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ANALYZING THE IMPACT OF THE INNOVATION PERFORMANCE ON HIGH-TECH ENTERPRISES: A CASE STUDY OF THE CHINESE SEMICONDUCTOR INDUSTRY

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Abstract. This study, which focuses on Chinese semiconductor companies, explores the relationship between government support (GS), proactive market orientation (PMO), science and technology (S&T) employees input (STEI), S&T employees management (STEM), and innovation performance (IP). In addition, existing studies examine the moderating effect of S&T employees management (STEM) on the relationship between S&T employees input (STEI) and innovation performance (IP). We obtained 324 valid samples through an email survey and utilized structural equation modeling (SEM) path analysis for hypothesis testing. The results of the analysis indicated that government support (GS), proactive market orientation (PMO), S&T employees input (STEI), and S&T employees management (STEM) exerted a positively significant effect on innovation performance. However, the moderating effect of S&T employees management on S&T employees input and innovation performance was not validated. Based on these findings, it can be concluded that Chinese semiconductor companies should utilize preferential policies of government offer. By adopting a proactive market orientation, companies can enhance communication with customers and can gain competitive advantage. In addition, enterprises should increase the number of S&T employees, and salaries and training costs. Finally, enterprises should implement the human resources strategy which can retain outstanding S&T employees.

Keywords: government support, proactive market orientation, S&T employees input, S&T employees management, innovation performance, Chinese semiconductor industry.

JEL Classification: O31, O32, O38, Q55.

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1. Introduction

In the context of economic globalization, high-tech firms are subjected to an increasingly dynamic, complex, and highly uncertain competitive market environment (Capozza & Divella, 2019), due to the turbulent international political environment. High-tech firms should respond quickly to market changes and innovate sustainably to maintain a competitive advantage. However, it has become increasingly difficult for emerging economies to develop high-tech industries using technology diffusion. The implementation of "independent innovation" in emerging economies, as a means of effecting technological breakthroughs, is a rational strategy, which enables emerging economies to catch-up with developed countries.

China, a representative emerging economies that is actively exploring "independent innovation models" for high-tech enterprises. In regard to tax policies, employees introduction policies, and R&D investments, the central and local governments have afforded high-tech enterprises greater support. In the existing literature, scholars analyzed the factors affecting the innovation performance of high-tech firms from different perspectives, such as government subsidies (Yi et al., 2021), human capital allocation (Li et al., 2021), knowledge acquisition (Papa et al., 2020), organizational learning capacity (Gomes & Wojahn, 2017), human resource management practices (Diaz-Fernandez et al., 2017), customer participatory market orientation (Wei et al., 2022). However, innovation in high-tech firms is influenced by a combination of factors, and the aforementioned factors exert varying degrees of influence on the innovation performance of high-tech firms or even fail to achieve the desired innovation performance, even though R&D investments could be fully utilized (Hall, 2002). Most existing studies were less focus on the impact of specialists on the innovation performance of high-tech firms. However, because both the generation of new knowledge within the firm and the acquisition of new knowledge from outside require the participation and execution of specialists, it is necessary to test the importance of professional staff in the firm's innovation process (Capozza & Divella, 2019). To value specialists, the human capital of the company and its human resource management practices should be emphasized. If the innovation practice of high-tech enterprises and the academic research results are considered, it can be observed that the innovation effect of high-tech enterprises is mixed.

China's semiconductor industry is divided into the four periods. The first period was 1967–1978. At this phase, China began to develop a semiconductor industry based on a model of the state-supported indigenous R&D, and achieved some technological achievements. The second period was 1978–2000. During that period the Chinese government announced a determination to develop the semiconductor industry and implemented the 908 and 909 programs. During that period, semiconductor companies in mainland China not only further widened the gap with the United States and Japan, but also lagged behind South Korea and Taiwan. Technological backwardness, short-term talents, and insufficient capitals were prominent during that period, constraining the ability of semiconductor companies to acquire technologies, adapt, and innovate. The third period was 2000–2014, and was a period of rapid development for China's semiconductor industry. In 2000, the State Council issued the Announcement on Several Policies to Encourage the Development of the Software Industry and the Integrated Circuit Industry. The notification covered the support policies for the semiconductor industry in terms of investment and financial, taxation, technology and export. The forth period was from 2014 to the present. In 2014, the government formulated two important policies on the semiconductor industry. Firstly, the National Integrated Circuit Industry Investment Fund was established. Secondly, the State Council issued the Outline for Promoting the Development of the National Integrated Circuit Industry. Both policies indicated that the Chinese government would increase its finance and policy support for the semiconductor industry.

Looking at the global semiconductor industry, Intel, Samsung, SK Hynix, and TSMC etc. are all leading companies. According to Omdia, a company specializing in market research, which published a ranking of global semiconductor companies by sales in 2022. The sales revenues of the world's top 20 semiconductor companies accounted for 76.65% of the total sales revenues of all semiconductor companies in 2022, while there were no Chinese companies in the top 20 semiconductor companies.

This study, which focuses on the Chinese semiconductor industry, aims to understand the factors that affect the "independent innovation" of companies from the perspective of corporate innovation practitioners and relevant researchers. Thus, the study evaluated the effects of government support, proactive market orientation, as well as S&T employees input and S&T employees management on innovation performance. Furthermore, the relationship between the four factors and innovation performance of Chinese semiconductor companies was obtained using structural equation modeling (SEM) path analysis.

The remainder of the study is organized as follows. Firstly, we describe the theoretical foundations of this study. Secondly, we conduct a literature review and formulate hypotheses. Thirdly, we present the study methodology and explanatory variables as well as describe the findings. Finally, we present the study conclusions, limitations, the practical and theoretical implications, and the scope of future research.

