Robot Impact and Innovative Quality

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Abstract: Enhancing the quality of innovation is an important measure to build a strong country in scientific and technological innovation. Based on Chinese province panel data acquired between 2011 and 2021, this study examines the direct influence of robots on innovation quality using the benchmark regression model first. Second, given the constraint factors of labor mismatch and entrepreneurial activity, the indirect and nonlinear impacts of robots' impact on innovation quality are investigated using the mediation effect model and threshold regression model. The results show that innovation quality is directly and significantly positively impacted by robots, and the outcome displays the traits of "Central > Eastern > Western." The robot impact can tangentially raise the quality of innovation by alleviating labor mismatch, and robot impact has a threshold effect on the quality of innovation depending on the features of regional heterogeneity, and under a high level of entrepreneurial activity, robot impact has a more advantageous and beneficial effect. This work offers a theoretical framework and scientific foundation for the quality of robot impact to support innovation.

Keywords: Robot Impact; Innovation Quality; Mediating Effect; Threshold Regression; Labor Mismatch; Entrepreneurial Activity

1. Introduction

Innovation is the primary driving force for development. We must abide by science and technology as the main productivity. Talent is the first resource. Innovation is the first driving force. Realization. Senior science and technology self-reliance. According to the Global Innovation Index 2023, it has risen rapidly over the past decade, rising 23 places and now ranking 12th in the world. However, Although China's innovation-driven policy is being implemented to encourage an increase in the degree of innovation generally, there is also a dilemma of "insufficient quantity and lame quality" [1], and there is an urgent need to break through the shortcomings of innovation quality and improve the national scientific and technological strength and international competitiveness.

Unlike other investment activities, talent is a key driver of the quality of innovation. The robot is often referred to as the "pearl in the crown." Its application, production, and research and development are crucial indicators of the level of high-end manufacturing and scientific and technological innovation in the country. Applying robots has a significant influence on the conventional labor relationship in the context of the current technology revolution and industrial upgrading, and the application of robots can not only affect labor demand [2] but also help enterprises optimize labor structure [3]. At present, China urgently needs to seize development opportunities to provide a steady stream of impetus for the enhancement of innovation's caliber. Currently, robot impact is a significant factor influencing efforts to raise the standard of innovation, so what is the internal working mechanism of the robot application that encourages higher-quality innovation? Furthermore, based on the characteristics of regional heterogeneity in China, is the robot's impact on the quality of innovation unique? To increase the power of national innovation and the quality of invention, a thorough examination of the influence of robots is essential.

The remaining portions of the article are organized as follows: The second part reviews the relevant research on robots, robot impact and innovation, and innovation quality; the third section explains the article's theoretical analysis and research premise. The fourth part introduces the measurement of data sources, constructing models, and related variables; the fifth part comprehensively analyzes the empirical results of this paper; and finally, we draw the main conclusions and suggestions for the future.

2. Literature Review

2.1 Research on Robot Impact

Robot impact and application is an area that has attracted much attention worldwide. Industrial robots are machines and equipment that are used in industrial automation, are versatile, reprogrammable automated control manipulators, can be programmed by artificial intelligence technology to achieve various manufacturing functions, and are also important representatives of Industry 4.0 [4]. The International Federation of Robotics (IFR) worldwide robot database involves robot data from multiple countries and industries globally and is currently the most authoritative database for extensive research on robots [5]. At present, most of the measures of robot impact are based on the model established by Acemoglu and Restrepo (2020) [5]. With the continuous expansion of the application scope of robots, the majority of current research focuses on the impact of robot adoption on employment [6,7], resources, and the environment [8,9]. To put it briefly, there is a wide range of businesses involved in pertinent robot research, and the future of robots seems endless.

2.2 Research on the Impact of Robot Impact on Innovation

How the application of robots affects enterprise innovation has become a hot issue in academic research. Throughout the existing research, scholars have affirmed the positive role of robot applications in innovation. Feng et al. (2023) confirmed that industrial robots have an incentive impact on innovation from the viewpoints of capital-machine and human-machine collaboration [10], Du et al. (2023) believed that the application of robots can exert governance effects and human effects, thereby helping enterprises improve their innovation capabilities [11], and Qu and Lv found that enterprises that apply robots have greater advantages in innovation input, innovation output, and innovation potential and have stronger innovation capabilities. Wang et al. (2023) argue that robotics applications promote innovation by increasing the equivalent of R&D staff members full-time and expanding the demand for highly skilled and highly educated personnel [12].

