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Study on the Disparities in Capital Requirements Across Different Stages of Technological Innovation and the Matching Logic of Patient Capital

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Abstract

Technological innovation serves as the core driver of high-quality economic development, exhibiting significant heterogeneity across its entire lifecycle. Correspondingly, capital requirements differ fundamentally in terms of scale, cycle, risk appetite, and other dimensions. Patient capital, centered on long-termism, provides stable financial support for technological innovation by tolerating short-term uncertainty and extending investment cycles. However, the matching logic between patient capital and the various stages of technological innovation has yet to be systematically clarified.This study, grounded in the theory of the technological innovation lifecycle, categorizes the innovation process into four distinct phases: basic research, applied development, commercialization, and industrial expansion. It systematically analyzes the capital demand characteristics of each phase. Building upon this foundation, a matching analysis framework for patient capital and different stages of technological innovation is constructed across four dimensions: scale of capital supply, risk-sharing mechanisms, return orientation, and value-added provision. Finally, drawing on case studies from representative industries, differentiated patient capital matching strategies are proposed.The findings offer theoretical insights and practical implications for optimizing innovation capital allocation efficiency and enabling patient capital to precisely empower technological innovation.

Keywords

Technological Innovation; Life Cycle; Patient Capital; Capital Demand; Matching Logic.

1. Introduction

1.1. Research Background

Amid intensifying global technological competition, technological innovation has become the core driver for nations to seize developmental initiative. China is undergoing a critical transition from "factor-driven" to "innovation-driven" growth, explicitly advocating for "adhering to innovation-driven development and accelerating the cultivation of new growth drivers."Simultaneously, the March 2025 State Council Government Work Report further emphasized that China should "accelerate the development of venture capital and strengthen patient capital." However, technological innovation is characterized by high investment, high risk, and long cycles [1], particularly in critical areas such as fundamental research and breakthroughs in core technologies. These sectors commonly face insufficient capital supply and the dilemma of short-term oriented capital being "reluctant to invest" [2][3]. Traditional venture capital predominantly focuses on later-stage innovations with clear short-term returns, struggling to meet the full-cycle capital needs of technological innovation [4]. This creates "breakpoints" and "bottlenecks" in the innovation chain.

Patient capital, as a new form of long-term capital, fundamentally abandons short-term profit demands and tolerates innovation uncertainties, aiming for long-term stable returns or non-

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financial value (e.g., technological breakthroughs, industrial upgrades) [5]. In recent years, China has progressively prioritized cultivating patient capital, accelerating the transformation of long-term funds-such as government-guided funds, pension funds, and insurance capital-into patient capital [6]. However, practical challenges persist in aligning patient capital with technological innovation: How can capital needs across different innovation stages be accurately identified? What supply models and risk-sharing mechanisms should patient capital adopt at each stage? How can dynamic alignment between patient capital and innovation stages be achieved? Resolving these issues is crucial for enhancing the efficiency of innovation capital allocation and promoting high-quality technological innovation development, forming the core research focus of this paper.

1.2. Literature Review

Based on the paper's core theme-"Capital Requirements Across Technology Innovation Stages and the Matching Logic of Patient Capital"-this section expands the literature review across three core dimensions: "Capital Requirements and Stage Compatibility," "The Nature and Characteristics of Patient Capital," and "Matching Mechanisms and Practical Outcomes of Patient Capital." This framework integrates academic research trajectories with the latest scholarly perspectives:

(1) Research on the Phases of Technological Innovation and Capital Demand Characteristics

The phased nature of technological innovation determines differentiated capital requirements-a view widely accepted in academia. Schumpeter (1912) first proposed in his innovation theory that technological innovation is a multi-stage evolutionary process, with significant differences in risk levels, capital usage, and return expectations across stages, laying the theoretical foundation for phased capital demand research [7]. Subsequent scholars refined this framework. Rothwell & Zegveld (1985) categorized technological innovation into three core phases—basic research, applied development, and commercialization-clearly defining the resource allocation priorities for each stage [8]. Lei J et al. (2019) comprehensively mapped China's technological innovation practices during its 40-year reform and opening-up period, categorizing them into a "four-stage climb": the "Learning-Introducing-Supplying Stage" (LIS Stage), "Introducing-Imitating-Improving Stage" (III Stage), "Integrating-Boosting-Creating Stage" (IBC Stage), and the "Innovating-Iterating-Promoting Stage" (IIP Stage) [9].