2. Theoretical foundations

A sectoral innovation systems is defined as a set of new and established products for a specific use, a set of agents that interact in market, and a set of non-market interactions to create, produce, and sell these products (Malerba, 2002). The sectoral innovation systems emphasized the interactive process of the drivers. Scholars viewed the sectoral innovation systems as a large innovation ecosystem, which includes productive firms, research institutes, universities, government agencies, financial institutions, and other subjects, which is a more comprehensive summary of the drivers. Therefore, in line with this academic views, this study argues that innovation activities from the sectoral innovation systems should emphasize the inter-disciplinarity, the learning and knowledge accumulation by actors (Edquist, 1997), and specific actions of innovation activities discussed collectively by actors (Carlsson & Staffan, 1994; Edquist, 1997; Lundvall, 1998). Malerba (2002) argued that the components of a sectoral innovation systems includes the following five dimensions. (1) the knowledge base and learning process, (2) technology, input and demand, and their inter-linkages and dynamic complementary, (3) the manner in which productive and unproductive organizations interact, (4) regimes, and (5) the process of innovation generation and selection. Since the semiconductor industry involves multiple domains of knowledge, its technological innovations requires a wide range of knowledge. Technological employees as knowledge carriers are important objects analyzed in this study. Sectoral innovation systems describes the industry as a bounded sector with frequent interactions between producers and non-producers within the sector. Therefore, this study also focuses on market strategies in the innovation process of the semiconductor firms. In addition, institutions are an important component of sectoral innovation systems, and industrial innovation is closely related to the government policy support. Therefore, it is necessary to analyze the relationship between the government support and the innovation performance.

3. Literature review and research hypothesis

3.1. Government support and innovation performance

The results of a large number of innovation studies indicated that governments support firm innovations in the form of public policies (Zúñiga-Vicente et al., 2014). It refers to government interventions, such as credit subsidy programs, government R&D subsidies, subsidies for scientific research projects, tax breaks, and regional innovation policies, etc. Lazzarini (2015) categorize government support into vertical and horizontal support based on industrial policy. Vertical support refers to policy assistance for a specific industry (Beason & Weinstein, 1996). For example, credit subsidy programs are designed to promote investment in a particular firm, region, or industry. Horizontal support refers to preferential policies that promote a regional innovation environment by targeting a particular region (Wei & Liu, 2015).

Several studies have indicated that some government support programs exert a direct and effective impact on firm innovation. For instance, R&D subsidies can positively affect innovation performance, and this relationship can be rationalized as follows: due to long research cycles and large capital investments, most of the innovation projects in high-tech firms are high risk endeavors. If firms do not possess sufficient funds, it is difficult to successfully implement R&D projects. In addition, in countries where intellectual property rights are not effectively protected, a company's innovations can easily be imitated by competitors. Thus, the company's incentive to innovate is reduced. However, government R&D subsidies are "public goods" in nature, and they encourage "knowledge spillovers", which can address the shortage of R&D funds and dispel the concerns of enterprises. In particular, large government-led R&D projects that are jointly implemented by universities, public research institutions and enterprises are more conducive to the transfer of R&D results in the relevant sectors (Cohen et al., 2002). In the Chinese context, the aforementioned public research projects are mainly financed by the central and local governments. Therefore, subsidies for scientific research projects facilitate firms' access to external resources and may enhance their innovation performance (Xu et al., 2014). Through empirical analysis, Wei and Liu (2015) observed that tax credits and subsidies for public scientific research projects did not exert a significantly positive effect on firms' innovation performance. By contrast, Guan and Yam (2015) postulated that tax subsidies could positively affect firm innovation performance.

In response to the inconsistent findings of prior studies on government support, this study aims to further test how government support affects the innovation performance of high-tech firms in the Chinese context. Therefore, the following hypothesis is proposed.

H1: There is a significantly positive relationship between government support and the innovation performance of Chinese semiconductor firms.

3.2. Proactive market orientation and innovative performance

Due to the development of artificial intelligence, 5G technology, and new energy vehicles, the demand for semiconductor chips has increased dramatically, and the number of industries and companies exhibiting this increased demand are increasing. Although with regard to the consumer market, the demand for <10 nm chip is increasing, the production technology and process equipment for <10nm chips, in China cannot achieve localization. Due to the huge market demand and the unique external environment, where in knowledge cannot be acquired through "knowledge diffusion", the desire of enterprises to realize the localization of technology and manufacturing equipment through an "independent innovation" strategy is becoming stronger. Dosi (1988) proposed that market and technology were the key factors that facilitate firm innovation. Therefore, this study proposes that proactive market orientation is one of the driving forces that promote innovation in Chinese semiconductor firms.

Market orientation, which refers to the ability of a firm to acquire, digest, assimilate, and utilize information pertaining to consumers and competitors, contributes to the success of the firm's innovation (Kohli & Jaworski, 1990). Proactive market orientation is a means of anticipating the future consumer market based on the existing market scenario, proactively collecting information pertaining to consumers and competitors, and allocating resources in advance to create products and services that meet consumer needs based on the acquired information. According to the knowledge-based theory, firms that adopt a proactive market orientation possess a strong absorptive capacity to acquire, understand, transform, and utilize market knowledge from external markets (Qu & Mardani, 2023). Innovation, which is a process of knowledge accumulation, absorption, and transformation, reflects the process of intellectual integration (Grant, 1996). Market-oriented firms are more capable of absorbing knowledge and performing effectively, which is especially crucial for knowledge-intensive firms (Abbu & Gopalakrishna, 2021). Owing to the different channels through which enterprises can obtain external knowledge, large differences in the quantity and quality of information exist (Chen & Huan, 2022). In addition, the effectiveness of utilizing external information is related to the ability of business members to understand it. Therefore, for a firm to process a large amount of heterogeneous market information, the business members should possess a strong discrimination and comprehension ability (Tjahjadi et al., 2022). Proactive market-oriented firms increase their innovation capabilities through a stronger ability to absorb external information (Khan & Tao, 2022). Therefore, we propose the following hypothesis.