2.3 Research on the Quality of Innovation

Regarding the development of superior quality, the improvement of innovation quality is particularly crucial. The existing research on innovation quality is mainly concentrated on measurement methods, influencing factors, and improvement paths. First of all, regarding the level of innovation's quality, most scholars use patent indicators, such as the number of invention patent applications, the breadth of patent knowledge, and the number of patent references [13,14]. Second, about the factors that influence the quality of innovation, Li et al. (2023) found that the quality of innovation is impacted to a certain extent by the growth of the digital economy [15]. Li, etc. (2024) It is found that the national high-tech zone can significantly promote innovation [16] cooperation and considerably raise the standard of innovation, and the business environment and the political context are also important factors that influence the quality of innovation [1]. For example, Gao et al. (2023) believe that manufacturing enterprises can improve the quality of innovation through three paths: driven by internal and external resources, driven by executives under the incentive of market competition, and jointly driven by the environment and executives under the lack of profitability [17], while Li and Zhang (2024) summarized the high-innovation quality path into two models: multi-linkage and two-wheel drive [18].

To sum up, there is still room for improvement in the research on robot impact and innovation quality: first, the existing research mainly explores the relationship between robot application and innovation ability and innovation effect, as well as the necessity for further improvement of the complex interaction between robot impact and innovation quality; second, most scholars elaborate on the impact of robot application and innovation quality from the microenterprise level and lack a comprehensive definition of provincial innovation quality; third, the complex nonlinear relationship between robot impact and innovation quality needs to be explored urgently.

Different from previous studies, this essay is dedicated to delving deeply into the nuanced relationship between robotics and innovation quality, and there may be the following three marginal contributions: First, the deep relationship between robot impact and provincial innovation quality is discussed; Second, the internal mechanism of robot impact on innovation quality is explored from the perspective of labor mismatch; Finally, considering how China's regional growth is diverse, this paper makes an in-depth analysis of the nonlinear effect of robot impact on innovation quality to contribute some theoretical and practical value to China's construction of scientific and technological power.

3. Mechanism Analysis and Research Hypothesis

3.1 Direct Conduction Mechanism and Research Hypothesis

This study suggests that the robot effect can directly alter the quality of innovation in two areas, based on the studies mentioned above: external market stimulation and internal production demand.

On the one hand, based on the "Schumpeterian innovation theory," the fundamental engine of societal progress is innovation, and the excess profits brought by innovation have caused other enterprises to imitate each other, thus forming a wave of innovation. Robots have the advantages of reducing production costs and improving work efficiency. In situations when the output is equal, robot applications can lower manufacturing costs for businesses and increase profitability. To seek greater benefits and occupy a larger market share, enterprises will compete to improve research and development efficiency and the technical level to improve the quality of innovation.

On the other side, as technology continues to progress, companies pay more and more attention to improving production efficiency, reducing production costs, and optimizing production processes in the production process. Also, in the context of the continuous emergence of new technologies and new business forms, it is necessary to continue to innovate if we want to maintain the vitality of the enterprise and enhance our competitiveness. In general, to maintain vitality and competitive advantage, businesses must consistently engage in internal innovation initiatives to raise the standard of innovation.

Research hypothesis 1: Robot impact can directly promote the improvement of innovation quality.

3.2 Indirect Conduction Mechanism and Research Hypothesis

As an important human resource, one significant factor in innovative activities is the labor force. Robotics applications offer a competitive advantage over labor, according to earlier studies; therefore, the application of robots makes low-skilled workers be replaced by technology and the demand decreases, while there is a growing need for highly trained labor, having more highly qualified personnel would help businesses become more efficient in their R&D and produce higher-quality innovations. [19]. In general, the optimization of the labor structure satisfies the current demand for complementary high-level elements for new tasks [20], reduces the labor mismatch rate, and enables people to fulfill their responsibilities, thereby improving the quality of innovation.

Hypothesis 2: Robot shock's moderating effect on innovation quality is mediated by labor mismatch.

