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Investment Efficiency in Manufacturing SMEs under Green Finance Incentives and Knowledge Diffusion

Emma Muller*, Louis B. Lambert

Toulouse School of Economics, Toulouse Capitole University, Toulouse, Occitanie, 31000, France

Corresponding author: emma.muller@gmail.com

Abstract

The transition towards sustainable manufacturing requires substantial capital investments and advanced technological capabilities, particularly for small and medium-sized enterprises. This paper explores the mechanisms through which green finance incentives and knowledge diffusion interact to explain investment efficiency in manufacturing small and medium-sized enterprises. Despite the increasing availability of green credit and environmental subsidies, these enterprises often suffer from underinvestment in high-risk sustainable projects or overinvestment in redundant conventional assets due to severe information asymmetry and a lack of absorptive capacity. By conceptualizing a dual-channel theoretical framework, this study argues that green finance provides the necessary liquidity and risk mitigation, while knowledge diffusion facilitates managerial foresight and technological adoption. Drawing on a comprehensive dataset of manufacturing enterprises, the empirical analysis reveals that green finance incentives significantly reduce financial constraints, thereby improving baseline capital allocation efficiency. Furthermore, knowledge diffusion acts as a critical moderating mechanism. Enterprises embedded in dense knowledge networks demonstrate a substantially higher capacity to translate green financial support into optimal capital allocation, mitigating both overinvestment and underinvestment tendencies. The findings offer crucial insights for policymakers aiming to design holistic support systems that combine financial instruments with capacity-building knowledge initiatives to foster long-term sustainable economic growth.

Keywords: Green Finance; Knowledge Diffusion; Investment Efficiency; Manufacturing SMEs; Management and Innovation

1. Introduction

The global imperative to transition toward a low-carbon and sustainable economic model has placed unprecedented pressure on the manufacturing sector, which remains one of the largest contributors to environmental degradation and resource depletion [1]. Within this sector, small and medium-sized enterprises play a dual role. On one hand, they form the backbone of global supply chains and are engines of economic growth and employment generation [2]. On the other hand, their cumulative environmental footprint is substantial, necessitating a rapid shift toward green production paradigms [3]. However, the ecological transition requires massive capital expenditure in green technologies, process upgrading, and human capital development. For manufacturing small and medium-sized enterprises, achieving optimal investment efficiency during this transition is profoundly challenging.

These enterprises frequently encounter suboptimal investment scenarios characterized by either underinvestment in necessary green innovations due to liquidity constraints, or overinvestment in redundant, inefficient technologies due to poor strategic foresight and agency conflicts [4].

Green finance incentives have emerged as a primary macroeconomic policy tool designed to alleviate the financial constraints hindering sustainable enterprise development [5]. Governments and financial institutions globally have introduced diverse instruments, including subsidized green credit, green bonds, and direct environmental grants, to lower the cost of capital for eco-friendly projects [6]. While the provision of green finance theoretically increases the volume of capital available to small and medium-sized enterprises, the mere availability of funds does not guarantee that these resources will be allocated efficiently [7]. The literature on corporate finance has long established that friction in capital markets, primarily driven by information asymmetry and agency costs, can distort investment behavior [8]. Therefore, understanding how green finance incentives influence the actual efficiency of corporate investments, rather than just the volume, remains a critical gap in contemporary academic discourse.

Concurrently, the paradigm of open innovation and regional innovation systems highlights the pivotal role of knowledge diffusion in shaping corporate capabilities [9]. Knowledge diffusion refers to the process through which technical know-how, managerial best practices, and market intelligence spread across enterprise boundaries through industry networks, supply chain linkages, and academic-industry collaborations [10]. For manufacturing small and medium-sized enterprises, which typically possess limited internal research and development capabilities, external knowledge acquisition is essential for recognizing the commercial viability of green technologies [11]. The extent to which an enterprise can absorb and utilize external knowledge heavily influences its strategic decision-making and project appraisal processes [12]. Consequently, knowledge diffusion has the potential to mitigate the uncertainty associated with green investments, thereby preventing misallocation of financial resources and enhancing overall investment efficiency.