Regarding capital demand characteristics, scholars have focused on the differences in capital requirements across stages. Empirical studies reveal that the basic research phase requires small-scale but long-term funding with high risks, leading to extremely low participation from traditional market capital. It primarily relies on government fiscal funds and public capital [10][11]. During the applied development phase, funding requirements significantly expand, attracting selective venture capital involvement. However, constrained by the medium-to-long cycle nature of this stage, the scale and depth of such involvement remain insufficient [12]. Regarding the technology transfer and industrial expansion phases, scholars note that as technological maturity and revenue certainty increase, capital requirements shift from "R&D support" to "market expansion" and "scale growth." Traditional capital forms like industrial capital and bank loans gradually become the primary suppliers [13][14][15]. Recent empirical validation using Chinese technology innovation enterprise data confirms that the core differences between the "growth-oriented" capital demands of the technology transfer phase and the "scale-oriented" demands of the industrial expansion phase lie in three dimensions: risk appetite, return cycle, and ancillary service requirements. This finding provides empirical support for the analysis of capital demand characteristics in this paper.

(2) Research on the Concept, Characteristics, and Theoretical Foundations of Patient Capital

The concept of "patient capital" was first introduced by American economist Mariana Mazzucato (2013), who defined it as "a form of capital that focuses on long-term value creation,

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is willing to bear high uncertainty risks, and does not pursue short-term financial returns" [16]. Compared to traditional venture capital (VC), patient capital exhibits three core characteristics: First, it features longer investment cycles, typically spanning 5–10 years or more, significantly exceeding the 2–7-year exit cycles of conventional VC. Second, it adopts a diversified return orientation, valuing non-financial outcomes such as technological breakthroughs and industrial upgrading alongside long-term financial returns.Third, it employs deep-level empowerment methods, not only providing financial support but also participating in enterprise growth through additional services like resource integration, management optimization, and strategic guidance ([17,18,19]).

Theoretically, the operational logic of patient capital aligns closely with long-term value investing theory and resource dependence theory. Warren Buffett's long-term value investing theory emphasizes that holding high-quality assets over extended periods while accompanying corporate growth is the core pathway to achieving excess returns [20][21][22], aligning with patient capital's core principle of "long-term accompaniment." The resource dependence theory proposed by Pfeffer & Salancik (1978) elucidates the enabling value of patient capital-innovative enterprises exhibit differentiated reliance on external resources across development stages. By connecting access to scientific research resources, industrial chain resources, and management resources, patient capital effectively reduces enterprises' resource acquisition costs and alleviates developmental bottlenecks [23]. Furthermore, scholars emphasize from a capital supply perspective that patient capital typically originates from stable sources such as pension funds, government-guided funds, and public welfare foundations. This enables it to escape short-term performance evaluation pressures and focus on long-term enterprise development [24][25][26].

(3) Research on the Matching Mechanism and Practical Effects of Patient Capital and Technological Innovation

Regarding the matching logic between patient capital and technological innovation, academic research primarily explores four dimensions: supply scale, risk sharing, return expectations, and value-added contributions. Concerning supply scale matching, some scholars propose that patient capital should adopt a tiered funding model-“small-scale continuous supply-moderate incremental supply-collaborative incremental supply-selective supply”-tailored to the capital requirements of different innovation stages. This approach satisfies phased needs while preventing capital idleness [27]. Regarding risk-sharing mechanisms, patient capital effectively disperses high risks in individual stages by forming joint investment frameworks with government funds, venture capital, and industrial capital. Key risk mitigation strategies for different phases include shared risk during basic research, risk buffering during applied development, and risk dispersion during commercialization [28][29].