3.3 Nonlinear Conduction Mechanisms and Research Hypotheses

Robot influence could have a nonlinear effect on raising the standard of innovation. Given the reality of uneven regional development in China, different implications for robots on the caliber of invention may exist. To a certain extent, the degree of entrepreneurial activity reflects the regional institutional environment. Strong ability to obtain technology and resources, and often have high-quality resources such as professional talent teams, which may offer robust technical assistance for raising the standard of innovation. In areas with low entrepreneurial activity, there is often a lack of support for technological innovation and scientific research, and entrepreneurs' grasp of the market declines, increasing innovation risks. Entrepreneurs mostly adopt conservative strategies, thereby reducing the impact of robots on innovation quality.

Hypothesis 3: Robot impact significantly affects innovation quality in a nonlinear way, and this positive effect is more significant when the innovation activity is higher.

4. Model Establishment and Variable Measurement

4.1 Model Building

This research investigates the direct impact, indirect impact, and nonlinear impact of robot impact on innovation quality, respectively, using a fixed-effect model, a mediating effect model, and a threshold regression model. The following is a baseline regression model:

$$IQ_{it} = \alpha_0 + \alpha_1 RI_{it} + \alpha_n X_{it} + \lambda_i + \varepsilon_{it} \quad (1)$$

Among them, i and t are provinces and years, IQ_{it} represent the quality of innovation, RI_{it} represent robot impact, and X_{it} represent the control variables in the model, including four types of variables: economic development level (Gdp_{it}), government support (Gov_{it}), talent gathering (Hur_{it}), and environmental regulation (Env_{it}). In addition, in Eq. (1), α_0 represents the intercept term and the random perturbation term is denoted by ε_{it}, and the unobservable individual fixed effect is expressed by λ_i.

Furthermore, this paper introduces the mediating variable Labor Mismatch ($Misla$), uses the mediating effect model to explore the indirect impact mechanism of robot impact on innovation quality, and establishes the model as follows:

$$mediation_{it} = \beta_0 + \beta_1 RI_{it} + \beta_n X_{it} + \lambda_i + \varepsilon_{it} \quad (2)$$

$$IQ_{it} = \omega_0 + \omega_1 RI_{it} + \omega_2 mediation_{it} + \omega_n X_{it} + \lambda_i + \varepsilon_{it} \quad (3)$$

The intercept terms are β_0 and ω_0, the parameters to be evaluated are β_1, ω_1, and ω_2, the vectors of the parameters to be evaluated are β_n and ω_n, and the remaining variables are the same as those in equation (1).

Additionally, the threshold effect between robot impact and innovation quality is tested in this paper using a panel threshold regression model. The construction of a multiple threshold model is established as follows:

$$IQ_{it} = \mu_i + \theta_1 RI_{it} \cdot I(threshold_{it} \leq \gamma) + \theta_2 RI_{it} \cdot I(threshold_{it} > \gamma) + \theta_n X_{it} + \varepsilon_{it} \quad (4)$$

where, μ_i is the intercept term, θ_1 and θ_2 are the parameters to be estimated, θ_n is the parameter vector to be estimated, the indicator function is denoted by $I(\bullet)$, and the threshold value is shown by γ. If the associated conditions are met, the value is 1, else it is 0. The remaining variables remain unchanged from equation (1).

4.2 Measurement and Description of Variables

4.2.1 Explained variables

Drawing on the study of Li et al. (2023), this study takes the amount of forward patent citations as a characteristic variable of innovation quality[15]. Because patent confirmation reflects the inheritance, continuity, and accumulation of knowledge and technological innovation, and can better reflect the quality and influence of innovation, it is more recognized to measure the quality of innovation[21,22].

4.2.2 Core explanatory variables

The influence of robots is measured in this research using the robot install density, which has been widely used in the academic community. Firstly, this paper draws on the data collation method of Yan et al. (2020)[23], and compiles the installed number of industrial robots in various industries in China according to the Chinese industry classification standard published by the International Federation of Robotics (IRF) to obtain the number of robot installations in each industry, and then uses the techniques of Lu and Zhu (2021), Kang and Lin (2021) [24, 25] to determine the robot install density at the province level. The precise equation is as follows:

$$RI_{it} = \sum_{j=1}^{n} \frac{E_{ijt}}{E_{it}} \times \frac{R_{jt}}{E_{jt}} \quad (5)$$

where, the total amount of workers in industry j in region i in year t is represented by the symbol E_{ijt}. E_{it} is a representation of the number of workers in region i in year t. The variables R_{jt} and E_{jt} denote the number of robot installations and workers, respectively, in industry j and year t.