Despite the individual importance of green finance and knowledge diffusion, existing literature rarely examines their intersecting effects on corporate investment efficiency. Most studies approach financial constraints and technological capabilities as isolated determinants of enterprise performance [13]. This paper bridges this gap by proposing an integrated framework that conceptualizes knowledge diffusion as a critical boundary condition for the effectiveness of green finance incentives. We hypothesize that the efficacy of green financial support in optimizing investment efficiency is contingent upon the enterprise position within knowledge diffusion networks. Without sufficient technological and managerial knowledge, subsidized green capital may be misallocated into speculative or technologically obsolete projects, exacerbating overinvestment. Conversely, robust knowledge diffusion equips enterprises with the necessary absorptive capacity to identify optimal green investment opportunities, thereby alleviating underinvestment and maximizing the utility of green finance [14].

The primary objective of this study is to systematically investigate the direct impact of green finance incentives on the investment efficiency of manufacturing small and medium-sized enterprises, and to rigorously test the moderating role of knowledge diffusion in this relationship. To achieve this, the research employs a comprehensive empirical design utilizing a large-scale panel dataset of manufacturing enterprises. By isolating the components of overinvestment and underinvestment through established financial models, the study provides a nuanced understanding of how external incentives and knowledge networks reshape corporate capital allocation. The structure of this paper is organized as follows. The subsequent section develops the theoretical framework and reviews relevant literature. The third section outlines the methodological approach, including data selection and variable

measurement. The fourth section presents the empirical results, encompassing baseline regressions, moderation analysis, and robustness checks. Finally, the fifth section concludes with theoretical contributions, policy implications, and avenues for future research.

2. Literature Review and Theoretical Framework

2.1 The Concept and Measurement of Investment Efficiency

In standard neoclassical financial theory, an enterprise operates with perfect investment efficiency when it undertakes all projects that possess a positive net present value and rejects all projects with a negative net present value [15]. Under the assumption of perfect capital markets, external financing is a perfect substitute for internal funds, meaning that investment decisions are solely dictated by the availability of profitable opportunities [16]. However, market imperfections, particularly information asymmetry and agency problems, induce deviations from this optimal level, resulting in investment inefficiency. This inefficiency manifests in two distinct forms. The first is underinvestment, which occurs when an enterprise foregoes positive net present value projects. This is typically driven by severe financial constraints, where external capital providers demand a high premium due to the inability to perfectly observe the risk profile of the enterprise, a phenomenon often explained by the pecking order theory [17].

The second form of inefficiency is overinvestment, which transpires when an enterprise allocates capital to projects with a negative net present value [18]. Overinvestment is classically attributed to agency conflicts between managers and shareholders. Managers may pursue empire-building strategies, investing excess free cash flow into unprofitable ventures to increase enterprise size, prestige, and personal compensation, rather than distributing dividends [19]. In the context of green transitions, overinvestment can also occur due to bounded rationality, where managers succumb to regulatory pressure or greenwashing trends, purchasing environmental equipment that offers no real operational or strategic value. Accurately measuring these deviations is crucial for empirical research. Scholars predominantly rely on expectations models, where normal investment levels are predicted based on growth opportunities, typically proxied by sales growth or Tobin Q ratio, and the residual from this prediction represents the degree of inefficiency [20].

2.2 Green Finance Incentives and Capital Allocation

Green finance encompasses a broad spectrum of financial instruments and policies designed to internalize environmental externalities and channel capital toward sustainable economic activities [21]. For manufacturing small and medium-sized enterprises, green finance incentives primarily take the form of preferential interest rates on green loans, government subsidies for energy-efficient equipment, and specialized credit guarantee schemes that lower collateral requirements. The theoretical linkage between green finance and investment efficiency operates primarily through the mitigation of financial constraints. By providing a dedicated pool of low-cost capital, green finance directly addresses the underinvestment problem. Enterprises that previously lacked the liquidity to overhaul their polluting production lines or invest in novel waste management technologies are empowered to undertake these positive net present value environmental projects [22].

Furthermore, green finance often comes with stringent monitoring and reporting requirements imposed by lending institutions and environmental protection agencies. This enhanced scrutiny acts as a governance mechanism that can restrain managerial opportunistic behavior [23]. When enterprises utilize green credit, they must demonstrate that the funds are specifically allocated to approved

environmental projects, thereby reducing the pool of discretionary free cash flow that might otherwise be squandered on negative net present value investments. Consequently, the conditional nature of green finance incentives not only alleviates underinvestment by injecting capital but also curtails overinvestment by imposing disciplinary oversight, theoretically leading to a holistic improvement in overall investment efficiency.