Regarding the alignment of return expectations with added value, research indicates that patient capital's return orientation dynamically adjusts with the innovation stage: during the basic research phase, it adheres to a non-financial value orientation, focusing on technological breakthroughs and knowledge accumulation [30][31]; in the applied development phase, it shifts toward a long-term return orientation, emphasizing the commercial potential of technologies [32]; the commercialization phase emphasizes profit sharing, collaborating with other capital sources to share commercial outcomes [33][34]; and the industrial expansion phase centers on long-term returns, achieving exit through scaled corporate profitability [35]. Value-added provision evolves from "research resource empowerment" during the basic research phase to "technology R&D empowerment" in application development, "commercialization empowerment" in technology transfer, and "operational management empowerment" in industrial expansion [36][37][38].

Regarding practical effectiveness, numerous domestic and international cases validate the positive impact of patient capital. The Howard Hughes Medical Institute (HHMI) in the United

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States, as a public-benefit patient capital entity, has facilitated major breakthroughs in fundamental medical research through sustained long-term, small-scale funding [39]; Germany's Fraunhofer Institutes, leveraging government-guided patient capital, employed a "phased investment + technical guidance" model to cultivate numerous market-ready technological achievements ([40]; domestically, provincial government-guided funds adopted a "fund-of-funds + sub-funds" model to synergize patient capital with market capital during the commercialization phase, effectively accelerating the commercialization of technological outcomes ([41][42]. However, scholars also note that the effectiveness of patient capital matching is influenced by institutional environments, industry characteristics, and corporate governance levels. Misalignment may lead to capital inefficiency and diminished corporate innovation incentives [43].

Based on existing research, academia has clarified the phased characteristics of technological innovation and its varying capital requirements, defined the essence, features, and theoretical foundations of patient capital, and preliminarily explored their matching mechanisms and practical outcomes, providing robust theoretical support for this study.However, existing research exhibits the following limitations: First, most studies focus on matching relationships within a single stage or dimension, lacking a systematic examination of the matching logic across the entire four-stage lifecycle. Second, research on the role transformation of patient capital across different stages is scarce, with insufficient exploration of the triggering conditions and implementation pathways for such transformations. Third, domestic studies predominantly emphasize qualitative analysis at the macro level, while empirical research integrating specific cases and data remains relatively scarce.

To address these gaps, this paper employs literature review, normative analysis, and case studies. Based on the four-stage framework of technological innovation, it systematically analyzes capital demand characteristics at each stage. A full-cycle matching framework for patient capital is constructed across four dimensions: supply scale, risk sharing, return expectations, and value-added contributions. Typical cases validate this matching logic, aiming to supplement existing research and provide theoretical guidance and practical insights for China's patient capital system development and technological innovation advancement.

(4) Research Innovations

The innovation of this paper manifests in three key aspects: First, it introduces a novel research perspective by systematically comparing capital demand differences across distinct stages of technological innovation from a full-lifecycle viewpoint, thereby overcoming the limitations of existing single-stage studies. Second, it innovates the analytical framework by constructing a multidimensional patient capital matching framework, providing theoretical tools for precise matching. Third, it pioneers practical pathways by proposing differentiated matching strategies based on typical industrial cases, enhancing the study's practical guidance.

2. Theoretical Foundation

2.1. Technology Innovation Life Cycle Theory

The technological innovation life cycle theory posits that technological innovation constitutes a continuous process from idea generation to industrialization, with distinct characteristics and patterns at each stage [44]. Based on the core tasks and output forms of the innovation process, it can be divided into four phases: the basic research phase, the applied development phase, the technology transfer phase, and the industrial expansion phase.The core task of the basic research phase is to explore scientific principles and technological laws, primarily yielding knowledge outputs such as academic papers and technical patents [45]. The applied development phase focuses on transforming basic research outcomes into concrete technical solutions or prototype products [46]. The technology transfer phase is dedicated to converting

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prototype products into market-ready mature products, achieving the integration of technology and market [47]; the industrial expansion phase centers on scaling production and expanding market share to achieve large-scale realization of innovation value [48]. Each phase exhibits significant heterogeneity in risk levels, capital requirements, and duration, providing a theoretical foundation for analyzing capital demand differences.