H2: Proactive market orientation exerts a significantly positive effect on the innovation performance of Chinese semiconductor firms.

3.3. S&T employees input and innovation performance

Semiconductor manufacturing entails numerous disciplines and knowledge areas. Thus, the industry is typically knowledge-intensive. Therefore, firms require adequate and specialized human capital to maintain innovation dynamics and achieve high innovation performance (Li et al., 2021). According to the modern management theory, human capital is a crucial factor of production for firms, which can promote innovation and influence economic growth (Miller & Upadhyay, 2000). Specifically, S&T employees is the main innovation force in firms. Because high-tech companies require higher innovation performance to maintain their competitive advantage and to match the high innovation performance, high-level S&T employees are imperative. Murphy et al. (1991) confirmed that when the level of human capital which a firm possesses is higher, its ability to innovate technologically becomes greater. This observation indicates that firm innovation requires a matching level of human capital. Most of the existing literature has confirmed that human capital is positively related to firm innovation performance. However, the technological level of firms in emerging economies is generally below the world technological frontier (Aghion, 2016). There are three common paths for enterprises to quickly catch up with advanced technologies as technology transfer, joint ventures, and imitation innovation. However, these three paths can easily lead emerging economies into the "technology catch-up trap". Moreover, according to the skill-biased technological change perspective, even if emerging economies can acquire advanced technologies through technology transfer, they need employees with the appropriate skills and knowledge to achieve innovative output. Therefore, the preceding argument indicates that companies require S&T employees that matches their innovation development needs, whether they adopt an "internally generated innovation strategy" or an "externally induced innovation strategy". Becker (1993) proposed that knowledge acquired by individuals through formal education was denoted as general human capital, whereas specialized knowledge and skills acquired through work experience were denoted as specialized human capital. S&T employees who choose technical majors in the formal education stage accumulate richer and more systematic theoretical knowledge for later R&D endeavors. Moreover, the R&D experience accumulated in the workplace are the knowledge and skills required for innovation in high-tech enterprises.

This study utilizes to more comprehensive human capital concepts that includes formal education level, professional knowledge, and skills which accumulated through work experience. The previous section has indicated that semiconductor manufacturing is a knowledge-intensive industry that requires a large number of S&T employees with solid theoretical knowledge and rich professional skills. The S&T employees of semiconductor enterprises should not only exhibit satisfactory general human capital but also possess rich professional human capital. Therefore, this study proposes the following hypotheses.

H3: S&T employees input significantly and positively affects the innovation performance of Chinese semiconductor firms.

3.4. S&T employees management and innovation performance

Corporate innovation activities require employees to be motivated. They can transform their individual-embedded knowledge and expertise into innovative output. However, there is a severe shortage of R&D employees in the Chinese semiconductor industry. Therefore, organizations can retain high-quality employees through strategic HRM practices. Laursen and Foss (2014) proposed two strategic HR practices namely on-the-job training and employees engagement. Moreover, with respect to the aspects of S&T employees management, this study adds employees benefits. Based on the motivation theory, by providing more optimal benefits to employees, they are motivated to work hard and ultimately create higher corporate value (Wei et al., 2020). Employees benefits promote employees engagement in the workplace, which ultimately translates into higher firm performance. For example, payment levels positively affect firm productivity (Levine, 1992). By implementing employee-friendly policies that can increase employees security, the recognition of the company is increased and thus, the turnover of outstanding employees is reduced. Because innovation is long-term and high-risk (Holmstrom, 1989), it requires the long-term and steady involvement of outstanding employees. Work participation enables S&T employees to express their perspectives, and it increases their motivation levels. On-the-job training is a crucial method through which employees can acquire corporate know-hows and skills and transform them into corporate innovation output (Freel, 2005). There are many studies that have analyzed the impact of on-the-job training on firms, and these studies consider the following perspectives: the number of company patent applications (Gallié & Legros, 2012), and increasing the probability of achieving process innovation (Goedhuys & Veugelers, 2012).

The implementation of a series of measures through which S&T employees can be encouraged to mobilize their enthusiasm, as well as the provision of opportunities through which they can express their opinions in decision-making, is conducive to their job satisfaction. Therefore, we propose that the implementation of an S&T employees management policy is beneficial to corporate innovation, and we postulate that a corporate S&T employees management policy can moderate the relationship between S&T employees input and corporate innovation. Based on the preceding analysis, this study proposes the following hypotheses.

H4: S&T employees management exerts a significantly positive effect on the innovation performance of Chinese semiconductor companies.

H5: S&T employees management exerts a moderating effect on the S&T employees input and innovation performance of Chinese semiconductor firms.

The theoretical hypothesis model of the current study is depicted in Figure 1.

