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National industrial investment fund and China's integrated circuit industry technology innovation

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ABSTRACT

Since the emergence of information technology, the integrated circuit industry has been a major contributor to sustained economic expansion. This paper proposes a theoretical model premised on the pertinent theories of technological progress in late-mover countries and concludes that it is challenging for late-mover countries to rely solely on market mechanisms to elevate the level of social technology; state policy support is indispensable. In addition, this paper employs the panel data of 81 A-share listed integrated circuit companies in China from 2011 to 2019 and implements the Difference in differences (DID) method to evaluate the impact of the National Integrated Circuit Industry Investment Fund on the technological innovation of the integrated circuit industry, and adopts the double-difference propensity score matching method for supplemental verification. This paper concludes that the National Integrated Circuit Industry Investment Fund has significantly enhanced industrial technological innovation and that the estimated results premised on the difference-in-difference based on propensity score matching (PSM-DID) method and the placebo test are not substantially differentiated from the benchmark regression results. The effects of industrial investment funds on policy are evidently different across different regions and industry chains, in accordance with research on industry heterogeneity. The promotion effect of the core link is significantly stronger than the support link in terms of branches of the industrial chain, and the Pearl River Delta region has a more pronounced promotion effect in terms of regions. Verification of the mechanism demonstrates that industrial investment funds can relieve corporate financing constraints, optimize corporate human capital structure, promote corporate RandD (research and development) investment, and subsequently promote technological innovation in the integrated circuit industry through the aforementioned three effects. On the one hand, the research presented in this paper offers empirical support and policy guidance for the implementation of technological innovation in China's integrated circuit industry. On the other hand, it also has significant reference value for fostering the growth of industrial investment funds.

Introduction

The introduction and advancement of integrated circuits have accelerated the development of information technology, thereby facilitating sustained economic growth. With the emergence of a new generation of information technologies, such as artificial intelligence and 5 G (5th Generation Mobile Communication Technology), in the 21st century, intelligent manufacturing has become a focal point in a number of countries, thus further boosting the demand for integrated circuit products. The growth of the integrated circuit industry has also attracted an increasing amount of attention from developed countries, as the governments of these countries have issued pertinent policies to promote the growth of the integrated circuit industry (Feng, 2018; Tomoo, 2020). Research demonstrates that technological innovation is the primary driving force behind the growth of the integrated circuit industry (Walsh et al., 2005; Cheng et al., 2010). As a consequence, clarifying the factors influencing the technological innovation of the integrated circuit industry and investigating the means and routes to promote the technological innovation of the integrated circuit industry are significant research aspects of industrial economics and also the primary driver for the government to develop economic policies and enhance the quality of economic development (Fan and Liu, 2020; Luo et al., 2022). Undoubtedly, theory and practice benefit greatly from in-depth research on this subject.

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Economic policy is crucial in fostering innovation in integrated circuit technology, as demonstrated by the growth of China's integrated circuit industry (Miao et al., 2019; Ding and Fang, 2019). Nevertheless, the integrated circuit industry is characterized by a large investment scale, a long return period, and a high level of technical complexity. Satisfying the medium- and long-term financing needs of businesses is challenging due to financial capital's focus on short-term profits, and traditional financial subsidies are difficult to monitor and measure (Aghion et al., 2015; Fan and Wang, 2019). Theoretically and practically, its results are easily contested. Therefore, can a policy instrument combine the benefits of financial capital and government investment to mitigate the drawbacks of financial capital and government investment? Through this policy instrument, the government not only fulfills the medium- and long-term financing needs of businesses but also enables the monitoring and measurement of the results of government investment, thereby promoting technological innovation and the sustainable growth of the integrated circuit industry. The National Integrated Circuit Industry Investment Fund, which the Chinese government established in September 2014, is one exemplification of such a policy instrument, according to our findings. The National Integrated Circuit Industry Investment Fund creates a fund pool with state-owned capital as an evolutionary form of financial subsidies and participates in the operation of target enterprises through the market-oriented method of bonds and equity, which not only eases the financial pressures that enterprises face but also sends a positive message to social capital, so as to direct enterprise investment and encourage technological innovation (Zhang and Zheng, 2021; Wang et al., 2022).

The results of the analysis presented above led to the choice of the subject matter for this research paper. Will the National Integrated Circuit Industry Investment Fund promote industrial technological innovation? Can the fund investment promote technological innovation and industrial growth for businesses in the integrated circuit industry? China's establishment of the National Integrated Circuit Industry Investment Fund in 2014 can be regarded as a quasi-natural experiment of this policy instrument, offering an excellent opportunity for this article to furnish answers to the aforementioned questions. In light of the fact that China's integrated circuit industry is pursuing a high-quality development path, it is of great theoretical value and practical guiding significance to study the impact of the national integrated circuit industry investment fund.

As the first national-level market-oriented operation industry fund that has been effectively implemented, the existing literature lacks a quantitative evaluation of its relationship with innovation, and the majority of studies focus on qualitative issues such as development status and defects (Liu, 2019). In terms of theoretical demonstration, this article attempts to build a mathematical model of the technological progress path of late-developing countries on the basis of existing research and analyzes the technological progress of late-developing countries under different circumstances. In terms of empirical research, this paper uses the relevant data of China's A-share listed integrated circuit companies from 2011 to 2019 and implements the difference in differences (DID) method to explore the role of the National Integrated Circuit Industry Investment Fund in promoting technological innovation in China's integrated circuit industry. This article has the potential to make at least three marginal contributions, which are as follows:

(1) The systematic evaluation of the role of national industrial investment funds in scientific and technological innovation enriches the research on the interaction between fiscal policy and enterprise behavior. However, one of the difficulties in current research is how to measure the mechanism of macro policies on micro enterprises (Rao et al., 2016). This study provides new empirical evidence for a more comprehensive understanding of the effects of industrial policies. Furthermore, focusing on national industrial investment funds with Chinese characteristics will help China further optimize relevant policies and measures and promote industrial development (Zhang and Zheng, 2021).

(2) Demonstrate the significance of state intervention in industrial technological advancement. The discussion of policy effects has dominated prior literature on fiscal policy and industrial technological innovation. The current research on fiscal policy is biased toward effect research (Lian et al., 2022; Zuo and Lin, 2022), but it does not pay much attention to why fiscal policy should be used at the current stage. This paper focuses not only on policy effects but also on the necessity of fiscal policy implementation, i.e., using a theoretical model of technological progress paths in late-mover countries to demonstrate that intervention measures play a crucial role in the entry of late-mover countries into the stage of independent innovation, consequently enhancing research on government intervention.

(3) To offer a theoretical and practical framework for technological innovation in late-mover countries. The theoretical analysis of this paper illustrates that in situations where the market mechanism is insufficiently developed and social and economic development levels are comparatively low, the use of suitable intervention techniques can encourage the advancement of industrial technology level and enable the country to pursue its own independent innovation (Aghmiuni et al., 2019; Huang et al., 2022). Moreover, Esteban et al. (2013) believed that economists should not only argue about whether industrial policies need to be implemented but also explore how to implement industrial policies optimally. Empirical analysis reveals that China, as the world's largest developing country, has its own peculiarities, but under the assumption of eliminating the interference of other factors, industrial funds have additional benefits in terms of improving corporate financing constraints, optimizing corporate human capital structure, and boosting corporate RandD investment. Consequently, the industrial fund has a degree of scalability and can aid late-mover countries in integrating market and government forces to achieve technological innovation in their own industries.

The structure of the article is arranged as follows: The second part sorts out the existing research on fiscal policy and technological innovation of the integrated circuit industry and theoretically analyzes the factors affecting the technological progress of the integrated circuit industry and the direct effect of the National Integrated Circuit Industry Investment Fund. The third part builds the corresponding DID model on the basis of introducing the policy background and explains the variable indicators and data. The fourth part uses the panel data of China's A-share integrated circuit listed companies for analysis and discusses the robustness and heterogeneity. The fifth part further analyzes the effect of the National Integrated Circuit Industry Investment Fund from the aspect of the influence mechanism. The sixth part draws conclusions and corresponding policy recommendations.

Literature review and mechanism analysis

Literature review

Many academics have investigated the underlying factors underneath technological innovation from various angles. Innovation ecosystem (Sydow and Müller-Seitz, 2018; Elia et al., 2020; Li et al., 2022), independent intellectual property rights (Chen and Xue, 2010; Li, 2019; Wang, 2019), fiscal policy (Zhang and Zheng, 2021; Luo et al., 2022; Li and Li, 2022), etc. are all significant factors influencing the technological innovation of the integrated circuit industry. The research in this paper is based on a number of different factors, while the literature on fiscal policy is the most relevant. However, the research conclusions of the related literature are inconsistent and can be divided into two categories: the first category holds that fiscal policy encourages technological advancement in the integrated circuit industry. The research of Fang (2006) and Yu (2008) proves that the technological advancement of the Japanese integrated circuit industry is dependent on government policies. Japan was successfully transformed into an integrated circuit power as a result of the government's VLSI (very large scale integration) planning and financial subsidies. Lu et al. (2014) discovered that interventions such as financial subsidies could have a significant positive impact on the innovation output of strategic emerging industries. According to Kong et al. (2014), government support can efficaciously encourage the participation of Chinese integrated circuit (IC) enterprises in RandD (research and development) activities. Wang and Wang (2019) noted that the improvement of China's integrated circuit industry efficiency is closely tied to preferential tax policies and that the policy effects are considerably different at the stages of technology research and development and achievement transformation. Gu (2019) utilized China's listed integrated circuit companies as a research sample and noticed that under the influence of financial subsidies, companies could obtain more equity financing, thereby increasing their RandD investment. Aghmiuni et al. (2019) discovered that government-supported innovation policies have a sizable impact on the expansion of biotechnology innovation activities. Gao (2020) discovered that industrial support policies consist of distinct phases. Early policies can significantly reduce the tax burdens placed on corporations, while medium-term policies can increase investment in integrated circuit companies through the establishment of measures such as the fund. Chen (2020) used the double-difference method to determine that preferential tax policies can significantly boost the number of invention patent applications of integrated circuit enterprises and that the policy effect is influenced by factors such as the size of the enterprise, the nature of ownership, and the location of the enterprise. Fan and Xu (2020) noticed that the establishment of an entire innovation chain policy tool system, from basic research to industrialization, will assist in encouraging industrial technological innovation. Zuo and Lin found in 2022 that Under the premise of high-quality accounting information, financial subsidies can effectively increase the RandD expenditures of businesses. Lian et al. (2022) discovered that under the constraints of environmental regulation policy, government subsidies encourage green innovation in business operations.