2.2. The Theory of Patient Capital

The concept of patient capital was first introduced by American political commentator Thomas Friedman in 2007. He noted that patient capital possesses the fundamental characteristics of venture capital while seeking long-term returns [49]. Compared to traditional forms of capital like venture capital and bank credit, patient capital exhibits three distinct characteristics: First, it features extended investment cycles, typically spanning 5–10 years or longer, covering the entire innovation lifecycle or critical extended phases. Second, it demonstrates high risk tolerance, accepting failure risks inherent in innovation while eschewing short-term profit-seeking. Third, it adopts a multifaceted value orientation, prioritizing non-financial benefits such as technological breakthroughs, industrial upgrading, and social impact alongside economic returns.The primary providers of patient capital include government-guided funds, pension funds, insurance capital, and public welfare foundations-all long-term capital entities. Its operational model emphasizes "long-term accompaniment" and "value co-creation," leveraging stable financial support and supplementary services to help technological innovation overcome critical bottlenecks.

2.3. Theory of Capital-Technology Innovation Compatibility

The theory of capital-technology innovation compatibility posits that the degree of alignment between capital forms and innovation activities directly impacts innovation efficiency. Different capital forms exhibit variations in risk appetite, investment cycles, and return expectations, while distinct stages of technological innovation possess unique core characteristics and demands. Efficient capital allocation and smooth innovation advancement occur only when capital form characteristics align with the needs of the innovation stage. Traditional capital forms, constrained by short-term profit orientation and risk aversion, struggle to meet the demands of early-stage technological innovation [50]. In contrast, patient capital's long-term orientation and multi-value focus grant it inherent advantages in aligning with the extended timelines and high-risk phases of technological innovation. This compatibility theory provides the core theoretical foundation for this paper's exploration of the matching logic between patient capital and different stages of technological innovation.

3. Analysis of Capital Demand Characteristics Across Technology Innovation Stages

Based on the technological innovation lifecycle theory, this paper categorizes technological innovation into four stages: basic research, applied development, commercialization, and industrial expansion. It systematically analyzes the capital demand characteristics of each stage across five dimensions: capital requirement scale, investment cycle, risk level, return certainty, and additional capital requirements.

3.1. Basic Research Phase: Seed-Stage Capital Demand Under High Risk and Long Cycle

The basic research phase serves as the foundational stage of technological innovation, primarily focused on exploring new scientific principles and technical methodologies to lay the groundwork for subsequent innovation activities. Capital requirements during this phase exhibit distinct "seed-stage" characteristics: First, funding needs are relatively modest,

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primarily allocated to basic inputs such as research equipment procurement, researcher compensation, and experimental materials. Second, investment cycles are exceptionally long, typically spanning 5–10 years or longer, with outcomes difficult to predict with precision.Third, the risk level is extremely high, as fundamental research carries significant uncertainty, with most studies potentially failing to achieve expected outcomes or even ending in complete failure. Fourth, the certainty of returns is extremely low, as this stage yields almost no direct commercial benefits. Returns primarily manifest as accumulated knowledge outputs, whose commercial value conversion carries substantial uncertainty. Fifth, additional capital requirements focus on facilitating access to research resources, necessitating investors' ability to connect with research institutions, expert teams, and other resources to support the smooth progression of research efforts.

At this stage, traditional market capital, influenced by short-term profit demands and risk-averse tendencies, generally exhibits reluctance to invest. Capital needs primarily rely on non-profit entities such as government fiscal funds and public welfare foundations. However, as the importance of basic research grows, the demand for patient capital with a long-term orientation becomes increasingly urgent.

3.2. Application Development Phase: Cultivating Capital Needs in a Medium-to-High Risk, Medium-to-Long Cycle Environment

The application development phase is critical for transforming basic research outcomes into concrete technical solutions or prototype products, with the core task being to validate the feasibility and applicability of the technology.Capital requirements during this phase exhibit "nurturing" characteristics: First, funding needs significantly expand compared to the basic research stage, requiring greater investment in technical prototyping, pilot testing, and intermediate trials to validate feasibility. Second, while investment cycles shorten, they remain medium-to-long term, typically spanning 3-5 years. Third, risk levels stay medium-to-high, primarily stemming from R&D failures and iterative adjustments to technical solutions.Fourth, while return certainty improves, it remains uncertain. Some prototypes may achieve small-scale trials but have not yet generated scalable commercial revenue. Fifth, capital's added value shifts toward technical guidance and resource integration, requiring investors to provide supplementary services such as R&D expertise and supply chain connections to refine technical solutions.