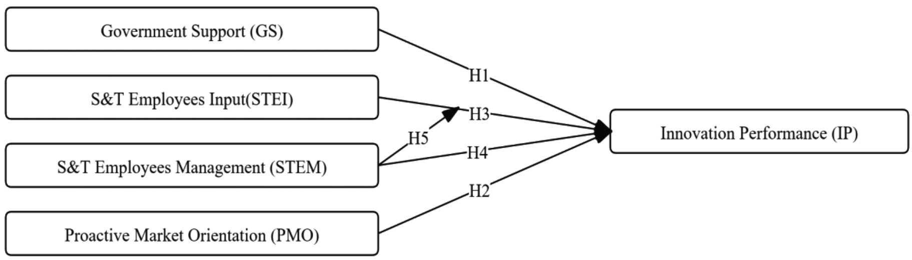

Figure 1. Conceptual framework

This study established research variables by summarizing the components of the sectoral innovation systems theory. Firms, government agencies, employees, and users are all participants in innovation , and have varying degrees of influence on the innovation. Sectoral innovation systems constructs the environment in which industrial innovation takes place so that actors within the sectoral innovation system interact with each other under the influence of certain factors. For instance, government agencies interacts with firms by formulating the industrial policies, firms establishes communication channels with employees through human resource policies, and firms exchange information with users through the market strategies.

4. Research methodology

4.1. Sample and data collection

Due to the technology embargo, the Chinese government has proposed an "independent innovation" model. Therefore, in the scenario where Chinese semiconductor companies represent the object of study, it is a worthwhile to analyze the factors influencing innovation in high-tech companies. Complexity of the corporate innovation process, the volatility of the market environment, and the uncertainty of the international political environment effect a more tortuous innovation process for Chinese semiconductor companies, it requires them to exhibit stronger innovation capabilities, and thus, they can overcome difficulties.

The questionnaire, which was derived from reliable scales obtained from existing studies, was translated into Chinese, (see Appendix for details). We utilized the traditional back-translation procedure to check the accuracy of the translation, and we consulted experts to correct the scale items according to the Chinese scenario and to remove unclear items. In addition, to ensure the accuracy of the data, we strictly screened the respondents. And the following groups were considered: engineers, R&D personnel, and managers of R&D teams involved in the implementation of corporate innovation activities; R&D managers of companies; and academics with no less than three years of innovation-based research experience in high-tech companies. Scholars engaged in innovation research were included as respondents and thus, this study obtained researchers' opinions on the factors influencing innovation from an academic research perspective. Finally, to protect their private information as well as the company's data, all respondents were anonymously surveyed.

This study distributed 1145 questionnaires via email to 145 semiconductor companies listed on the Shanghai Stock Exchange and Shenzhen Stock Exchange, as well as academics from universities and research institutions. However, only 324 valid questionnaires were received, with a valid response rate of 28.2%. the questionnaires were distributed and collected from February to May 2023. Descriptive statistics pertaining to the distribution of sample characteristics are illustrated in Table 1.

Table 1. Demographics of the sample

Variables	Features	Frequency	Percentage (%)
Age(years)	28_32	27	8.33
	33_36	110	33.95
	37_42	86	26.54
	43_48	33	10.19
	49_55	43	13.27
	56 and above	25	7.72
Academic Qualifications	Bachelors	24	7.41
	Master	208	64.2
	PhD	92	28.39
Work Status	Scholars	53	16.36
	R&D Participants	192	59.26
	R&D Team Manager	46	14.2
	Corporate R&D Manager	33	10.18

4.2. Evaluate the reliability and validity of the measurement

To ensure that the designed questionnaire exhibits satisfactory internal consistency and validity, this study first conducted a reliability and validity analysis. The results of the reliability analysis are depicted in Table 2. The results of the analysis indicates that the scale exhibits satisfactory internal consistency.

Table 2. Reliability analysis of scales and measured variables

Variables	GS	STEI	STEM	PMO	IP	Scale as a whole
Cronbach'α	0.866	0.857	0.965	0.943	0.867	0.963
Number of items	5	3	15	8	4	35

This study utilized confirmatory factor analysis (CFA) to measure construct validity. Furthermore, the confirmatory factor analysis (CFA) model fitness results pertaining to the scale are depicted in Table 3. Fitness index are all at an excellent level. Therefore, based on the analysis results, the CFA model of the innovation performance affect factors scale exhibits satisfactory fitness.

The convergent validity (AVE) and combined reliability (CR) of the measured variables will be further examined under the premise that the scale CFA model exhibits satisfactory fitness. The standardized factor loading of each measurement item were first calculated as per the established CFA model. Subsequently, the AVE and CR values of the five measurement varia-

Table 3. Fitness test of the CFA model

Fitness Index	X^2 /df	RMSEA	CFI	NFI	RFI	IFI	GFI	TLI
Measured Results	1.229	0.027	0.985	0.924	0.918	0.985	0.896	0.984
Reference Value	<3	<0.05	>0.9 is excellent					

bles were obtained by the convergent validity (AVE) and combined reliability (CR) calculation formulas, and the results are depicted in Table 4. The AVE values all exceeded the 0.5 level, and the CR values all exceeded the 0.8 level. Thus, in regard to the scale, all five measurement variables exhibited satisfactory convergent validity and combined reliability. The formulae for convergent validity and combined reliability are as follows:

$AVE = \left(\sum \lambda^2\right) \div n$ (λ denotes the normalized factor loading of the variable's measurement items; and n denotes the number of the variable's measurement items);

$CR = \left(\sum \lambda\right)^2 / \left(\left(\sum \lambda\right)^2 + \sum \delta\right)$ (λ denotes the normalized factor loading of the variable's measurement items; and δ denotes the standardized residual value).