According to the second school of thought, fiscal policy is not conducive to technological innovation in the integrated circuit industry. The growth of Taiwan's integrated circuit industry and governmental intervention strategies like fiscal policy, according to Ouyang (2006), are not strongly and causally related. He believes that reducing the agency problem within government agencies is the most important factor. The research of Wang and Rao (2007) signifies that the preferential tax policy conflicts with China's tax system, thereby diminishing the effect of the policy on the technological advancement of the integrated circuit industry. In addition, the period of regular reduction and exemption of tax incentives, the absence of prior support, and the benefits to RandD-engaged businesses are limited. The State Taxation Bureau of Fujian Province's research program has confirmed this theory (2008). South Korea's IC industry cannot succeed by relying solely on government promotion, as Kim (2011) claimed, and it is more important to increase the competitiveness of South Korean companies by establishing ties between the government, academia, and industry. Liu and Tian (2012) suggested that China's tax incentives are primarily regional tax incentives and that there is an absence of systematic policy formulation. Kim (2018) realized that for China, the fiscal policy of the central government is more aggressive than that of local governments and that such aggressiveness may contribute to uncertainty in the industrial structure. Zhou and Li (2019) looked into the current preferential tax policies associated with the integrated circuit industry and concluded that the relevant preferential policies lack support and have an insufficient incentive effect on industrial development. This is because the existing tax breaks are not yet completely integrated and incorporated into the system. The characteristics of the circuit industry match those of a fragmented industry, and there is still a significant gap between forming a systematic policy system and introducing a risk compensation policy, which diminishes the investment appeal of the industry. Sun and He (2020) observed that the tax reduction and exemption of corporate income tax have no significant effect on the technological progress of enterprises for integrated circuit enterprises. Song et al. (2021) revealed that financial subsidies did not improve corporate performance, as it was necessary to account for the moderating effect of market mechanisms on the effect of financial subsidies. Yang et al. (2022) discovered that the effect of financial subsidies is contingent not only on the subsidies themselves but also on the recipients of the subsidies and how they are obtained. Subsidies to industries the government does not support have any positive effect, as do subsidies obtained through non-standard means. Thus it is believed by the author that the impact of ongoing updates to fiscal policy tools, which may have been overlooked in the aforementioned literature, provides a solid foundation for further investigation of the connection between fiscal policy and technological advancement in the integrated circuit industry in this paper.

Mechanism analysis and research hypothesis

Analysis of factors affecting technological innovation

The term "technological innovation" can be defined as the process by which economic entities increase their level of technical sophistication through the acquisition of patents, equipment, or other external means or through the development of novel technologies and other endogenous means. Economic entities with relatively low levels of technology typically adopt external strategies to implement technological innovation in accordance with the path of technology introduction since the cost and risk are lower under this strategy, and technological innovation is easier to implement. On the other hand, the majority of economic entities with a relatively higher level of technical sophistication utilize the endogenous method to realize technological innovation along the path of independent research and development, as this method allows them to maintain their own competitive advantages.

In this process, the accumulation of factors such as capital, labor, and knowledge spillover will significantly impact the technological innovation capability of economic entities regardless of the method or path assigned. The above three elements can be represented by financing constraints, human capital structure, and RandD intensity predicated on practical considerations. This paper focuses primarily on the impact of these three types of factors on technological innovation. However, as the fundamental unit of the industry, it is even more important to recognize the impact of the preceding factors on the enterprise.

Technological innovation necessitates substantial capital expenditures for all businesses, so it is necessary to consider the impact of financing constraints on changes in the technological level of businesses. Financial constraints impede technological progress (Ayyagari et al., 2007). First, financing constraints inhibit the continuity of corporate innovation, thereby jeopardizing corporate interests. The lack of willingness from private sector investment is a result of the high risk involved in technology research and development. In the case of investment willingness, due to the consideration of risk and return, the investment volume is modest, and the return period is brief; resource allocation must maximize business interests, and the scale of privately held funds used for research and development is marginal, making it challenging to fulfill the ongoing demand for significant sums of funds for technology research and development. Lack of funding can cause RandD at one point in the project process to stall, which can slow down project progress or even result in the failure of the entire endeavor. In the event of project failure, the company will be unable to recoup its substantial research and development expenditures and will be forced to absorb the resulting losses. As it stands, technological research and development is a major stumbling block to expanding business output. Second, when businesses are faced with limited financial resources, the commercialization of their technological research and development results may be delayed, to their detriment. When businesses face financial constraints, their investments in RandD personnel and equipment are constrained, resulting in slower technological innovation under the same conditions or even forced interruptions, which lengthen the time required to transform technological innovation achievements. In a competitive market, firms with financing constraints cannot gain a competitive advantage; consequently, their market share and value creation decrease. Third, when companies are faced with financing constraints, they may reduce RandD outlays due to rising financing costs. The unpredictability of technology research and development makes it difficult for investors to evaluate the benefits of related projects; therefore, a higher risk premium is necessary to compensate for investment risks. Currently, the innovation cost of businesses is rising, and under the same conditions, innovation funds are being constrained by the high cost of capital. This results in inadequate investment, making innovation difficult to achieve its desired outcomes.

However, relieving corporate budgetary pressures cannot fully resolve the obstacles to technological innovation in corporations. Under the premise that all other conditions remain unchanged, enterprises facing the same financing constraints have varying technological research and development performance. The RandD intensity of a business (Sharma, 2012) and the level of human capital accumulation (Lucas, 1988) are also significant determinants of technological innovation. The initial technological level of the late-mover country and the first-mover country determines the extent of technological innovation that can be achieved by its introduction or imitation for enterprises from late-mover countries adopting the path of non-independent innovation; that is, late-mover countries cannot increase their technological level unrestrictedly through non-independent innovation paths. Liu (2011) believes that under these conditions, the late-mover countries can achieve a higher level of technological advancement by following the independent innovation path; in order to achieve technological innovation, the late-mover countries will increase the scale of RandD investment and the proportion of investment in independent RandD. Human capital is the most important and direct factor influencing technological innovation. Human capital, as the primary source of scientific and technological innovation, can play a significant role in the process of technology research and development, enable the transformation of scientific research achievements, and promote the dissemination of science and technology. The greater the level of human capital, under the assumption that all other conditions remain unchanged, the greater the capacity for technological innovation. The degree of structural optimization is closely related to the level of human capital. In other words, the higher the degree of the human capital structure optimization, the greater the level of human capital, and the stronger the scientific and technological innovation capacity of late-mover countries. This innovation capability enhancement accelerates the dissemination of science and technology, promotes the faster transformation of scientific research results, and enables late-mover countries to achieve technological innovation.

Analysis of technology innovation path of the late-mover country

The preceding analysis demonstrates that there are two avenues for developing countries to achieve technological innovation in the industrial sector: introduction and independent research and development. The path will be impacted by financing restrictions, RandD intensity, and human capital structure, regardless of which one is designated. The question of how to combine these two different paths with the aforementioned three components and how government interventions affect the realization of technological innovation must then be further addressed.

Barro and Sala-I-Martin (1997)) and Wei (2014) confirmed that both the introduction of technology and independent research and development can contribute to technological innovation, thereby fostering economic growth. However, the advantage of latecomers is not always realized, and Wei (2014) based his research on the fact that there are countries in the world, such as Mexico and Argentina, that have not yet tumbled into the middle-income trap. That is, the economy has reached a steady state and cannot enter a state of relying on independent innovation to promote technological progress when the technological progress path of a late-mover country is still in the imitation stage. What can be performed instead to avoid falling into the trap of technical imitation? Referencing the studies of Barroand Sala-I-Martin (1997)), Wei (2014), and Peng (2019), this paper further optimizes the relevant assumptions of the model, restricts the introduction of technology to late-mover countries to make it more realistic, and considers the introduction of state intervention as an exogenous shock. Consequently, it analyzes the technological innovation status of late-mover countries at various stages of development and provides a theoretical foundation for the empirical research as follows:

In the interest of clarity, this article assumes the existence of a two-sector economic system. The first department is responsible for the production of the final product. The second department is also a production department; however, it is tasked with the manufacture of intermediate products. Final goods can be consumed or invested in technology and production, whereas intermediate goods are monopolized by capital investment. As a late-mover economy, the primary means of achieving technological innovation are restricted to introducing and imitating advanced technology and independent research and development. The introduction and imitation of advanced technology are referred to as non-independent innovation in order to distinguish the path chosen by the economic system.