At this stage, some high-risk-tolerant venture capital firms begin to explore entry. However, due to the extended investment cycle and significant return uncertainty, traditional venture capital involvement remains limited. Patient capital must now play a "nurturing" role, supporting technological maturity and refinement through long-term funding and resource empowerment.

3.3. Commercialization Phase: Growth Capital Requirements in a Medium-Risk, Medium-Cycle Environment

The technology commercialization phase involves transforming mature technical solutions or prototype products into marketable offerings, with the core task being the integration of technology and market demands. Capital requirements during this stage exhibit "growth-oriented" characteristics: First, funding needs expand significantly, primarily allocated to pre-commercialization investments such as production line construction, market research, brand development, and channel expansion. Second, the investment cycle remains relatively stable, typically spanning 2-3 years, allowing for a clearer prediction of product launch timelines.Third, risk levels decrease to moderate, with primary risks stemming from market acceptance and product competitiveness rather than technical uncertainties. Fourth, revenue certainty significantly improves as products establish a commercial foundation, enabling initial

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profitability through small-scale sales with increasingly clear revenue projections. Fifth, capital requirements shift toward enhancing commercialization capabilities, necessitating investors to provide supplementary services like marketing strategies, channel resources, and supply chain management to accelerate market penetration.

At this stage, traditional venture capital and industrial capital begin large-scale involvement. Patient capital gradually shifts from being the "primary provider" to a "supplementary provider," collaborating with other capital forms to jointly drive the commercialization of technological achievements.

3.4. Industrial Expansion Phase: Scalable Capital Requirements in Low-Risk, Short-Cycle Environments

The industrial expansion phase represents the scaled realization of technological innovation value, with core objectives centered on expanding production scale, capturing market share, and maximizing innovation value. Capital requirements during this stage exhibit "scaled" characteristics: First, funding needs peak, primarily allocated to production line expansion, market growth, raw material procurement, and other large-scale operational investments. Second, investment cycles are relatively short, typically 1-2 years, with clear return-on-investment timelines.Third, risk levels are lowest, as both technology and market viability have been validated, with primary risks being intensified market competition and operational challenges like overcapacity. Fourth, return certainty is highest, as products have established stable market demand, enabling sustained profitability and clear investment payback. Fifth, capital's ancillary demands focus on operational management and capital operations, requiring investors to provide services such as refined operational guidance, M&A restructuring, and IPO advisory to support enterprises in achieving scaled growth.

At this stage, traditional capital forms like bank loans, bond financing, and equity financing become primary funding sources. Patient capital may choose to exit or continue holding, achieving long-term investment returns through the enterprise's scaled profitability.

4. The Matching Logic Between Patient Capital and Different Stages of Technological Innovation

Based on the analysis of capital demand characteristics across different stages of technological innovation, this paper constructs a matching framework for patient capital and technological innovation stages from four dimensions: capital supply scale, risk-sharing mechanisms, return orientation, and value-added provision. This framework clarifies the core matching logic for each stage.

4.1. Basic Research Phase: Small-Scale Continuous Funding and Non-Financial Value-Oriented Research Empowerment

During the basic research phase, the core matching principles for patient capital are "long-term commitment" and "risk-sharing." Regarding capital supply scale, a "small-scale, continuous supply" model should be adopted, with funding injected in phases according to research progress. This approach meets the fundamental funding needs of basic research while preventing idle capital and waste.Regarding risk-sharing mechanisms, given the extremely high risks at this stage, a single capital entity cannot bear all risks alone. Patient capital should establish risk-sharing mechanisms with government fiscal funds and research institutions, reducing the risk burden on individual entities through joint investment, risk compensation, and other means. In terms of return orientation, patient capital should adhere to a "non-financial value orientation," eschewing short-term profit returns and instead prioritizing non-financial values such as technological breakthroughs and knowledge accumulation as core objectives.Regarding value-added contributions, patient capital should focus on "empowering

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research resources" by leveraging its networks to connect research institutions, expert teams, and experimental platforms, thereby ensuring the sustainability of fundamental research.