Table 4. Results of convergent validity (AVE) and combined reliability (CR) tests

Path Relationships			Estimate	AVE	CR
GS1	←	Government Support	0.756	0.567	0.867
GS2	←	Government Support	0.798		
GS3	←	Government Support	0.732		
GS4	←	Government Support	0.749		
GS5	←	Government Support	0.728		
STEI1	←	S&T employees input	0.871	0.664	0.856
STEI2	←	S&T employees input	0.783		
STEI3	←	S&T employees input	0.788		
STEM1	←	S&T employees Management	0.851	0.65	0.965
STEM2	←	S&T employees Management	0.808		
STEM3	←	S&T employees Management	0.820		
STEM4	←	S&T employees Management	0.779		
STEM5	←	S&T employees Management	0.789		
STEM6	←	S&T employees Management	0.814		
STEM7	←	S&T employees Management	0.812		
STEM8	←	S&T employees Management	0.793		
STEM9	←	S&T employees Management	0.805		
STEM10	←	S&T employees Management	0.790		
STEM11	←	S&T employees Management	0.798		
STEM12	←	S&T employees Management	0.811		
STEM13	←	S&T employees Management	0.788		
STEM14	←	S&T employees Management	0.821		
STEM15	←	S&T employees Management	0.811		

End of Table 4

Path Relationships			Estimate	AVE	CR
PMO1	←	Proactive Market Orientation	0.812	0.676	0.944
PMO2	←	Proactive Market Orientation	0.819		
PMO3	←	Proactive Market Orientation	0.811		
PMO4	←	Proactive Market Orientation	0.794		
PMO5	←	Proactive Market Orientation	0.845		
PMO6	←	Proactive Market Orientation	0.838		
PMO7	←	Proactive Market Orientation	0.818		
PMO8	←	Proactive Market Orientation	0.840		
IP1	←	Innovation performance	0.786	0.62	0.867
IP2	←	Innovation performance	0.805		
IP3	←	Innovation performance	0.768		
IP4	←	Innovation performance	0.789		

The discriminant validity of the five measured variables of the scale was further examined, and the results are illustrated in Table 5. The test results indicated that the correlation coefficient between any of the measured variables and the other four measured variables was less than the square root of the convergent validity (AVE) of that variable. It indicates satisfactory discriminant validity between the measured variables.

Table 5. Results of the discriminant validity test

Variables	GS	STEI	STEM	PMO	IP
GS	**0.753**				
STEI	0.507***	**0.815**			
STEM	0.512***	0.571***	**0.806**		
PMO	0.519***	0.506***	0.59***	**0.822**	
IP	0.512***	0.58***	0.55***	0.537***	**0.787**

5. Analysis and summaries

5.1. Descriptive statistics and normality tests

The results of the descriptive statistics and normality tests for the items and measurement variables are depicted in Table 6. Descriptive statistics indicated mean scores between 4.5 and 6 for both items and measured variables. A 7-point Likert scale, which represents a positive count on a scale of 1 to 7, was applied. Therefore, with regard to five measurement variables, the results indicated that the respondents' cognitive and behavioral levels are above the medium level. Herein, skewness and kurtosis were utilized to test the normality of the items. The results indicate that the absolute value of skewness is within 3 and the absolute value of kurtosis is within 8 for all items, which meets the test criteria proposed by Kline (1998). Therefore, the test results can indicate that the data pertaining to the items approximately satisfy the normal distribution.

Table 6. The descriptive statistics of measured variables and normality test of items

Variables	Items	Mean	SD	Skewness	Kurtosis	Overall M	Overall SD
GS	GS1	5.759	1.246	–1.546	2.940	5.480	1.055
	GS2	5.451	1.345	–1.131	1.639		
	GS3	5.327	1.283	–0.648	0.445		
	GS4	5.457	1.296	–1.068	1.518		
	GS5	5.407	1.361	–1.042	1.291		
STEI	STEI1	5.000	1.584	–0.805	0.056	5.017	1.378
	STEI2	4.985	1.627	–0.830	0.009		
	STEI3	5.065	1.474	–0.795	0.195		
STEM	STEM1	4.932	1.655	–0.823	–0.117	4.874	1.432
	STEM2	4.867	1.729	–0.622	–0.486		
	STEM3	4.830	1.750	–0.662	–0.361		
	STEM4	4.873	1.775	–0.583	–0.593		
	STEM5	4.775	1.692	–0.592	–0.285		
	STEM6	4.923	1.752	–0.713	–0.346		
	STEM7	4.969	1.761	–0.692	–0.405		
	STEM8	4.787	1.735	–0.606	–0.472		
	STEM9	4.821	1.770	–0.586	–0.521		
	STEM10	4.892	1.808	–0.613	–0.577		
	STEM11	4.852	1.755	–0.650	–0.408		
	STEM12	5.012	1.724	–0.723	–0.329		
	STEM13	4.809	1.731	–0.592	–0.424		
	STEM14	4.914	1.792	–0.714	–0.414		
	STEM15	4.855	1.749	–0.636	–0.409		
PMO	PMO1	4.642	1.530	–0.524	–0.346	4.693	1.482
	PMO2	4.719	1.796	–0.535	–0.623		
	PMO3	4.611	1.648	–0.469	–0.492		
	PMO4	4.667	1.710	–0.537	–0.520		
	PMO5	4.753	1.899	–0.628	–0.737		
	PMO6	4.611	1.855	–0.606	–0.692		
	PMO7	4.719	1.759	–0.586	–0.597		
	PMO8	4.824	1.800	–0.651	–0.584		
IP	IP1	4.827	1.638	–0.711	–0.117	4.833	1.426
	IP2	4.806	1.723	–0.610	–0.400		
	IP3	4.775	1.697	–0.580	–0.393		
	IP4	4.923	1.689	–0.588	–0.432		

5.2. Correlation analysis

The study utilized Pearson correlation analysis to conduct an exploratory analysis pertaining to the correlations of the five measured variables. The results of the analysis (Table 7) depicted significant correlations between any of the variables and the other four variables, and all were significant at the 0.01 significance level (two-tailed). In addition, the correlation coefficients *r* between the variables all are greater than 0. Therefore, the analysis indicates that there is a significantly positive correlation between all the measured variables herein.