(1) Final product production department

According to the model put forth by Barro and Sala-I-Martin (1997)), Wei (2014), and Peng (2019), the final product market is assumed to be a perfectly competitive market. Taking into account the technical complexity, the function of the final product production sector can be written as follows:

$$Y_t = \left(\int_0^J A_{it} x_{it}^{\alpha} L^{1-\alpha} di \right)^{\frac{1}{\alpha}}, 0 < \alpha < 1, A_{it} \geq 1 \tag{1}$$

Y_t is the total industrial output in period t, A_{it} is the technical level of the sector i in period t, x_{it} is the number of specialized intermediate products used by firms in period t, J is the number of product types, and α is output elasticity. Due to the low technological level of late-mover countries, it is assumed that the marginal revenue of intermediate product input does not change. L represents the number of industrial labor. To simplify the discussion, assuming that L is fixed in the economy and normalized to 1, (1) can be transformed into:

$$Y_t = \left(\int_0^J A_{it} x_{it}^{\alpha} di \right)^{\frac{1}{\alpha}}, 0 < \alpha < 1, A_{it} \geq 1 \tag{2}$$

(2) Intermediate product production sector

We assume that firms use production capital to establish monopolies in the production of intermediate products, and for the purpose of simplicity, the production function is expressed as a linear expression:

$$x_{it} = K_{it} \tag{3}$$

The product production capital of a particular sector i in period t is denoted by K_{it}. To simplify the relevant discussion, this paper refers to the relevant assumptions of Wei (2014), and assumes that the intermediate manufacturers have the same input in product production and are in a perfectly competitive capital market, and the production cost can be represented by the rental rate R_{it} of production capital. At this point, each firm produces the same amount of intermediate goods, that means $x_{it} = x_t$, and x_t can be written as:

$$x_t = \frac{1}{J}\sum_{i=1}^{j} K_{it} = \frac{K_t}{J} \tag{4}$$

Substituting (4) into (2), the output function is transformed into

$$Y_t = x_t J^{\frac{1}{\alpha}}\left(\int_0^J A_{it} di\right)^{\frac{1}{\alpha}} = x_t J^{\frac{1}{\alpha}} A_t^{\frac{1}{\alpha}} \tag{5}$$

Among them, A_t represents the overall technical level of late-mover countries.

This paper restricts the use of production capital to two categories as a matter of simplicity: investment in technology research and development and production of intermediate products, assuming that the new capital is fully utilized in a single period and there are no issues with legality or depreciation. To further calculate production costs, this paper refers to the steady state equation in the neoclassical economic growth model and fixes the overall social savings of late-mover countries as a constant s. Therefore there is

$$K_t = \sum_{1}^{J} K_{it} = sY_t - I_t \tag{6}$$

Among them, I_t represents technology investment in period t.

Assuming that the cost-plus method is adopted to set the price of intermediate products, the degree of technological sophistication of the products has a significant impact on the price of intermediate products in the monopoly sector. If the technology level of the product is higher, the price of the intermediate product will be higher; thus, it can be assumed that the price $p_{xt} = A_t R_t$. According to the previous assumption, the final product manufacturer operates in a perfectly competitive market environment; correspondingly, the value contained in the intermediate product is equal to the value contained in the final product; there is $\sum_{n=1}^{J} P_x^n x_n = JP_x x = P_y Y$, for simplicity, the value of this equation is set to 1.

The profit of a monopoly firm can be expressed as $\pi_t = P_{xt}x_t - R_t K_t / J = \frac{1-A_t^{-1}}{J}$. The profit margin brought by the new technology is $\phi = \frac{d\pi}{dA} = \frac{A^{-2}}{J}$. In addition, it is essential to consider all of the present and future benefits that the new technology can bring to the business. From the perspective of the time value of money, all profits should be discounted to period t under the assumption that the new technology can generate profits for the enterprise indefinitely. Therefore, the discounted present value $v(t)$ in period t, that is, the marginal market value of the new technology, can be expressed as:

$$v(t) = \int_t^{\infty} e^{-[R(\tau)-R(t)]}\pi(\tau)d\tau \tag{7}$$

(3) Technical department

When the potential benefits of acquiring new technologies are greater than their associated costs, entrepreneurs will invest in the acquisition of new technologies. According to the preceding analysis, the path to technological innovation is classified into two categories: non-independent innovation and independent innovation.

First, the progress path of non-independent innovation. Frequently, first-mover countries preserve their advantage by preventing the spread of crucial technologies and transferring only mature ones. In fact, after acquiring technology transfer, late-mover countries can raise the technological level of their local societies. When the gap between the technological level of the first-mover countries and the technological level of the latter-developing countries reaches a critical value, the first-mover countries will provoke events such as trade conflicts to prevent the technological level of the latter-developing countries from continuing to advance. We, therefore, hypothesize that as the level of technology rises, the investment associated with technology transfer will drive technological innovation less effectively. Liu (2011) noted that when the intellectual property protection system is imperfect, late-mover countries adopt the non-independent innovation path to increase their own technological level; however, after reaching a certain cost threshold, enterprises abandon the introduction and imitation of technology in favor of independent innovation. Therefore, the gradual improvement of the intellectual property protection system in late-mover countries will have a negative impact on the effectiveness of technology transfer in achieving technological innovation. The technological level of late-mover countries shifts as follows:

$$dA = [I/(A^{\alpha} m^{\alpha})]dt, 0 < m < 1 \tag{8}$$

Among them, m represents the intellectual property protection system, and the larger m is, the more perfect the current social, intellectual property protection system is.

Multiplying the marginal market value v of the new technology by the change in technology level in 7 yields the marginal benefit vdA obtained by investing in technology transfer in late-mover countries. The current value of the investment cost, according to Wei (2014), the is $RIdt$. From the point of view of profit, only when the marginal benefit is greater than the current cost, that is, $vdA > RIdt$, will manufacturers in late-mover countries choose to acquire new technologies through technology transfer, and when $vdA \leq RIdt$, manufacturers will not choose technology transfer. Therefore, for technology transfer, there is a marginal market value tipping point $v_0 = (mA)^{\alpha}R = \frac{m^{\alpha}A^{\alpha-1}}{Jx}$, when $v > v_0$, technological progress rate $\dot{A} > 0$, when $v \leq v_0$, technological progress rate $\dot{A} = 0$.

Second, independent innovation path. When late-mover countries choose the independent innovation path, the level of change in their technology is influenced by factors such as their current technological prowess and the capacity of domestic businesses for technological innovation.

On the basis of the preceding analysis, the financial constraints and human capital structure are presented. Assuming financing constraints are inversely proportional to changes in technology levels, whereas RandD investment and human capital structure are proportional to changes in technology levels, under the path of independent innovation, changes in technology levels can be expressed as:

$$dA = m^{\alpha}A^{\alpha}HI/(F)dt \tag{9}$$

H stands for innovative human capital. I represents technology investment, and F represents the degree of financing constraints. In a similar manner, multiply the (7) by the change of technology level to obtain the marginal benefit vdA obtained when the enterprise adopts independent innovation, and the current investment cost is $RIdt$. Similar to technology transfer analysis, for independent innovation, there is a critical point of marginal market value $v_1 = RF/(m^{\alpha}A^{\alpha}H) = \frac{F \cdot A^{-\alpha-1}}{m^{\alpha}JHx}$, when $v > v1$, enterprises will choose to invest in independent innovation, technological progress rate $\dot{A} > 0$, when $v \leq v_1$, technological progress rate $\dot{A} = 0$.

(4) Market static equilibrium

Total output and total demand must be equal to achieve static equilibrium. Substitute (5) into (6), and multiply both sides of the equation by P to obtain:

$$JPx_t = sPx_tA_t^{\frac{1}{\alpha}}J^{\frac{1}{\alpha}} - IP \tag{10}$$

Substitute $JP_xx = 1$ into (10); we can obtain:

$$sPx_tA_t^{\frac{1}{\alpha}}J^{\frac{1}{\alpha}} - IP = 1 \tag{11}$$

When an enterprise chooses the path of non-independent innovation, substituting Eqs. (2)-8 into Eqs. (2)-11 and adjusting for the critical value v_0, the technological progress rate is:

$$\dot{A} = \begin{cases} \left(sA^{\frac{1}{\alpha}}J^{\frac{1}{\alpha}-1} - 1\right) \cdot \dfrac{1}{P(mA)^{\alpha}} v > v_0 \\ 0 v \le v_0 \end{cases} \tag{12}$$

Correspondingly, when a business chooses to innovate independently, the technological progress rate can be calculated by substituting (9) into (11) as:

$$\dot{A} = \begin{cases} \left(sA^{\frac{1}{\alpha}}J^{\frac{1}{\alpha}-1} - 1\right) \cdot \dfrac{(mA)^{\alpha}H}{P \cdot F} v > v_1 \\ 0 v \le v_1 \end{cases} \tag{13}$$

For the purpose of simplification, we assume that an enterprise can only choose one path at a time; therefore, when an enterprise decides to acquire new technology, it must choose between technology transfer and independent innovation in conformity with the maximization of profits principle. Specifically, compare the marginal yields of two investments. At this time, there is a critical value A_0 so that $v[I/(A_0^{\alpha}m^{\alpha})]dt = vm^{\alpha}A_0^{\alpha}HI/(F)dt$, which means $A_0 = m^{-1}(F/H)^{\frac{1}{2\alpha}}$, there are different technological innovation paths before and after A_0, when $A > A_0$, the enterprise will choose independent innovation, and when $A \le A_0$, the enterprise will choose technology transfer. Substitute A into (12) and (13) to obtain:

$$v = \begin{cases} v_0, A < A_0 \\ a, A = A_0 \ , v_0 < a < v_1 \\ v_1, A > A_0 \end{cases} \tag{14}$$