4.2.3 Mediation and threshold variables

Labor mismatch ($Misla$). Drawing on Chen and Hu[26] (2011), this paper measures the degree of regional labor mismatch by constructing a relative price distortion coefficient.

Entrepreneurial activity ($Enact$). Referring to the study of Bai et al.[27] (2022), this work is characterized by the number of new start-ups per 100 people in the city.

4.2.4 Control variables

To manage the influence of external circumstances on the caliber of innovation, drawing on existing studies such as Li et al. (2021)[28] and Chen and Li (2023)[29], a series of control variables are added in this paper. Economic Development Level (GDP): Expressed by the GDP of each region, Government Support (Gov): Characterized by local fiscal expenditure on science and technology, Talent Agglomeration (Hur): Location entropy method is used to measure the concentration of talent factors in each region, and Environmental Regulation (Env) is expressed by the amount of investment completed by industrial governance.

4.3 Data Sources and Descriptive Statistics

Thirty province-level regions in China from 2011 to 2021 were chosen as the research sample for this study. Data sources: National Patent Office, National Bureau of Statistics, China Statistical Yearbook, China Environmental Statistical Yearbook, etc. To mitigate heteroskedasticity and multicollinearity and enhance the estimation's accuracy and trustworthiness, we logarithmic the relevant variables, and the missing data in some years in the region were filled by linear interpolation. Table 1. shows the correlation coefficient matrix of each variable and its descriptive statistical results in detail.

Table 1. Correlation Matrix and Descriptive Statistics for Each Variable

	IQ	RI	Gdp	Gov	Hur	Env
IQ	1					
RI	0.821^{***}	1				
Gdp	0.820^{***}	0.875^{***}	1			
Gov	0.893^{***}	0.851^{***}	0.879^{***}	1		
Hur	0.608^{***}	0.389^{***}	0.397^{***}	0.631^{***}	1	
Env	0.329^{***}	0.292^{***}	0.488^{***}	0.343^{***}	0.109^{**}	1
Obs	330	330	330	330	330	330
Mean	8.1731	8.4684	9.8698	4.3398	1.4371	0.2162
Std. Dev.	1.644	1.5209	0.8637	1.0529	1.2749	0.2087
Min	3.7377	4.7123	7.4208	1.3244	0.2263	0.0005
Max	12.3357	12.1902	11.731	7.0637	6.867	1.416

5. Empirical Results and Analysis

5.1 Benchmark Regression Result Analysis

According to the benchmark model constructed by Eq. (1), in the regression analysis, China is split into three sections for the regression analysis: the eastern, central, and western regions. Table 2 lists the regression results of robot impact and innovation quality. In column (1), the impact coefficient of robot impact on innovation quality is 0.595, and it is significant at the level of 1%, demonstrating that robot impact is extremely beneficial to the improvement of innovation quality in general, and it is verified that the robot impact proposed in hypothesis 1 can directly promote higher-quality innovation. According to columns (2)-(4), it can be found that the impact of robot impact on the innovation quality of the three regions shows the results of "middle> east > west". This paper argues that the main reason is that the initial level of economic development and scientific and technological innovation in the eastern region is high, and the quality of innovation has made great achievements. Therefore, from the analysis results, the application of robots in the eastern region is slightly less effective in improving the quality of innovation than that in the central region. In other words, in the central region, driven by the application of robotics, the improvement of innovation quality is more significant. The central region has a latecomer in the management system and the scale of innovation, and the impact of robots can greatly enhance higher-quality innovation, inject new impetus into economic development and social progress, and thus maximize the benefits. The economic development level and human capital level of the western region are far behind those of the eastern and central regions, and the direct promotion effect of robots affect the quality of innovation is not obvious.

Table 2. Benchmark Regression Results

Variable	(1)	(2)	(3)	(4)
	Nationwide	Eastern	Central	Western
RI	0.595^{***}	0.596^{***}	0.789^{***}	0.495^{**}
	(-6.47)	(-5.34)	(-4.02)	(-3.13)
Gdp	0.324	0.922	-0.508	0.011
	(-1.08)	-1.7	(-0.73)	(-0.03)
Gov	0.132	-0.203	0.064	0.734^{*}
	(-0.72)	(-0.81)	(-0.17)	(-1.93)
Hur	0.005	0.106	0.017	-0.637
	(-0.02)	(-0.47)	(-0.03)	(-1.05)
Env	1.172^{***}	0.888^{**}	1.656^{**}	1.534^{***}
	(-5.05)	(-3.1)	(-2.71)	(-4.61)
Cons	-0.894	-5.313	5.725	0.879
	(-0.40)	(-1.28)	-1.07	-0.32
N	330	121	88	121
R^2	0.699	0.744	0.739	0.673