Table 7. Results of Pearson correlation analysis between variables

Variables	GS	STEI	STEM	PMO	IP
GS	1				
STEI	0.442**	1			
STEM	0.472**	0.502**	1		
PMO	0.472**	0.449**	0.561**	1	
IP	0.447**	0.491**	0.499**	0.486**	1

5.3. Structural equation model (SEM)

Table 8 indicates the model (Figure 2) fitness indicators that affect the structural equation model (SEM) of the factors influencing innovation performance. The model fitness test indicators reveal that the indicators are within a reasonable range, which indicates that the model fitness is satisfactory.

Table 8. Model fitness test

Fitness Index	X^2 /df	RMSEA	CFI	NFI	RFI	IFI	GFI	TLI
Measured results	1.344	0.033	0.976	0.912	0.905	0.976	0.881	0.974
Reference value	<3	<0.05	>0.8 is acceptable					

Table 9 depicts the results of the structural equation modeling (SEM) path relationship test for the factors influencing innovation performance. The path hypothesis relationship test, herein, indicates that government support exerts a significantly positive effect on innovation performance ($\beta = 0.131$, $p < 0.05$), and H_1 passes validation. Proactive market orientation exerts a significantly positive effect on innovation performance ($\beta = 0.175$, $p < 0.05$), and H_2 passes validation. S&T employees input exerts a significantly positive effect on innovation performance ($\beta = 0.353$, $p < 0.001$), and H_3 is confirmed. S&T employees management exerts a significantly positive effect on innovation performance ($\beta = 0.22$, $p < 0.05$), and H_4 is supported. In addition, S&T employees management did not exert a moderating effect on the relationship between S&T employees input and innovation performance ($\beta = 0.108$, $p > 0.05$), and H_5 did not pass the validation.

Table 9. Results of the SEM path relationship test

Path Relationship			Estimate	S.E.	C.R.	P
IP	←	GS	0.155	0.09	2.246	0.025
IP	←	STEI	0.353	0.099	3.966	***
IP	←	STEM	0.22	0.067	2.994	0.003
IP	←	PMO	0.175	0.059	2.543	0.011
IP	←	STEI*STEM	0.108	0.038	1.471	0.141

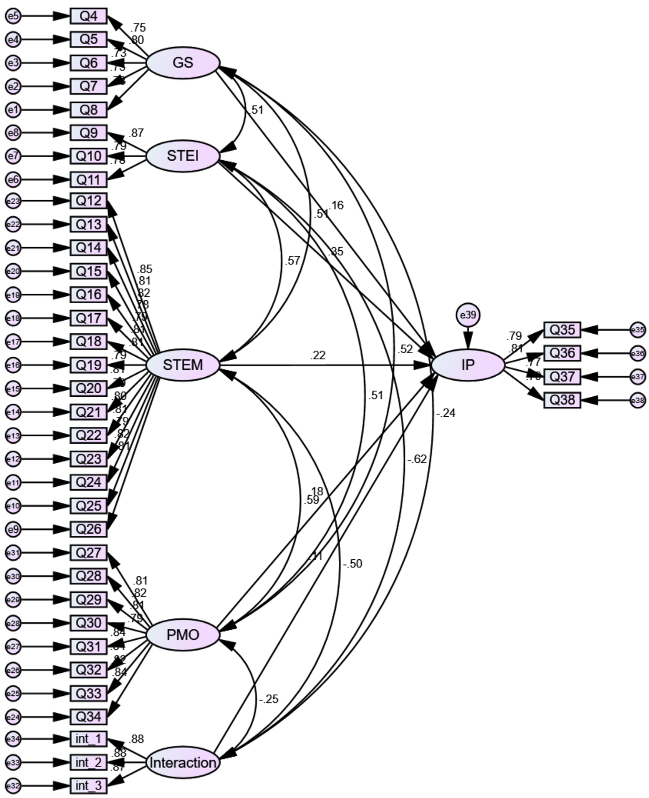

Figure 2. Structural EQUATION MODEL

5.4. Summaries

This study analyzed the factors influencing the innovation performance of Chinese semiconductor companies under the "independent innovation" model, and it utilized two perspectives (i.e., external and internal factors). External factors refer to government support and proactive market orientation. Internal factors include S&T employees input and S&T employees management. The hypothesis testing results indicated that government support, proactive market orientation, S&T employees input, and S&T employees management could positively affect the innovation performance of Chinese semiconductor firms. The content of the Government Support Scale suggests that many government support programs can significantly affect the innovation performance of semiconductor firms. Under the "independent innovation" model, government support positively impacts strategic industries that exhibit a national dimension. The government can utilize administrative interventions to support a certain industry or enterprise. The Chinese government should provide targeted and innovation-friendly programs to semiconductor companies to improve the efficiency of government resource utilization. High-tech firms relies on the specialized human capital for the innovation. The technological innovation in the semiconductor industry requires more breadth and depth of knowledge, and S&T employees are important resources for the technological innovation in the semiconductor industry. On the premise that the total number of S&T employees in China was insufficient. Semiconductor companies should strengthen the management of S&T employees, and comprehensively improves the salary and performance system, training inputs, work participation, and work environment. As it concerns the market, on the one hand, chips were widely used in smartphones, smart home appliances, automobiles, aerospace, military, etc., and their importance to high-tech enterprises is well known. On the other hand, since China's population is at the first in the world, there is a huge consumer market. Therefore, the market promise of the China's semiconductor industry is good. However, accelerated chip updates have made it more difficult for semiconductor companies to predict the technology development through user's demand preferences. Although China's semiconductor industry has a huge market, the real difficulties it faces are weak technical capabilities and slow product updates. Business operators understands the importance of the market for the innovation, but solving real difficulties still comes first.