According to the critical values v_0 and A_0, it is possible to summarize the choice of technological innovation paths for enterprises in late-mover countries, as shown in Table 1:

In addition, capital market equilibrium should also be considered. During the same period, the marginal market value of the new technology consists of the profits generated by the enterprise from acquiring the new technology and the resulting changes in the net value, namely $\phi dt + \dot{v}dt$, and the corresponding risk-free bond investment return is $rvdt$, where r is the investment return. Under the perfectly competitive capital market, assuming that the technology RandD department is risk-neutral, with $r = R$, that is, the investment rate of return is equal to the capital rental rate; thus, the capital market equilibrium expression is:

$$\phi dt + \dot{v}dt = Rvdt \tag{15}$$

Therefore:

$$\dot{v} = Rv - \frac{A^{-2}}{J} \tag{16}$$

Utilizing A as the horizontal axis and v as the vertical axis, (16) and (14) are incorporated into a road map for technological innovation. Let $\dot{v} = 0$, then, $v = \frac{A^{-2}}{JR}$ is the marginal market value curve of the new technology. The curve indicates that the marginal market value of technology is inversely proportional to the technological level. The marginal market value of new technology is higher when the current technological level of society is lower; moreover, as the technological level of society rises, the marginal market value of the new technology will also decrease. Given any point in the coordinate system, when it is above the curve, there is $\dot{v} > 0$. At this time, the marginal market value of the new technology will further increase. In contrast, when it is below the curve, there is $\dot{v} < 0$, and the marginal market value of the new technology will further decline.

For (14), neither technology transfer nor independent innovation can offset the investment cost in the region below the horizontal line. At this time, neither option is being considered by the business, and the current level of social technology will not be altered. The $v = v_0$ horizontal line intersects the $v = \frac{A^{-2}}{JR}$ curve at point B. For points B and below B on the curve, the technical level will remain unchanged, and the marginal market value of the new technology is equal to the risk-free bond investment return, which is in a state of equilibrium. For late-mover countries, the initial state frequently occurs in the intersection area above the $v = v_0$ horizontal line and below the $v = \frac{A^{-2}}{JR}$ curve, and any point in this area will converge to point B. At the beginning of the period, the technical level is low, and the marginal market value of new technologies is high. The enterprise will increase technology investment, encourage the adoption and imitation of technology, raise its own technology level, and lower the marginal market value of new technology based on the principle of profit maximization. When the technological innovation path intersects with $\dot{A} = 0$ and is tangent to the marginal market value curve of the new technology at point B, the technological level of the enterprise does not change, the marginal market value of the new technology remains at v_0, and the enterprise reaches an equilibrium state. Fig. 1 shows the path of the enterprise technology level converging to equilibrium.

(5) Technological traps of late-mover countries

Scenario 1: Falling into the “Independent Innovation Path Trap”

At point B, the enterprise has reached a balance between the technological level and the marginal market value of the new technology, and it will no longer take steps to advance its own technological level. Assuming that the technological level at point B is A_B, as long as the gap between A_B and A_0 remains stable, exogenous shocks are insufficient to alter the equilibrium state of the enterprise, and the technological level of late-mover countries will stagnate for an extended period of time. This condition is referred to as the “non-independent innovation path trap.”.

For this state, late-mover countries should take intervention measures to move the curve to the upper right, causing A_B move to the right, or to move A_0 to the left and v_1 to move down, and finally make the curve intersect Eq. (2)-14 at $v = v_1$ horizontal line; the

Table 1
The choice of technological innovation path of enterprises in late-mover countries.

Condition	$A < A_0 = m^{-1}(F/H)^{\frac{1}{2\alpha}}$		$A > A_0 = m^{-1}(F/H)^{\frac{1}{2\alpha}}$		$A = A_0 = m^{-1}(F/H)^{\frac{1}{2\alpha}}$
Situation	$v/(mA)^{\alpha} > R$	$v/(mA)^{\alpha} \le R$	$v(mA)^{\alpha}H/F > R$	$v(mA)^{\alpha}H/F \le R$	$v/(mA)^{\alpha} = v(mA)^{\alpha}H/F$
Action	non-independent innovation	not select any path	independent innovation	not select any path	not select any path
Rate	$\dot{A} > 0$	$\dot{A} = 0$	$\dot{A} > 0$	$\dot{A} = 0$	$\dot{A} = 0$

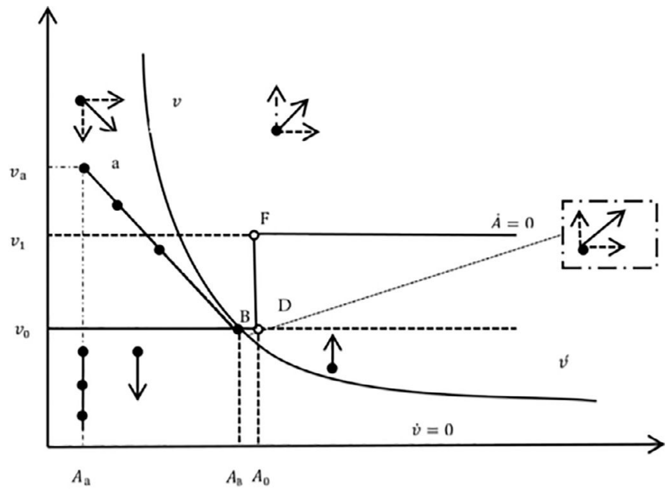

Fig. 1. The technological level of the enterprise converges to the equilibrium state.

equilibrium point is C. For the initial state in the intersection area above the $v = v_1$ horizontal line and below the $v = \frac{A^{-2}}{JR}$ curve, it will follow the independent innovation path and converge to point C. Point C has a higher technical level and a higher marginal market value. Fig. 2 depicts the path for enterprises to transform into independent innovation.

Scenario 2: "Independent Innovation Path Trap" in late-mover countries

The late-mover countries take intervention measures to impel equilibrium point B toward equilibrium point C; the movement trajectory is B-D-F-C. (both move along a straight line). The entire movement process can be separated into three stages: B-D, D-F, and F-C. In the beginning stage, the late-movers promote the transition from point B to point D. At this point in time, there has been an increase in both the social and technological levels; however, the marginal market value of the new technology has not changed. In the second stage, point B is transferred to point F. At this time, the marginal market value of the new technology continues to increase, but the technology level always remains at A_0. In the third stage, point B traverses point F and advances to point C. At this time, the level of social technology continues to advance while the marginal market value of new technology remains at the level of v0. In the process of moving from point B to point F, the intervention measures of late-mover countries cannot advance the social and technological level but can only increase the marginal market value of new technologies. This situation qualifies as the "independent innovation path trap" being experienced by late-mover countries. Fig. 3 depicts the trajectories of businesses caught in the independent innovation path trap.

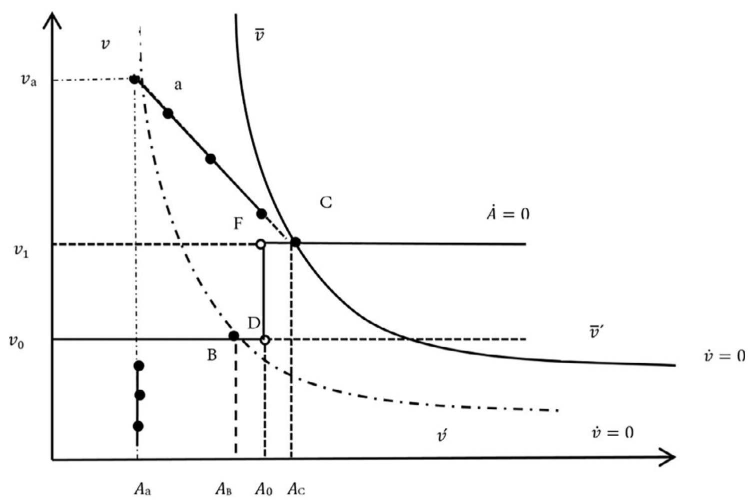

Fig. 2. Enterprise transformation to independent innovation.

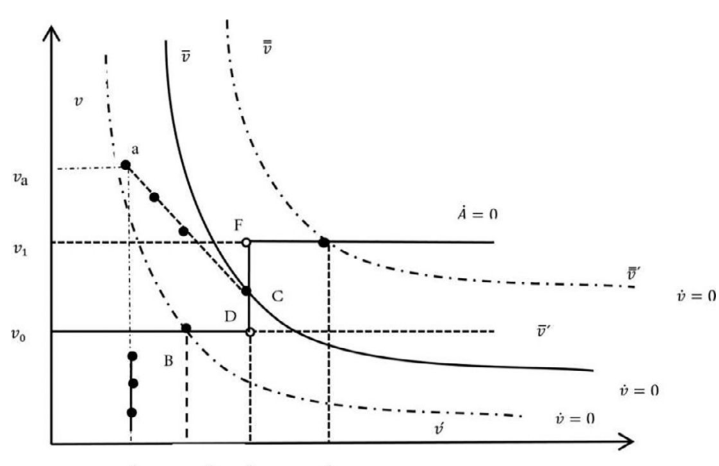

Fig. 3. Enterprises fall into the trap of independent innovation path.