For instance, the Howard Hughes Medical Institute (HHMI) in the United States, a quintessential public-benefit patient capital entity, provides sustained small-scale funding for basic medical research over the long term. It refrains from interfering in the research process, does not demand short-term outcomes, and focuses solely on the scientific value of the research. Multiple basic research projects it has supported have ultimately achieved major breakthroughs, fully demonstrating the matching logic of patient capital during the basic research phase.

4.2. Application Development Phase: Empowering Technology R&D Through Moderate Incremental Funding and Long-Term Value Orientation

The core matching principles for the application development phase are "cultivating empowerment" and "risk buffering." In terms of capital supply scale, an "appropriately incremental supply" model should be adopted. Building upon the small-scale funding provided during the basic research phase, capital investment should be moderately increased according to the progress of technological R&D to meet funding needs for prototype development, small-scale trials, and pilot-scale testing.Regarding risk-sharing mechanisms, patient capital should establish "risk buffers" through phased investments, convertible bonds, and other methods to mitigate losses from R&D failures. Simultaneously, it may collaborate with limited venture capital to jointly bear risks. In terms of return orientation, the focus should shift toward "long-term returns." While not pursuing immediate profitability, attention should begin to center on the technology's long-term commercial potential, laying the groundwork for future returns.Regarding value-added services, the focus should be on "technology R&D empowerment." By leveraging its own resources, patient capital can provide enterprises with technical expertise, facilitate connections to upstream and downstream industry resources, and assist in building R&D teams, thereby optimizing and refining technological solutions.

Take Germany's Fraunhofer Institute as an example. Leveraging patient capital guided by government support, it provides funding and R&D assistance for SMEs' application development projects. Employing a "phased investment + technical guidance" model, it helps enterprises overcome R&D bottlenecks and cultivates numerous market-ready technological achievements, aligning with the patient capital matching logic during the application development phase.

4.3. Commercialization Phase: Collaborative Incremental Supply and Value-Sharing Commercialization Empowerment

The core matching focus during the commercialization phase lies in "collaborative empowerment" and "value co-creation." Regarding capital supply scale, a "collaborative incremental supply" model should be adopted, where patient capital synergizes with traditional venture capital and industrial capital to expand funding scale and meet the diverse investment demands of the pre-commercialization stage.Regarding risk-sharing mechanisms, a "risk dispersion" framework should be established. By involving diverse investment entities, market and operational risks are distributed across different capital sources, reducing pressure on any single participant.Regarding return orientation, a shift to "return sharing" is warranted. At this stage, the commercial value of the technology has begun to materialize, allowing patient capital to share in the returns generated by innovation alongside other capital entities. In terms of value-added provision, the focus should be on "commercialization empowerment," offering enterprises services such as marketing strategies, channel resources, supply chain management, and brand building to facilitate the integration of technology with the market.

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For instance, some provincial government-led funds in China, acting as patient capital entities, adopt a "fund of funds + sub-funds" model during the technology transfer phase. They collaborate with market risk capital to invest in local technology innovation enterprises, not only providing financial support but also leveraging government resources to open up markets for these enterprises. This achieves synergistic empowerment between patient capital and market capital.

4.4. Industrialization Expansion Phase: Selective Supply and Long-Term Return-Oriented Operational Management Empowerment

The core focus of the industrialization expansion phase lies in "value enhancement" and "return realization."Regarding capital supply scale, a "selective supply" model should be adopted. Patient capital can decide whether to continue follow-on investments or gradually exit based on the enterprise's development status and its own investment strategy. For enterprises with significant industrial value, continued financial support can be provided to help them scale up. In terms of risk-sharing mechanisms, a "risk control" mechanism should be established. This involves strengthening monitoring of enterprise operations and refining investment agreement terms to manage operational and market risks.Regarding return orientation, a shift toward "long-term return orientation" is essential. Achieving long-term investment returns through scaled profitability can be realized via exit strategies such as equity transfers or corporate listings to capture investment gains. In terms of value-added provision, the focus should be on "operational management empowerment." This involves offering services like refined operational guidance, M&A restructuring, IPO coaching, and industrial chain integration to support enterprises in achieving scaled, high-quality development.