Table 3. Mechanism Test of the Impact of Robot Impact on Innovation Quality

	(5)	(6)
	Misla	IQ
RI	-0.090***	0.249***
	(-5.06)	(4.12)
Gdp	-0.086**	0.173
	(-2.24)	(1.36)
Gov	0.186***	0.786***
	(5.68)	(7.01)
Hur	0.132***	0.276***
	(10.04)	(5.60)
Env	-0.159**	0.118
	(-2.36)	(0.53)
Misla		-0.403**
		(-2.22)
Cons	0.994***	0.658
	(4.6)	(0.82)
Sobel test	Z=2.00 P=0.05	
Bootstrap test1	Z=2.38 P=0.02	
N	330	330
R^2	0.543	0.828

5.2 Mechanism Analysis

Table 3 presents the outcomes of the mediating mechanism test of robot shock affecting innovation quality, and according to the model's mediating and central explanatory variables' influence coefficient and significance level, it can be concluded that under the influence of labor mismatch, robot impact has an indirect effect on innovation quality to a certain extent, which offers enough proof to support Hypothesis 2 in our work.

The findings of a stepwise regression based on column (1) with labor mismatch as the mediating variable are shown in columns (5) and (6). It can be found that under the influence of labor mismatch, there is a mediating effect of robot impact on the quality of innovation. Every 1% change in robot shock will lead to a 9% decrease in labor mismatch, which in turn indirectly increases the quality of innovation by 0.036 (0.090*0.403), suggesting that labor mismatch innovation is improved by robot shock, which has a beneficial effect. The research results of this paper are generally consistent with the conclusions drawn by Feng et al. (2023)[10].

5.3 Nonlinear Effect Analysis

For the validity analysis of threshold regression results, the basic assumption of threshold effect should be satisfied. The single-threshold test is passed by the entrepreneurial activity, according to the findings of Bootstrap repeated sampling, but the P value is not significant in the double-threshold test, proving that the influence of robot impacts and the quality of innovation have a nonlinear relationship, supporting study hypothesis 3 put forward in this work. To more clearly see the threshold value's estimation and confidence interval, the likelihood ratio statistic (LR) of the least squares approach is utilized to identify the threshold value. The threshold estimate is the value obtained when the LR is zero, as seen in Figure 1.

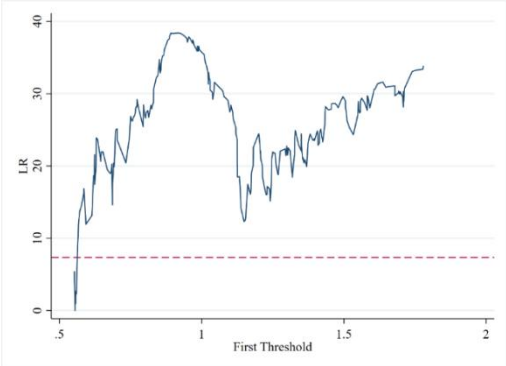

Figure 1. Likelihood Ratio Function of Entrepreneurial Activity

Table 4. Threshold Regression Results of Robot Impact on Innovation Quality

	(7) IQ
Threshold variables	Enact
Thresholds γ	0.5550
IQ·I (Threshold ≤ γ)	0.440*** (4.69)
IQ·I (Threshold ≥ γ)	0.540*** (5.76)
Gdp	0.410 (1.43)
Gov	0.048 (0.26)
Hur	-0.033 (-0.13)
Env	0.993*** (3.89)
Cons	-0.790 (-0.38)
F	92.34
N	330
R^2	0.728

The findings of the threshold panel regression for the impact of robots impact on innovation quality are shown in Table 4. In particular, after entrepreneurial activity surpasses the 0.5550 threshold, the coefficient of robot impact on the quality of provincial innovation increases from 0.440 to 0.540, showing an increasing characteristic. It can be argued that in regions with higher entrepreneurial activity, robot impact has greater potential to improve the quality of innovation. Furthermore, the research hypothesis 3 of this work receives good support from it.