In the “independent innovation path trap,” state intervention measures that are implemented too late cannot improve the social and technological level in the short term. Only by shifting the marginal market value curve of new technologies to the right and causing it to intersect with the horizontal line $v = v_1$ can society embark on the path of independent innovation. It requires more time and resources for late-mover countries to push the curve along DF. This level of consumption exceeds the tolerance of most countries and is a major factor in that many developing countries cannot improve their independent innovation capabilities.

(6) Whether to follow the comparative advantage

As stated previously, technological innovation paths can be divided into two categories based on whether they follow comparative advantages. In the event that a late-mover country adopts the path of following comparative advantage, it will first arrive at equilibrium point B along the path of technological imitation. Thereafter, long-term intervention measures are implemented to assist the industry in escaping the “traps of non-independent innovation paths” and the “traps of independent innovation paths” and to facilitate the movement from equilibrium point B to equilibrium point C. In this scenario, the industry must endure long-term technical-level stagnation, suffer from path lock-in, and incur higher economic costs. If the path deviating from the comparative advantage is assumed, the late-mover country must shift the curve to the right and intersect the horizontal line $v = 1$ at point C. When this occurs, the technological level of the country that was a late mover will have arrived at the equilibrium point C along the path of independent innovation. Theoretically, this path is superior to the comparative advantage-based path. Fig. 4 depicts the decision regarding the comparative advantage of technological innovation.

The theoretical model constructed in this paper provides solid evidence that the government should employ appropriate intervention strategies to encourage technological innovation. This model presupposes that there are no government intervention measures and that businesses operate in a completely competitive market environment. In the absence of external intervention, given the initial state of the enterprise, the enterprise will move toward equilibrium point B and remain there, forming a steady state. At this point, businesses are caught in the “traps of non-independent innovation paths,” and the marginal market value of new technologies and technological advancements is low, which results in a significant waste of social resources and limits the continued development of late-mover countries. To gain a competitive advantage, late-mover countries will take appropriate intervention measures to push businesses out of equilibrium at point B, aiming to raise the technological level of society as a whole. To maintain their competitive advantage, first-mover countries will impose restrictions on later-mover countries in an effort to keep them in the “traps of non-independent innovation pathways.” In order to achieve the same level of technological innovation as the first-mover countries, the later-developing countries must sustain a longer and larger investment period. That is to say, the national power competition between first-mover countries and later-developing countries is essentially the prime motivator behind the industrial development of various countries, which cannot be completed by enterprises independently. It is important to emphasize that a pro-interventionist stance does not necessarily imply a rejection of free market mechanisms. Following this model, late-mover countries intervene prudently to shift the curve. The aim is to foster an environment that is more fair and competitive for industrial development, allowing the market mechanism to more effectively determine how resources are allocated and resulting in a dynamic equilibrium between the government and the market.

Policy mechanism analysis

The preceding theoretical analysis substantiates the significance of intervention measures to realize industrial technological innovation in late-mover countries. However, the model does not demonstrate explicitly how government interventions influence technological innovation. As the focal point of this study, the China Integrated Circuit Industry Investment Fund will serve as a case study for analyzing the mechanism underlying the industrial fund’s role in technological innovation.

The participation of industrial funds in enterprise management is a critical component of corporate governance, with direct investment effects, signal guidance effects, and indirect competition effects. These three factors influence the degree of financing constraints, RandD expenditures, and the human capital structure of businesses, thereby influencing technological innovation.

(1) The direct investment effect. The scale of the first phase of the industry fund, which is close to 140 billion yuan, indicates that a substantial amount of capital will enter China’s integrated circuit industry between 2015 and 2019. In addition, the industry fund engages in investment and financing activities through the establishment of sub-funds and leasing companies to develop a multi-level financing system for China’s integrated circuit industry. Regarding its impact on technological innovation in the integrated circuit industry, the direct investment effect of industrial funds can help improve the financing environment of businesses and increase their RandD expenditure. Concerning the financing

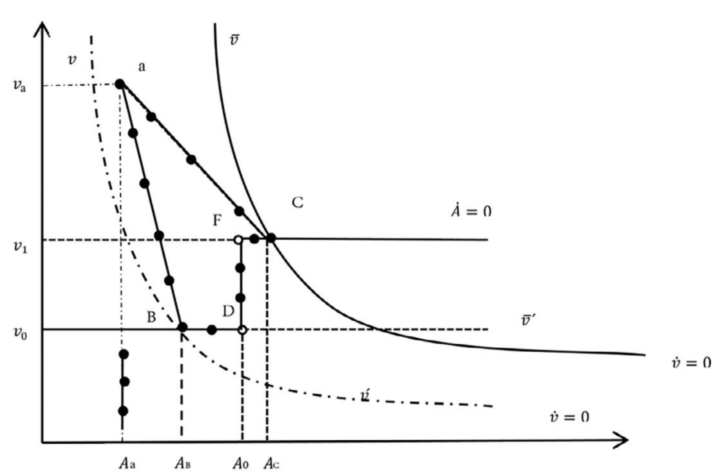

Fig. 4. Whether the enterprise follows the technological innovation path of comparative advantage.

environment, industrial investment funds can directly inject capital into enterprises and relieve the financial pressure on enterprises; they can also boost the investment propensity of businesses. Enterprises may raise their expectations for future investment returns after receiving funding, enabling them to resume an investment plan that had been put on hold due to unpredictability as their willingness to invest has grown. Considering RandD investment, the industrial fund can supervise the decision-making of the enterprise through institutional shareholding and rely on the RandD decision of the enterprise to guide the enterprise in upgrading its existing equipment and enhancing its innovation level.

(2) Signal guidance effect. The establishment of industrial funds can send positive signals to the market, facilitating social capital participation in relevant investments in the integrated circuits industry. Compared to other industrial policies, industrial funds are more concentrated and targeted, indicating that the integrated circuit industry is a key industry in which the state government will concentrate its efforts in the future, reflecting its commitment to developing this industry. This makes the policy more consistent and guides businesses in establishing reasonable long-term expectations for it. In addition, the government backing of the industrial fund can provide a symbolic investment guarantee for the investment risk of financial capital, instill confidence in the financial capital, and leverage the funds of social institutions and even individual funds to participate in the investment. Additionally, the signal guidance effect of industrial funds helps to mitigate the financing strain on businesses. As a barometer of capital investment, industrial funds can increase investors' recognition of businesses and entice more capital investment. Simultaneously, the positive signals released by industrial funds can help reduce the information asymmetry between investors and businesses, thereby increasing investors' willingness to invest.

(3) Indirect competition effect. The industry fund offers potential market entrants policy support in addition to innovation sources for currently operating domestic integrated circuit companies. In the five years following the establishment of the Industrial Fund, 34 integrated circuit companies went public, accounting for 39% of the total number of integrated circuit companies before 2015. This effectively increased market competition in the integrated circuit industry and cultivated innovative activity. The commissioning of a 12-inch silicon wafer production line, the supply of China Micro's semiconductor etching machine to TSMC, and the progress made in the domestic 7 nm process are all instances of significant advancements in related technologies in China's integrated circuit industry from 2019 to 2020. Such developments represent an improvement in the domestic integrated circuit industry's independent innovation capabilities. The indirect competition effect of industrial funds is advantageous for businesses seeking to increase RandD expenditure and optimize human capital structure. Technology RandD is characterized by a large scale, a long cycle, and a high level of risk, which discourages investors from making investments. Likewise, the cultivation of technology RandD talent necessitates substantial enterprise investment over an extended period of time. However, the mobility of talent will increase the risk of enterprises optimizing their human capital structure, thereby impeding industrial technological innovation. The degree to which businesses are willing to invest in technological research and development and employee training will be influenced by market competition. In China, the technology gap between firms within the same industry is typically limited. When market competition is intense, companies invest more in technology RandD and talent development to gain a competitive edge. When the level of competition among businesses is low, the low pressure to survive will motivate enterprise management to develop steadily to reduce their own risks. Therefore, sufficient market competition will increase the pressure on businesses to survive, compelling them to increase their investments in RandD and talent to achieve or maintain a competitive advantage.

This paper presents the research hypothesis based on the above analysis. Under the assumption that other conditions remain unchanged, the implementation of the National Integrated Circuit Industry Investment Fund can alleviate financing constraints, increase enterprise RandD investments, and encourage enterprises to optimize their human capital structure, thereby nurturing technological innovation in the integrated circuit industry.

Research method

In 2014, China operated industrial funds for the first time in a market-oriented manner, providing strong support for the development of the integrated circuit industry and providing a good case study for this paper to examine the effects of fiscal policy. This section primarily analyzes the policy effects of industrial investment funds using the financial data of A-share-listed companies from 2011 to 2019.

Policy background

The level of technology prevents China's integrated circuit industry from achieving high-quality growth. However, there are stumbling blocks to mastering essential technologies and establishing independent intellectual property rights, such as high financing constraints, low RandD investment, and urgent human capital structure optimization. Despite the fact that the Chinese government has increased its investment in the integrated circuit industry each year, it does not appear to have significantly improved the technological innovation of businesses. The lack of long-term, large-scale investments is the primary factor inhibiting technological innovation. On September 24, 2014, the Chinese government and eight large enterprises established the National Integrated Circuit Industry Investment Fund to open up capital channels, encourage enterprises to increase their investments in research and development, and enhance the human capital structure. Since then, seven additional companies have participated in capital increase and share expansion in December 2014, resulting in the formation of a large capital injection fund by 15 companies. This is China's first national industrial investment fund operating in a market-oriented manner.