Taking patient capital like pension funds as an example, during industrial expansion phases, they typically invest long-term in innovative enterprises with stable profitability and long-term growth potential. They provide operational management empowerment by deploying directors and participating in strategic planning, while enjoying investment returns from the enterprise's sustained development.

5. Case Study: The Semiconductor Industry

5.1. Phased Characteristics of Technological Innovation in the Semiconductor Industry

The semiconductor industry is a quintessential technology-intensive and capital-intensive sector characterized by lengthy innovation cycles, high risks, and substantial funding requirements. Its innovation process exhibits distinct, clearly defined phases [51]. The foundational research phase focuses on fundamental areas such as semiconductor materials and chip design principles, spanning 5-8 years with extremely high risks;The application development phase concentrates on translating fundamental research outcomes into chip design solutions and manufacturing processes, spanning 3-5 years and requiring substantial capital for R&D equipment procurement and process validation. The commercialization phase emphasizes advancing prototype chips through market testing and promotion, lasting 2-3 years, with capital demands shifting toward production line construction and market expansion. The industrial expansion phase centers on scaling chip production capacity and expanding domestic and international markets, lasting 1-2 years, during which capital requirements reach their peak.

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5.2. Matching Practices of Patient Capital Across Semiconductor Innovation Stages

As a quintessential technology-intensive and capital-intensive industry, the semiconductor sector is characterized by extended innovation cycles, high risks, substantial funding requirements, and clearly delineated innovation phases. Its end-to-end innovation process urgently requires patient capital tailored to its industrial attributes to deliver precise support.As the core vehicle for government-guided patient capital, China's National Integrated Circuit Industry Investment Fund (referred to as the "Big Fund") has established differentiated capital matching logic and practical models tailored to the core needs of each stage in the semiconductor industry's innovation lifecycle. This approach has effectively supported breakthroughs across the entire chain, from fundamental research to industrial expansion [52][53][54].

During the foundational research phase, the National Integrated Circuit Industry Investment Fund (referred to as the "Big Fund") serves as the core patient capital entity. Through collaborations with research institutions such as Tsinghua University and Peking University, it establishes specialized foundational research funds providing small-scale, sustained financial support. This focuses on fundamental research in critical areas like semiconductor materials and core components-areas where technological bottlenecks exist-without demanding short-term returns, concentrating solely on achieving technological breakthroughs.Simultaneously, it connects with top-tier international research resources, offering technical exchange platforms for research teams. This approach embodies the matching logic of "small-scale continuous funding + risk sharing + non-financial value orientation + research resource empowerment."

During the application development phase, the National Integrated Circuit Industry Investment Fund adopts a "phased investment + technology empowerment" model, providing moderate incremental funding to companies like SMIC and Hua Hong Semiconductor for chip manufacturing process R&D and validation.Concurrently, it collaborates with upstream and downstream semiconductor industry players to connect portfolio companies with R&D resources and assist in building development teams, helping them overcome technical bottlenecks. This aligns with the matching logic of "moderate incremental funding + risk buffering + long-term value orientation + R&D empowerment."

During the commercialization phase, the National Integrated Circuit Industry Investment Fund collaborates with market-driven venture capital firms like Sequoia Capital and Hillhouse Capital to expand capital supply. This supports portfolio companies in establishing mass production lines, conducting market research, and promoting brand awareness. By leveraging government resources, it facilitates market access for these companies into domestic high-end manufacturing and new energy vehicle sectors, bridging technology with market demand. This embodies the matching logic of "collaborative incremental supply + risk diversification + profit-sharing orientation + commercialization empowerment."

During the industrial expansion phase, the Fund selectively reinvests in enterprises with core competitiveness to bolster capacity expansion and international market penetration. Concurrently, it provides services like IPO guidance and M&A restructuring to accelerate scaled growth.For instance, it supported SMIC's listing on the STAR Market, enabling expanded financing through capital operations to enhance international competitiveness. For mature enterprises, the Fund gradually exits via equity transfers to realize long-term investment returns, aligning with the matching logic of "selective supply + risk control + long-term return orientation + operational management empowerment."