5.4 Robustness Test

Table 5. Robustness Test

Variable	(8) l.IQ	(9) Delete the control variable	(10) 1% tail reduction on both sides
RI	0.821*** (8.46)	0.585*** (6.39)	0.643*** (8.39)
Gdp	0.103 (0.29)	0.281 (0.88)	0.231 (0.80)
Gov	0.018 (0.11)	0.142 (0.73)	0.065 (0.43)
Hur	0.337* (1.77)	0.137 (0.57)	0.148 (0.77)
Env	1.172*** (4.83)		1.219*** (5.53)
Cons	-0.817 (-0.32)	-0.367 (-0.16)	-0.303 (-0.14)
N	300	330	330
R^2	0.706	0.670	0.703

To investigate how reliable the empirical findings are, this paper examines the results of robot impact on innovation quality by transforming the explanatory variable[15], removing the control variable[30], and reducing the tail of 1% on both sides[31], as shown in Table 5. Firstly, taking into account the patent's validity, the explanatory variable in this paper is the patent citation, which used a lag of one year, and through comparative testing, we found that the results obtained were consistent with the previous studies in both significance and coefficient, which supported the paper's conclusions' robustness even more; Secondly, the control variable of environmental regulation is excluded in this paper, and the impact coefficient of robot influence on innovation quality is still significantly positive, which is essentially in line with the findings of the benchmark regression; Finally, to avoid outliers and outliers affecting the precision of the regression's findings, the data are processed by 1% tailing on both sides. The significance and coefficients of the results obtained were not significantly different from those above, indicating the reliability of the empirical findings in this work.

6. Conclusions and Recommendations

Using panel data spanning from 2011 to 2021, this paper expounds on the impact of robots on innovation quality from three aspects: direct effect, indirect effect, and nonlinear impact, and the following are the primary conclusions: (1) Robot impact is positively correlated with invention quality and exhibits "central> eastern> western" traits, which is an important force in improving the quality of innovation in China.

(2) Robot impact has different degrees of indirect impact on innovation quality. Robot shock can improve the quality of innovation by mitigating labor mismatches.

(3) Regarding the robot impact's promotion of the innovation quality, there is a notable threshold effect. When the entrepreneurial activity is higher than the threshold, the impact of robots on the innovation quality is more significant.

The conclusions of this paper have certain policy implications for promoting robot impact and improving the quality of innovation:

(1) Comprehensively improve the application level of robots. Therefore, governments at all levels need to formulate policies that are conducive to the development of robotics technology and products and encourage enterprises to further improve the application level of robots, to help improve the quality of innovation.

(2) Accurately formulate the impact propulsion strategy of robots in each region. The findings demonstrate that the effects of China's robot revolution on innovation quality are not limited by labor mismatch, but also exhibit the traits of "central> eastern> western.". In the eastern region, the level of economic development and scientific and technological strength have been significantly improved. The level of human capital is more reasonable, the innovation index is higher than that of other regions, but its technological efficiency is exhibiting a notable tendency of convergence, such areas should guard against impetuousness, steadily improve the technical level, optimize the allocation of resources and achieve efficient use to promote the overall improvement of innovation quality; Although the economic level and scientific and technological level of the central region are backward compared with the eastern region, but exhibit a stronger innovation effect, making them powerful latecomers; hence, these sectors ought to focus on the active introduction of technology, build a robot industry system, and provide a favorable environment for the impact of robots to promote the quality of innovation; The western region's development is somewhat lagging, and the eastern and central regions should enhance their own strength at the same timeand jointly drive the common development of the western region.

(3) Improve the activity of regional entrepreneurship and lay the foundation for giving full play to the positive role of robot impact. The previous study found that robot impact can enhance innovation quality by influencing entrepreneurial activity. Therefore, it is necessary to actively provide support for saving the cost of innovation and entrepreneurship and expanding the innovation and entrepreneurship market, such as continuing to inject capital into small and medium-sized enterprises, optimize the policy environment, actively stimulate the vitality of entrepreneurship and innovation, and contribute an important force to improve the quality of innovation.

Even though this research assesses the process by which robots affect the innovation quality and offers recommendations based on the real world, there are still certain limitations. The mechanism of the robot's influence on innovation quality is examined in this work. To further fully uncover the mechanism black box of the robot's impact on innovation quality, we can attempt to incorporate additional mediating or moderating variables, such as information spillover, in the follow-up research.

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