In terms of scale, the first phase of the industrial fund is the largest investment by the Chinese government in the integrated circuit industry since the reform and opening up, amounting to 138.72 billion yuan in total. The investment scope of the first phase of the industrial fund encompasses the entire integrated circuit industry, the funds are primarily oriented toward the manufacturing sector, and social capital is encouraged to participate in the investment of the whole chain of the integrated circuit industry. Methodologically, the first phase of the industrial fund will inject capital into the target company in the form of equity or debt investment and withdraw from relevant projects through repurchase, public listing, etc., at the appropriate time to avoid excess capacity and vicious competition.

The second phase of the IC investment fund was established in October 2019 after the first phase of fund investment was completed. Its objective is to compensate for any potential shortfalls left by the initial investment in order to establish a sustainable innovation capacity. However, large-scale investment has not yet begun; therefore, this paper is within a good time window to evaluate the first phase of industrial investment funds.

Model settings

The National Integrated Circuit Industry Fund invested in 17 A-share listed companies during its first phase, and these investments were primarily made in 2015, according to announcements and financial reports of listed companies. The enterprises in the sample in which the fund made an investment in 2015 were classified as the experimental group, while the remaining enterprises were defined as the control group.

Evaluation of industrial investment funds is conducted using the DID estimation method. Construct the policy dummy variable du and the time dummy variable dt, let the enterprises that have received investment in the sample be the experimental group and assign the value 1, and let the enterprises that have not received investment in the sample be the treatment group and assign the value 0; assign the year 2015 and later to 1, and before 2015 to 0.

According to the above analysis, the model set in this paper is as follows:

$$y_{i,t} = \beta_0 + \beta_1 du \times dt + \sum_{i=1}^{N} b_j X_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \qquad \text{(Model 1)}$$

Among them, y is the technological innovation of the enterprises in the sample. $X_{i,t}$ is the control variable of the corresponding model, which controls several related variables that affect the total factor productivity of enterprises. μ is the individual fixed effect of the enterprise, which represents the characteristics of the company's registration location that do not change with time. δ controls the annual fixed effect and controls certain external shocks that affect enterprises over time, such as economic fluctuations and national policy changes, etc., ε is the disturbance term. Control variables consist of firm size, age, financial leverage, and return on assets.

Variable selection and data interpretation

Total factor productivity can be adapted to represent technological innovation in the integrated circuit industry from the perspective of sustainable development (TFP). Regarding the estimation method of TFP, this paper refers to the practice of Levinsohn and Petrin (2003) and employs the LP method to determine the total factor productivity, which can be expressed as:

$$\ln\ Y_{it} = \alpha_0 t + \alpha_1 \ln L_{it} + \alpha_2 \ln K_{it} + \alpha_3 \ln M_{it} + \varepsilon_{it} \qquad \text{(Model 2)}$$

Among them, i represents the corresponding enterprise, and t represents the corresponding year. Among the above variables, Y indicates the output, which is represented by the main business income of the enterprise, and the unit is million yuan; L is the labor input, which is represented by the number of employees, and the unit is person; K is the capital input, which is represented by the net fixed assets, and the unit is million yuan; M is the intermediate input, expressed in cash paid for purchasing goods and accepting labor services, and the unit is million yuan. To ensure the logarithm of the variable value and to minimize the impact on the estimation accuracy, this paper employs the method of adding 1 to the above variables.

This paper addresses the following additional elements that influence the technological advancement of businesses:

(1) Enterprise size (Size). Let Size=ln (the total assets of the enterprise), in which the unit of the total assets of the enterprise is million yuan. Yang et al. (2015) discovered that the technological innovation of enterprises is highly correlated with their scale; as the scale of an enterprise expands, it is able to invest more resources in technological research and development under a similar condition. Consequently, the natural logarithm of the firm scale is utilized as one of the control variables.

(2) The age of the enterprise (Age). Let age = observation time - the year of establishment of the enterprise + 1. As the age of the enterprise increases, its technological accumulation, talents, capital, and other elements become more comprehensive. Therefore, this paper draws on the existing literature to assess the impact of firm age on technological progress.

(3) Financial leverage (Lev). Let Lev = enterprise asset-liability ratio = total liabilities/total assets. Yang et al. (2018) revealed that the asset-liability ratio of a business is closely related to the RandD resources invested by the business. When the asset-liability ratio reaches a certain threshold, the enterprise may experience insufficient funds, which will have a detrimental effect on its RandD investment. Therefore, the debt-to-asset ratio is utilized to gage the level of corporate debt.

(4) Return on Assets (ROA). Let ROA = net profit/total assets. As the return on assets increases, companies have access to a greater amount of liquid capital. Enterprises must base their investment decisions on their available capital. Given other conditions, technological advancement is influenced by the level of investment in technology RandD, which is dependent on the funds available for RandD. Therefore, it is necessary to manage the impact of return on assets on technological advancement.

This analysis explores the mechanisms by which industrial funds influence technological innovation in the integrated circuit industry. The variables are set as follows, based on the results of the analysis:

(1) Financing constraints (SA). KZ index (Owen et al., 2001), WW index (Whited and Wu, 2006), and SA index are presently the standard methods for measuring the severity of financing constraints (Hadlock and Pierce, 2010). However, the KZ index and the WW index contain numerous endogenous variables, which compromise the accuracy of the index calculation results; the SA index is simple to calculate and consists of two exogenous variables, enterprise age and enterprise size, and the index calculation results are relatively accurate. Consequently, the SA index is implemented in this paper to measure the degree of financing constraints faced by businesses. Let $SA = -0.737 * Size + 0.043 * Size^2 - 0.04 * Age$. It should be noted that the SA index calculated by this equation is negative, and as the SA index rises, the degree of financing constraints confronted by businesses increases.

(2) Optimization of human capital structure (H). The human capital structure is represented in this paper by the ratio of high-skilled to low-skilled employment. The higher the value, the more advanced the human capital structure is, which indicates that the enterprise has reached its optimized state in terms of its human capital structure. Yao et al. (2005) utilized the distribution of employees' work types to measure the human capital structure of businesses, whereas Tie and Liu (2018) believed the human capital structure could be represented by the distribution of employees' education levels. This paper draws on the above literature to evaluate the human capital structure of enterprises premised on the education level of employees. Employees with a bachelor's degree or above (including a bachelor's degree) are defined as high-skilled labor, while employees with a degree below technical secondary school (including technical secondary school) are defined as low-skilled labor.

(3) R&D investment level (Rd_level). Referring to the practice of Gu et al. (2018), the level of RandD investment is expressed as "enterprise RandD expenses/operating income."

The data used in this article are from the financial reports of A-share listed companies in China's integrated circuit industry between 2011 and 2019. It should be noted that, after integrating the information of the Ministry of Industry and Information Technology and the China Semiconductor Association in order to ensure the integrity of the data in the industry chain, the initial sample of this article contains a total of 81 integrated circuit companies; however, only nine of these companies are state-owned or state-controlled, while the rest are private. Using the methodology of previous research, we exclude ST types, financial industries, and companies with significant missing variable data, and we employ double-ended tailing to eliminate the impact of extreme values. The final sample contains 442 valid observations. This sample, however, is an unbalanced panel, and the process of selecting samples is no longer carried out owing to the inconsistent listing periods of the companies and the failure of companies due to poor management and other reasons that affect the overarching concerns of the research.

The descriptive statistics of the primary variables are displayed in Table 2. The table reveals that the standard deviation of TFP during the observation period is 0.939, the minimum value is 5.968, the maximum value is 10.400, and the mean value is 7.681, indicating that there is a difference in TFP among enterprises in the sample, reflecting the different effects of fiscal policy, and that extended testing is required; In terms of enterprise characteristics, the size, age, financial leverage, and return on assets of the enterprises exhibit large fluctuations, indicating that listed companies in China differ substantially. The aforementioned examples of typical occurrences serve as an excellent test subject for the empirical investigation presented in this paper.

Empirical result analysis

The influence of the national integrated circuit industry investment fund on technological innovation

The regression results of model (1) are shown in Table 3. Column (1) represents the benchmark regression of the policy effect of industrial investment funds, in which the representative variables of industrial investment funds have passed the significance test, suggesting that during the observation period, industrial investment funds have a significant impact on the technological innovation of integrated circuit companies in the sample. Specifically, the Industrial Investment Fund ($du \times dt$) is significantly positive at the 10% level. During the observation period, it is evident that industrial investment funds can significantly increase the total factor productivity of businesses, thereby promoting technological innovation in the integrated circuit industry.

In terms of control variables, the effects of Size, Lev, and ROA are significantly positive, whereas the effect of age is significantly negative; however, the coefficient is modest, and it only passes the significance test from the perspective of preferential tax policies. The above estimation outcomes are due to the low asset-liability ratio and uneven age distribution of listed companies in the integrated circuit industry. According to statistics, the average industry asset-liability ratio in 2017 was 59.5%, while the average asset-liability ratio of integrated circuit companies was 33.99%, which was significantly lower than the industry average. This may be associated with research and development within the integrated circuit industry. It relates to the characteristics of high risk and the required scale of investment. Usually, the asset-liability ratio is related to the medium- and long-term loans of commercial banks. Therefore, the low indicator may be a result of the need for companies and banks to control their own costs and risks. Evidently, it can be noted that integrated circuit companies still have a relatively sufficient margin for debt financing to invest in RandD. Therefore, there is a positive correlation.

