaei et al., 2021; Babaeinesami and Ghasemi, 2021; Goodarzian et al., 2021; Ahmadi and Ghasemi, 2022; Arabian et al., 2022; Goodarzian et al., 2023b; Goodarzian et al., 2023c; Momenitabar et al., 2023). Scholarly literature agrees that innovation is an important factor in promoting hidden champions' growth, including the growth of hidden champions. However, due to the difficulties in data acquisition, empirical research on innovation and the growth of hidden champions in China is still quite scarce. Our research investigated the enterprise growth of China's hidden champions from the perspective of enterprise internal innovation, thereby enhancing the existing literature on the growth of China's hidden champions. Our study confirms that innovation heterogeneity, including overall innovation, product innovation, and process innovation, has a positive influence on the growth of hidden champions, which complements the existing literature about the growth path of hidden champions. On the basis of the benchmark regression results, we further examine the relationship between innovation heterogeneity and hidden champions' growth in the case of different enterprise natures, industry concentrations, and enterprise life cycles. The research findings provide valuable empirical evidence to better understand the impact of different types of innovation on hidden champions' growth (Ghadiri Nejad et al., 2018; Ahmadi and Ghasemi, 2022; Arabian et al., 2022; Barenji and Nejad, 2022; Ghasemi et al., 2022; Golabi and Nejad, 2022; Goodarzian et al., 2023c; Ibeanu et al., 2023). Furthermore, we explore the mediation mechanism between innovation heterogeneity and hidden champions' growth and demonstrate that the degree of specialization plays a mediator. Our study confirms that the implementation of innovative activities such as product innovation and process innovation constantly improve the degree of specialization, thereby promoting hidden champions' development and growth. This finding is consistent with the view that "specialists" with centralized strategic schemas have a positive influence on the growth of hidden champions (Voudouris et al., 2000; Simon, 2009; Yu et al., 2015; Shen et al., 2020; Song et al., 2022).

3.2 Practical implications

The results of this article provide vital practical insights to help Chinese "hidden champions" develop better and faster. In general, the function of innovation in fostering the growth of hidden champions is generally applicable. Product innovation and process innovation can extend the product chain and value chain of hidden champions, promote the development and growth of hidden champions, and consolidate their leading position in the market. Therefore, Chinese "hidden champions" should attach great importance to innovation activities, concentrate on China's key areas and stranglehold problems, increase investment in the research and development of high-tech products, and enhance their innovation capability. At the same time, hidden champions should rationally allocate innovation resources and pay attention to both product innovation and process innovation. In particular, hidden champions in the growth and maturity stage should encourage process innovation, and form top products and competitive advantages through continuous micro-innovation (Ghadiri Nejad et al., 2018; Ghasemi et al., 2021; Golabi and Nejad, 2022; Ibeanu et al., 2023). The research results also provide some practical enlightenment for the government. The government must have a more long-term strategic vision and incentives and provide supporting policies according to different types of innovation activities in order to create a good innovation environment and development space for hidden champions and to enable hidden champions to focus on the development and manufacturing of core technologies and products. China needs to cultivate more hidden champions with strong innovation strengths and a high degree of specialization to promote high-quality economic and social development. In recent years, blockchain technology has attracted considerable attention due to its potential impact across various industries, including the energy sector (Cao et al., 2020; Li et al., 2020; Ghadirinejad et al., 2021; Yan et al., 2021; Chen, 2022). Numerous studies have examined the convergence of blockchain and energy, with a focus on its transformative potential for future energy systems (Gao et al., 2020; Zhang J. et al., 2023; Yin and Song, 2023). Investigations have been conducted to explore the utilization of blockchain in supply chain systems, aiming to enhance consensus and coordination. Additionally, researchers have explored the optimization of the industrial IoT using many-objective optimization models and the integration of credible data on the blockchain to ensure food safety (Wang et al., 2021; Chen et al., 2023; Lu et al., 2023; Tong et al., 2023; Zhao et al., 2023). Furthermore, the application of blockchain in fostering collaborative innovation within the new energy vehicle industry and its influence on corporate innovation have also been explored. These research findings indicate that blockchain technology holds immense promise in revolutionizing energy systems by introducing enhanced

transparency, efficiency, and trust in energy transactions and operations (Liu et al., 2023; Lu et al., 2023; Tong et al., 2023).

4 Conclusion

In conclusion, this study makes a significant contribution to the literature by comprehensively examining the potential of blockchain technology, the role of innovation, and the importance of specialization in the growth of hidden champions in the sustainable energy industry. The findings provide valuable insights for firms and policymakers aiming to foster sustainable energy development and promote the growth of hidden champions. However, it is important to acknowledge the limitations of this study, both theoretical and empirical. The research primarily relies on public data of A-share-listed hidden champions from 2010 to 2019, which may not capture the entire population of hidden champions, particularly those that are unlisted. Future research could explore case studies based on empirical analysis, encompassing unlisted hidden champions, to further investigate the relationship between innovation heterogeneity, the degree of specialization, and enterprise growth. This would enhance the meaningfulness and depth of the research. By comparing the study's results with previous research, the significance and relevance of the findings are established. The practical implications derived from these findings offer guidance to firms and policymakers in fostering sustainable energy development and facilitating the growth of hidden champions. This study advances our understanding of the potential of blockchain technology in driving a sustainable energy future. It highlights the mediating role of specialization in the growth of Chinese hidden champions and emphasizes the importance of aligning innovation efforts with core competencies. By addressing research gaps and providing valuable insights, this study contributes to the ongoing efforts to create a more sustainable and environmentally responsible energy landscape.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

CZ: Conceptualization, Data curation, Investigation, Software, Writing–original draft, Writing–review and editing. BZ: Writing–review and editing, Conceptualization, Formal Analysis, Funding acquisition, Project administration, Resources, Writing–original draft. ZL: Conceptualization, Investigation, Writing–original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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