6. Conclusions

By combing through the development history of China's semiconductor industry, it was found that it is experiencing the most difficult period. Firstly, the Chinese government's attention, investment, and policy support for the semiconductor industry was higher than in the previous three periods. However, the realities of insufficient funds, backward technology, and insufficient high-quality S&T employees had made it more difficult to "independent innovation". The gap between ideals and reality had hammered governments and entrepreneurs. The Chinese government must face the real difficulties of the technological innovation in the semiconductor industry. Secondly, the long-term reliance on imported equipment had led to weak capacity for independent production, as well as research and development. The existing production capacity of China's semiconductor industry is unable to meet the rapidly updating market changes. For example, SMIC can only produce 14nm wafers, but the current demand for smartphones is dominated by 7nm chips. Even if firms implementing the proactive market orientation are able to access users' demand preferences, they will not be able to manufacture products that satisfy customers' needs. Thirdly, whenever a Chinese semiconductor company breaks through a certain technology, it will be technologically sanctioned by the United States, making it more difficult to innovate independently. Technology sanctions can lead to the collapse of high-tech firms in China. For example, the U.S. banned TSMC for supplying chips to Huawei led to the divestment of the Honor phone from Huawei. If China's semiconductor companies are technologically decoupled from the global market will become information and market islands. Failure to realize independent innovation in the short term will affect China's economic and S&T development.

In summary, China's semiconductor industry is of national strategic significance. The formulation of S&T development strategies by the government indicated that the technological innovation in the semiconductor industry is a proactive innovation behavior of the Chinese government. However, it is inevitable that the process of innovation is sanctioned by the first-mover countries. From the perspective of the theory of catching up, when a catching-up country tries to break through technological barriers to overtake, the first-mover country will impose sanctions or embargoes on the catching-up country in order to maintain its leading position in the industry. From the analysis of sectoral innovation system theory, the technological innovation is never the independent behavior of a particular actor, but affects all participants in the industrial environment. The incumbent's response makes the catch-up environment even more volatile for the catcher. Therefore, the Chinese semiconductor enterprises should keep technical communication, and strengthen knowledge acquisition and accumulation on a global scale when facing the realistic conditions of insufficient capital, technology, and talents. In promoting the technological innovation in the semiconductor industry, the Chinese government should provide a favorable policy environment and remove obstacles for enterprises. It was encouraging to witness that the Integrated Circuit Industry Fund set up by the Chinese government in 2014 had helped companies to resolve the financial difficulties. In addition, China's semiconductor industry faced a shortage of total S&T employees. In the short term, it is difficult to resolve the conflict between the cultivation of talents in higher education and the demand for the S&T employees in semiconductor companies. This is because the S&T employees are the bearers of specialized knowledge and need to undergo a long period of the formal education. On January 13, 2020, the Ministry of Education issued an opinion on the pilot reform of enrollment in basic disciplines in some universities, and the implementation of the "Strong Foundation Program" had began in 2022, indicated that the Chinese government had valued basic research and reformed higher education to cultivate the basic research talents for high-tech enterprises.

The analysis results of this study indicated that the S&T employees were an important resource for the technological innovation in China's semiconductor industry. In the short term, it is not possible to solve the problem of insufficient total volume, but the Chinese government has carried out targeted reforms. Overall, the Chinese government and business operators were able to realize the difficulties faced by the semiconductor companies in the technological innovation, and provided solutions to the problem, which was a realistic manifestation of the government's support.

7. Theoretical and practical implications

7.1. Theoretical implication

There are two theoretical contributions to this study. The first is the development and enrichment of sectoral innovation systems. This study is based on the sectoral innovation system theory to analyze the factors affecting technological innovation in China's semiconductor industry. The sectoral innovation system provides the analytical boundary for this study, so the components of the sectoral innovation system provide the theoretical basis for identifying variables for this study. Analyzing the technological innovation of the semiconductor industry with the theoretical basis of sectoral systems can verify the scientific, and systematic feasibility of the sectoral systems with specific industries. The author tested whether the proposed variables play a role in the technological innovation process of semiconductor firms and the extent of their impact on the innovation performance. Therefore, this study is a typical case of empirically testing the theory of sectoral innovation systems, and enriches the knowledge of sectoral innovation systems theory. The second contribution is the enrichment of existing research variables as well as the proposal of more targeted variables. As far as human resources are concerned, the most commonly used in the existing literature is general human resources. While scholars have recognized the difference between generalist and specialized human resources, there are also differences in expertise among specialized human resources in different industries. Therefore, this study takes S&T employees as research subjects based on the multidimensional nature of the semiconductor industry's knowledge domain and designs survey questions so as to conduct a more targeted analysis. In addition, regarding HRM practices, this study adds practice measures based on existing research, such as compensation, benefits, work environment, and fairness. Therefore, this study enriches the factors influencing technological innovation in the semiconductor industry.

7.2. Practical implication

Since the U.S. sanctioned China's high-tech companies related to the semiconductor industry in 2018, it has become more difficult for China's high-tech industry to develop. Autonomous innovation is an imperative national strategy. The analytical results of this study provides guidance for the Chinese government as well as semiconductor companies in their technological innovation practices. Firstly, the government support significantly affects innovation performance provides empirical evidence for the government to formulate preferential policies for the semiconductor industry. The Chinese government should comprehensively analyze the difficulties faced by the semiconductor industry in the process of technological innovation to formulate specific, targeted, and effective industrial promotion policies. For example, China's semiconductor industry faces a shortage of S&T talents and funds. The Chinese government should address the lack of S&T talents and funds at the institutional level. Fortunately, the Chinese government has recognized the key issue of technological innovation in China's semiconductor industry, and has set up a series of measures. The Chinese government's implementation of the "Strong Foundation Program" in 2020 is a concrete measure to cultivate the S&T talents. The National Integrated Circuit Industry Investment Fund was established that is a concrete measure to solve the lack of funds. For firms, S&T employees input and management significantly affect innovation performance providing guidance for Chinese semiconductor firms to implement human resource strategies. The significant effect of proactive market orientation on innovation performance suggests that firms should implement market strategies targeting high-performance chips smaller than 7 nm to accelerate the process of technological breakthroughs. To summarize, the analytical results of this study are of practical guidance to the government in formulating industrial policies, as well as to enterprises in implementing human resource strategy and market strategy.