Table 3
The promotion effect of the national integrated circuit industry investment fund on the technological innovation of the integrated circuit industry.

	Technological innovation (1) Industrial investment fund	(2) Placebo test
du × dt	0.140*	0.153
	(1.88)	(1.29)
Size	0.502***	0.513***
	(15.16)	(15.73)
Age	−0.015	−0.016
	(−1.14)	(−1.20)
Lev	0.853***	0.824***
	(5.81)	(5.62)
ROA	1.662***	1.664***
	(7.44)	(7.38)
_cons	3.706***	3.656***
	(13.2)	(13.15)
individual	control	control
years	control	control
N	442	442
r2	0.5586	0.556

Note: 1. t values are in brackets, *, **, *** represent passing the 10%, 5%, and 1% significance tests, respectively. 2. All models control the fixed effects of individuals and time, which are omitted in the subsequent tables.

To ensure the robustness of the results in Table 3, the placebo test results are reported in column (2) of Table 3. This paper tests the robustness of the estimated results of industrial investment funds by establishing fictitious policy time points and observing the significant coefficient changes. To determine if the coefficient of the industrial investment fund is still significant, the method entails recalculating the time from 1 to 2012 and comparing the results. If the estimated result of the false policy time point fails the significance test, the estimated result of the benchmark regression is deemed robust. Otherwise, it lacks robustness.

The insignificance of the coefficient of du × dt in column (2) indicates that 2015 is a rational option for the implementation of the policy. In addition, the parallel trend test results of the double difference method are presented in Table 4 and Fig. 5 to further substantiate the dependability of the empirical results. Before the policy time point,

Table 2
Descriptive statistics for primary continuous variables.

Variable name	Observations	Average value	Standard deviation	Minimum	Maximum value
TFP	442	7.681	0.939	5.968	10.400
Size _	442	7.908	1.083	5.998	10.948
Age	442	18.077	5.100	8.000	31.000
Lev	442	0.331	0.193	0.046	0.775
ROA	442	0.044	0.055	−0.164	0.266
SA	442	−3.811	0.216	−4.277	−3.280
H	442	1.584	2.700	0.027	14.846
Rd- level	442	0.086	0.080	0.005	0.423

Table 4
Parallel trend test.

	Technological innovation
Before2	0.153
	(0.72)
Before1	0.347
	(1.64)
Current	0.424**
	(2.06)
After1	0.498**
	(2.47)
After2	0.528***
	(2.65)
After3	0.577***
	(2.87)
After4	0.645***
	(3.18)
_cons	7.195***
	(44.28)
N	442
r2	0.072

Note: t-values are in brackets, *, **, *** represent passing the 10%, 5%, and 1% significance tests, respectively.

Table 5
PSM-DID robustness test.

	Technological innovation	
	Benchmark regression	PSM-DID
du × *dt*	0.140*	0.131*
	(1.88)	(1.75)
Size	0.502***	0.489***
	(15.16)	(14.13)
Age	−0.015	−0.015
	(−1.14)	(−1.10)
Lev	0.853***	0.808***
	(5.81)	(5.36)
ROA	1.662***	1.674***
	(7.44)	(7.49)
_cons	3.706***	3.804***
	(13.2)	(13.08)
N	442	441
r2	0.5586	0.663

Note: t-values are in brackets, *, **, *** represent passing the 10%, 5%, and 1% significance tests, respectively.

the coefficient is close to 0 and not statistically significant, as indicated by the results. The coefficients become significant following the implementation of the policy, which satisfies the assumption of a parallel trend.

This paper also employs the PSM-DID estimation method to raise the robustness of the double difference estimation method. First, the PSM method was utilized to identify the control group with identical firm characteristics to the experimental group. When matching, the propensity score of each enterprise to obtain RandD subsidies is estimated annually with the reconstructed Logit model, the 1:1 nearest neighbor matching method in the caliper with replacement is utilized, the caliper range is set according to the standard deviation of the propensity score (matching radius) is 0.05, and important factors such as control variables in the benchmark regression are designated as matching variables. Second, model (1) is used to estimate the matched samples, and the regression results are presented in Table 5. The findings indicate that the regression of the policy effect of the industrial investment fund in column (1) of Table 3 is robust and can be inspected further.

Heterogeneity test

When enterprises are stimulated by policies, their diverse characteristics will induce them to respond in a variety of ways. Therefore, it is necessary to consider the effect of enterprise heterogeneity on policy effects. Based on the research object of this paper, the development of different links in the integrated circuit industry chain has its own characteristics, and the level of economic development in the region where the enterprise is located varies, which will impact the promotion effect of the industrial fund. On the basis of the preceding analysis, this paper conducts a heterogeneity test from two perspectives: the differences in the branches of the industrial chain and the differences in the regions where the companies are located.

Industry chain heterogeneity

The difficulty and willingness of businesses to implement technological innovation in the production process vary depending on the link in the industrial chain they are in, which will have a different impact on their financial policies based on the perspective of the heterogeneity of the industrial chain. EDA (electronic design automation) tools, IP (intellectual property) cores, materials, and manufacturing equipment constitute the upstream supporting

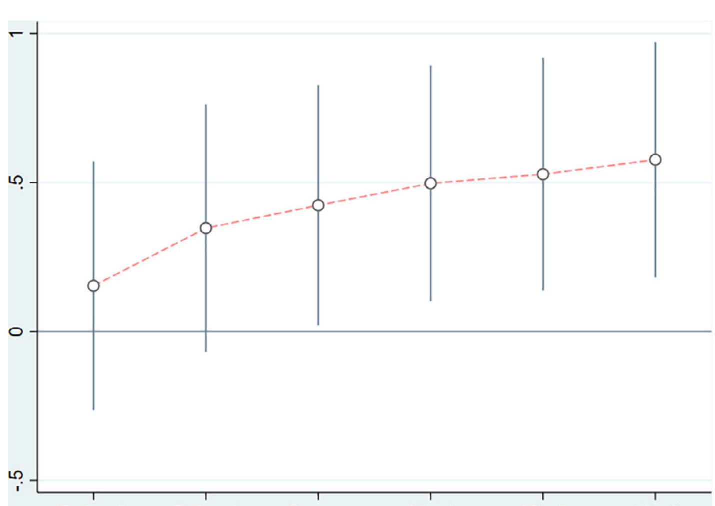

Fig. 5. Parallel trend test result graph.

Table 6
The impact of industrial funds on the technological innovation of integrated circuits in different links.

	Technological innovation	
	Industrial investment fund	
	(1) Support link	(2) Core link
du × *dt*	−0.178	0.294***
	(−1.35)	(3.11)
Size	0.637***	0.447***
	(9.85)	(10.86)
Age	−0.014	−0.018
	(−0.55)	(−1.19)
Lev	0.665***	1.065***
	(3.33)	(5.05)
ROA	2.330***	1.553***
	(5.93)	(5.61)
_cons	2.785***	4.085***
	(5.48)	(11.38)
N	205	237
r2	0.5778	0.607

Note: t values are in parentheses, *, **, *** represent passing the 10%, 5%, and 1% significance tests, respectively.

industries of integrated circuits. Chip design, chip manufacturing, and packaging and testing represent the midstream core industries. The downstream application industries consist of the computer, network communications, consumer electronics, and automotive electronics industries. This section of the research will be subdivided into supporting links and core links in accordance with the industrial chain and will only take the core industries in the midstream into account for the reason of simplicity. The supporting links include the materials and equipment industry, while the core links involve the design industry, the manufacturing industry, and the packaging and testing industry.

Table 6 illustrates the impact of industrial funds on the technological innovation of integrated circuit enterprises. As depicted in the table, industrial funds have a negligible effect on government policy in terms of assisting businesses. The emphasis on the materials and equipment industry in China's integrated circuit industry development process is obviously weaker than that of other branches, which may contribute to the preceding findings. However, as a supporting link, the materials and equipment industry is the weakest link. This issue, combined with the accumulation of more patents by foreign companies, results in high technical barriers and high levels of industrial concentration. In order to complete the process of technology accumulation, companies in the materials and equipment industry need to invest more resources in research and development. It would be necessary to assist businesses in overcoming obstacles for such an effect to be negligible. The accumulation of technology is relatively weak for enterprises in the core link, and their products are in the middle and low-end links. The industrial investment fund can integrate the advantages of subsidies and financial capital to overcome the capital challenge for enterprises, and it also provides investment incentives for their technological innovation. Resultantly, its role in fostering technological innovation among businesses is self-evident.

Regional heterogeneity

From the perspective of regional heterogeneity, resource endowment and industrial structure vary from region to region, resulting in varying degrees of economic development and policy implementation effects. Moreover, the development environment of the region has a close relationship with the behavior patterns of businesses. In a region with a high level of economic development, for instance, enterprises have access to a more favorable investment and financing environment, and the government also has sufficient financial resources to provide support; as a result, enterprises may be more capable of achieving technological innovation in the region.

Table 7 reports the effect of industrial investment funds (du × dt) among IC companies in various regions. It can be observed from the table that only the coefficient in the Pearl River Delta region is significantly positive, while the coefficients in other regions are positive but not statistically significant. The aforementioned findings indicate that the industrial investment fund plays a significant role in promoting the technological innovation of integrated circuit enterprises in the Pearl River Delta region but has little impact on other regions. One possible explanation for this is that the industry fund primarily provides financial assistance to the most successful businesses in the industry. Due to the limitations of the original data source, the statistics exclude a number of industry-leading companies. Therefore, the promotion effect of the industry fund is undesirable in the Yangtze River Delta, the Beijing-Tianjin-Hebei Rim of the Bohai Sea, and the central and western regions. The results also indicate that the promotion of industrial funds to the technological innovation of integrated circuit companies stems from investments in leading firms, which

Table 7
Impact of Industrial Investment Funds on Technological Innovation of Integrated Circuit Enterprises in Different Regions.