5.3. Insights from Case Studies

The semiconductor industry case demonstrates that precisely matching patient capital with different stages of technological innovation is crucial for driving breakthroughs. In practice,

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patient capital must dynamically adjust its matching strategy based on innovation stage characteristics: During early innovation phases (basic research and application development), emphasize a long-term orientation, focusing on risk-sharing and resource empowerment;In the later innovation stages (technology transfer and industrial expansion), it should enhance synergy with market capital, concentrating on commercialization empowerment and long-term return realization. Concurrently, government-guided patient capital should play a leading role in mobilizing market patient capital participation, thereby constructing a diversified, multi-tiered innovation capital supply system.

6. Conclusion and Policy Recommendations

6.1. Research Findings

Based on the technological innovation lifecycle theory, this paper systematically analyzes the capital demand characteristics across the fundamental research phase, applied development phase, technology transfer phase, and industrial expansion phase. It constructs a matching analysis framework between patient capital and different stages of technological innovation from four dimensions: capital supply scale, risk-sharing mechanisms, return orientation, and value-added provision.The study finds: Capital requirements vary significantly across innovation stages. The basic research phase requires high-risk tolerance, long-term oriented seed capital; the applied development phase demands medium-to-high risk tolerance, nurturing capital; the technology transfer phase necessitates medium risk tolerance, growth capital; and the industrial expansion phase requires low risk tolerance, scaled capital.The matching logic between patient capital and each stage exhibits differentiated characteristics, centered on dynamically adjusting capital supply models, risk-sharing mechanisms, return expectations, and value-added provision methods according to the specific capital requirements of each phase. Case studies from the semiconductor industry validate the rationality and practical feasibility of this matching logic.

6.2. Policy Recommendations

Based on research findings, the following policy recommendations are proposed to enhance the precise alignment of patient capital with technological innovation and improve the efficiency of innovation capital allocation:

First, categorize and guide patient capital investments to optimize capital allocation structures. Introduce differentiated policy support measures addressing the distinct capital needs of various technological innovation stages: - Provide targeted support such as tax incentives and risk compensation for patient capital invested in foundational research. - Encourage joint investments with government-guided funds for patient capital directed toward application development. - Support synergistic efforts with market capital for patient capital invested in commercialization and industrial expansion, enabling shared risk and shared returns.

Second, refine the patient capital cultivation system to expand long-term capital supply. Facilitate the conversion of long-term funds like pension and insurance capital into patient capital by streamlining investment approval processes and increasing investment proportions in science and technology innovation sectors. Encourage the establishment of public-benefit patient capital funds to support fundamental research and breakthroughs in core technologies. Strengthen international cooperation to attract cross-border patient capital participation in China's technological innovation.

Third, establish diversified risk-sharing mechanisms to mitigate investment risks for patient capital. Create government-led innovation risk compensation funds to provide proportional compensation for losses incurred by patient capital in technology innovation projects. Improve the technology innovation insurance system by developing insurance products tailored to

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different innovation stages, covering risks such as R&D and market exposure. Promote innovative financial tools like intellectual property pledge financing and convertible bonds to diversify investment risks.

Fourth, enhance the value-added capabilities of patient capital to amplify innovation empowerment effects. Establish innovation resource matching platforms to help patient capital connect portfolio companies with scientific research resources, industrial chain resources, and market resources; encourage patient capital institutions to form specialized empowerment teams providing additional services such as technical R&D guidance, marketing, operational management, and capital operations; establish an evaluation system for patient capital empowerment effects to guide improvements in empowerment capabilities.

6.3. Research Limitations and Future Outlook

This study has certain limitations: First, the analysis of the matching logic between patient capital and technological innovation relies primarily on normative analysis, lacking quantitative empirical verification. Second, the case selection focuses solely on the semiconductor industry, and its applicability to other innovation-intensive industries requires further validation.Future research could be expanded in the following ways: First, develop a quantitative indicator system to empirically test the matching efficiency between patient capital and different innovation stages. Second, broaden the scope of case studies to compare and analyze differences in patient capital matching patterns across various industries. Third, explore the dynamic adjustment mechanisms of the matching logic between patient capital and technological innovation in the context of the digital economy and deglobalization.

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