8. Limitations

From a theoretical perspective, sectoral innovation systems include five components. However, this study only involved the market, government, and S&T employees, and did not discussed some important influencing factors. For example, how enterprises access the external heterogeneous knowledge and internalize it into the enterprise-specific innovation knowledge by accumulating, absorbing and digesting it. With regard to knowledge, it involves knowledge sharing, R&D alliances, and the absorptive capacity of firms. In addition, the entrepreneurs, as the important promoters of innovation in Chinese semiconductor firms, and their awareness of innovation should also be discussed. From a practical perspective, the technology sanctions from the U.S. had devastated the China's semiconductor industry. The impact of environmental turbulence on technological innovation in China's semiconductor industry should be discussed in terms of the innovation environment. It was clear that Chinese semiconductor companies had lost market share as well as revenue. But could the environmental turbulence shake the China's determination to independently innovate, and could the technology sanctions completely stifle the technological innovation in China's semiconductor industry? These issues are worthy of discussion. Because the China's political system may play a role. The scope of this study did not covered the content mentioned above, and there were limitations to this study from both theoretical and practical perspectives.

In addition, the small sample size of this study and the low valid respondent rate might have affected the analyzed results. Therefore, in future studies, survey flaws should be avoided to improve the validity of the analyzed results.

9. The scope of future research

By summarizing the limitations of this study, it is found that there are more research contents worth exploring in the field of technological innovation in China's semiconductor industry. The sectoral innovation systems provides a more integrated scope of research for China's semiconductor industry. The authors will conduct further research based on the components of the sectoral innovation system and in-depth exploration of the innovation practices of China's semiconductor industry. Future research will analyze the impact on technological innovation in China's semiconductor industry in terms of knowledge sharing, firms' absorptive capacity, and environmental turbulence.

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Author contributions

Feng Yin and Woon-Seek Lee conceived the study and were responsible for the design and development of the data analysis. Yaoyao Guo was responsible for data collection and analysis. Feng Yin wrote the first draft of the article. Woonseek Lee was responsible for the final revisions.

Disclosure statement

The author declares that we have no competing financial, professional or personal interests with other parties.

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APPENDIX

Government Support (GS)

The government has

1. provided necessary technology information and support to our firm;
2. provided support for our firm to seek for financial resources;
3. provided support to import technology and equipment when we needed;
4. provided direct financial support to our firm such as tax reduction and subsidiary;
5. provided necessary legal support for our firm to enter a new market;

(Scale source: Shu et al., 2016).

Proactive Market Orientation (PMO)

1. We help our customers anticipate developments in their markets.
2. We continuously try to discover additional needs of our customers of which they are unaware.
3. We incorporate solutions to unarticulated customer needs in our new products and services.
4. We brainstorm on how customers use our products and services.
5. We innovate even at the risk of making our own products obsolete.
6. We search for opportunities in areas where customers have a difficult time expressing their needs.
7. We work closely with lead users who try to recognize customer needs months or even years before the majority of the market may recognize them.
8. We extrapolate key trends to gain insight into what users in a current market will need in the future.

(Scale source: Narver et al., 2004).

S&T Employees Input (STEI)

1. The ratio of the number of enterprise technology centers to the total number of employees;

2. Ratio of per capita income of enterprise technology center to per capita income of employees;

3. Ratio of per capita training cost of enterprise technology center to per capita income of center personnel;

(Scale source: Ballot et al., 2001).

S&T Employees Management (STEM)

1. The process of performance appraisal and salary allocation of scientific and technological talents is open and transparent;

2. The appraisal standard of scientific and technological talents is scientific and fair, in line with the work characteristics of employees;

3. Science and technology talent salary distribution standards are fair and reasonable;

4. The performance appraisal system of scientific and technological talents can solicit suggestions or opinions from employees;

5. The enterprise has established a good performance appraisal and supervision mechanism for scientific and technological talents;

6. The enterprise can make reasonable compensation distribution according to the size of scientific and technological talents' contribution;

7. The remuneration system of scientific and technological talents can be adjusted accordingly with environmental changes;

8. Enterprises encourage scientific and technological talents to put forward rationalized suggestions on management system;

9. The enterprise respects scientific and technological talents to put forward scientific suggestions on R&D projects;

10. Scientific and technological talents can participate in enterprise management decision-making activities;

11. The enterprise has established a good two-way communication system;

12. The enterprise has developed a good vocational training and learning plan for scientific and technological talents;

13. The enterprise has developed a scientific and specific innovation incentive system for scientific and technological talents;

14. The enterprise can strictly implement the innovation reward and punishment system for scientific and technological talents;

15. Enterprises support and encourage scientific and technological talents to combine innovation and growth;

(Scale source: Huselid, 1995).

Innovation Performance (IP)

1. The degree of growth of the number of new products;

2. The degree of growth of the number of patents;

3. The degree of growth of R&D investment;

4. Revenue of investment growth;

(Scale source: Hagedoorn & Cloodt, 2003).