	Technological innovation			
	(1) Pearl River Delta	(2) Yangtze River Delta	(3) Beijing-Tianjin-Hebei Rim Bohai Sea	(4) Midwest
du × *dt*	0.662**	0.068	0.096	0.116
	(2.29)	(0.67)	(0.27)	(0.94)
Size	0.604***	0.406***	0.592***	0.339***
	(7.52)	(7.29)	(7.53)	(6.19)
Age	−0.037	0.001	−0.019	−0.005
	(−0.70)	(0.06)	(−1.10)	(−0.22)
Lev	−0.085	0.732***	1.273**	0.393*
	(−0.25)	(3.34)	(2.16)	(1.73)
ROA	1.146	1.623***	4.836***	1.297***
	(1.46)	(4.8)	(3.42)	(5.1)
_cons	3.321***	4.299***	2.683***	4.988***
	(4.11)	(9.69)	(4.36)	(10.43)
N	69	204	85	185
r2	0.8627	0.4547	0.5512	0.5017

Note: t values are in parentheses, *, **, *** represent passing the 10%, 5%, and 1% significance tests, respectively.

may widen the technological gap between them and SMEs and restrict the development space of SMEs.

Mechanism inspection

Referring to the practice of Shi et al. (2018) to examine the effects of industrial investment funds on financing restrictions, enterprise human capital structure optimization, and capital allocation of RandD investment levels, this paper designs the following model:

$$H_{i,t}(SA_{i,t}, Rd\_level_{i,t}) = \rho_0 + \rho_1 du \times dt + \sum_{i=1}^{N} \rho_j X_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \quad \text{(Model 3)}$$

$$TFP_{i,t} = \beta_0 + \beta_1 du \times dt + \sum_{i=1}^{N} b_j X_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \quad \text{(Model 4)}$$

$$TFP_{i,t} = \gamma_0 + \gamma_1 du \times dt + \gamma_2 H_{i,t}(SA_{i,t}, Rd\_level_{i,t}) + \sum_{i=1}^{N} \gamma_j X_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \quad \text{(Model 5)}$$

Model (3)-model (5) refers to the method of Baron and Kenny (1986) to verify the action mechanism of industrial investment funds, as it is impossible to multiply the difference term with ROA when examining industrial investment funds. Model (3) is applied to verify the impact of industrial investment funds on the above mechanisms, Model (4) serves to verify the impact of industrial investment funds on technological innovation, and Model (5) is employed to verify the existence of the mechanism.

Models (3)-(5) only examine the significance of ρ_1, $\beta_{1,}$ and γ_1. If ρ_1 is significant, it indicates that industrial fund investment has an impact on financing constraints, human capital structure optimization, and RandD investment level; if β_1 is significant, it indicates that industrial fund investment has an impact on technological innovation. If γ_1. is not significant or its absolute value is smaller than the absolute value of β_1, it is considered that industrial fund investment has an impact on technological innovation through three types of effects.

Table 8 reports the mechanism test of technological innovation by industrial investment funds. The results of the regressions in columns (2), (4), and (6) indicate that the implementation of industrial investment funds has significant coefficients on corporate financing constraints, human capital structure optimization, and RandD investment. It demonstrates that the industrial investment fund can alleviate the financing constraints of businesses, encourage the optimization of their human capital structures, and raise their RandD investment levels. The effect of industrial investment funds on the technological innovation of businesses is detailed in column (1). According to the estimated results, the coefficient of the principal explanatory variables is significantly positive, indicating that industrial investment funds can promote technological innovation among businesses. Columns (3), (5), and (7) indicate whether industrial investment funds can promote technological innovation by easing financing constraints, promoting the optimization of the human capital structure of enterprises, and increasing investment in technological research and development by enterprises. The estimation results indicate that, relative to column (1), the coefficients of industrial investment funds in columns (3), (5), and (7) exhibit a significant decrease in coefficient value. This illustrates that the industrial investment fund promotes technological innovation within enterprises through the three mechanisms outlined above.

Conclusion and implications

Research conclusions

Financial constraints, RandD investment, and human capital structure influence technological innovation in the integrated circuit industry from the perspective of driving factors. As a late-mover country, China's integrated circuit industry cannot rely solely on market mechanisms to promote technological innovation; rather, the Chinese government must take appropriate intervention measures to achieve this objective.

From the perspective of policy effects, industrial funds, as a combination of financial subsidies and financial capital, have significantly promoted the enhancement of enterprise innovation willingness and the implementation of innovation accomplishments. The promotion effect of industrial funds in design, manufacturing, packaging, and testing, as well as other industries, is exceptional; however, the varying effects of industrial fund policies across regions highlight the limitations of funds being concentrated in large enterprises. Further research on policy mechanisms reveals that industrial funds can relieve corporate financing constraints, increase corporate RandD expenditures, and promote the optimization of human capital structure.

Policy recommendations

The achievement of technological innovation, which raises the industry's overall technical level and increases the irreplaceability of products, is essential to the high-quality development of China's integrated circuit industry. China's integrated circuit industry is still playing catch-up on a global scale in terms of its technological level. For technological innovation and even technological advantage, a larger investment is required. The National Integrated Circuit Industry Investment Fund possesses the characteristics of both government intervention and market regulation, enabling it to not only satisfy the RandD funding needs of enterprises but also direct the use of

Table 8
Mechanism inspection of technological innovation by industrial investment funds.

	(1) Technological innovation	(2) Financing constraints	(3) Technological innovation	(4) Human capital structure	(5) Technological innovation	(6) RandD investment level	(7) Technological innovation
$du \times dt$	0.129**	−0.043***	0.062	0.071**	0.099	0.157*	0.033
	(2.04)	(−3.1)	(1.03)	(2.06)	(1.28)	(1.91)	(0.58)
SA			−1.467***				
			(8.72)				
H					−0.058		
					(−0.64)		
Rd_level							−0.001*
							(−1.61)

Note: t-values are in parentheses, *, **, *** represent passing the 10%, 5%, and 1% significance tests, respectively.

financial resources, thereby promoting integrated circuit enterprises to achieve technological breakthroughs. Therefore, it is essential to continue implementing this policy and increase its funding to encourage more social capital to participate in the research and development of integrated circuit technology. Concomitantly, it is essential to consider adjusting the investment direction in a timely manner by considering the following aspects of specific measures:

(1) Devote more resources to materials and equipment. Affected by investment objectives and capital scale, the first phase of the fund primarily invests in integrated circuit manufacturing. At the moment, the second phase of the fund has progressed to the stage where comprehensive investments are being made. Therefore, it should prioritize investments in enterprises in supporting links, such as materials and equipment, in order to improve the technical level of China's integrated circuit industry in weak links, thereby promoting industrial technological innovation.

(2) Moderately increase support for corporate mergers and acquisitions. Integrated circuit companies can introduce new technologies through mergers and acquisitions, reduce the risk of RandD failure, adjust product structure to increase market share, and ultimately enhance competitiveness. Export restrictions are currently in place for Chinese integrated circuit enterprises. Through mergers and acquisitions, they can realize the integration of domestic enterprises, cultivate leading enterprises, rapidly improve the technical level of enterprises, and alter the current situation of China's small and fragmented integrated circuit industry.

(3) Fully consider the impact of heterogeneity on the effect of industry funds. According to empirical tests, the heterogeneity of enterprises has an impact on how well industry funds promote businesses. As a result, industry funds must also consider regional and branch coordination. For enterprises in the supporting links, as well as those in the Yangtze River Delta, Beijing-Tianjin-Hebei, and central and western regions, the investment strategy of industrial funds should be optimized to ensure that the policy effect is more noticeable. For enterprises in the core links and in the Pearl River Delta, continued efforts should be exerted to increase investment in industrial funds while focusing on enhancing the investment operation mechanism of industrial funds and maximizing their promotional effect.

Future prospects

In spite of the extensive efforts and meaningful outcomes of the construction of industrial funds and industrial technology innovation in this paper, there are still some limitations to be aware of. First, this paper can only utilize a brief time period in the analysis of policy effects due to the limited time period available for public data collection and the influence of policy regulation. Second, this paper analyzes government intervention as an exogenous shock in its theoretical framework. Therefore, although the path of analysis has been simplified, the effect of the policy mechanism cannot be accurately determined. Finally, in the theoretical analysis, only the late-mover countries are the research subjects, and the behavior of the first-mover countries is also considered an exogenous shock; thus, the impact of the behavior of the first-mover countries on the industrial-technological progress of the late-mover countries cannot be studied in its entirety.

Subsequent research into the policy effect of the National Integrated Circuit Industry Fund is feasible in light of the findings presented in this paper. On the one hand, in the theoretical model section, intertemporal games can be applied to discuss the behavioral comparison between late-mover and early-mover countries to better portray the technological innovation path of late-mover countries. On the other hand, the mechanism of action of industrial funds can be further investigated; for instance, the principal-agent problem can be enhanced through institutional shareholding to optimize corporate governance; and it is possible for an attempt to exclude the influence of other industrial policies from the empirical process.

Data availability statement

The data used to support the findings of this study are included within the article.

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Declaration of Competing Interest

The authors declare that they have no competing interest.

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