2.3 Knowledge Diffusion in Industrial Networks

Knowledge diffusion is the mechanism by which information, technological innovations, and operational best practices propagate through an economic system [24]. Unlike large multinational corporations that internalize research and development, manufacturing small and medium-sized enterprises rely heavily on external knowledge spillovers to maintain competitiveness. This diffusion occurs through various channels, including inter-firm collaborations, supply chain interactions with larger downstream clients, employee mobility, and spatial proximity to innovation hubs or universities. The knowledge-based view of the firm posits that the ability to acquire, assimilate, and apply external knowledge is a fundamental driver of dynamic capabilities and strategic agility [25].

In the context of environmental investments, the role of knowledge diffusion is particularly critical due to the high degree of technical complexity and market uncertainty associated with green technologies [26]. Environmental upgrading requires an integration of novel processes, such as circular economy principles and advanced emission control systems, which fall outside the traditional expertise of conventional manufacturing managers. Knowledge diffusion reduces this technological uncertainty. When an enterprise is embedded in a dense knowledge network, it gains access to the experiential learning of its peers. Managers can observe successful technology implementations, understand regulatory compliance pathways, and accurately assess the operational risks of specific green investments. This influx of external intelligence enhances the enterprise absorptive capacity, enabling more accurate valuation of prospective projects and minimizing the risk of technological missteps.

2.4 The Dual-Channel Interactive Framework

This study posits that evaluating green finance or knowledge diffusion in isolation provides an incomplete picture of investment efficiency dynamics. Instead, we propose a dual-channel interactive framework where knowledge diffusion serves as a critical boundary condition for the effectiveness of green finance incentives. The theoretical rationale is grounded in the synergy between financial capacity and cognitive capacity [27]. Green finance provides the objective financial capacity required to execute investments, while knowledge diffusion supplies the subjective cognitive capacity needed to select the correct investments.

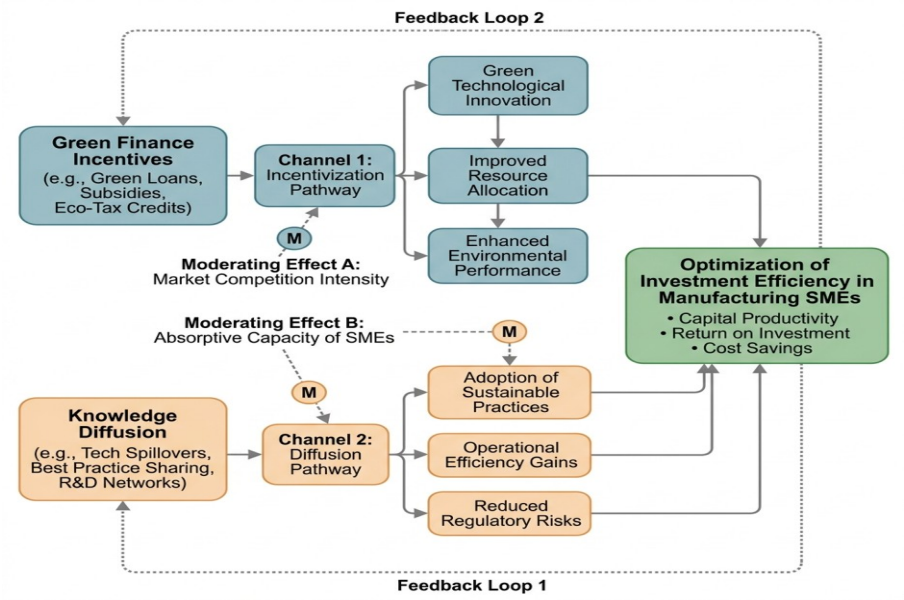

Figure 1: Comprehensive Theoretical Framework of the Dual

If an enterprise receives substantial green finance incentives but operates in a knowledge vacuum, the influx of capital may actually exacerbate overinvestment. Lacking the technical expertise to identify genuinely productive green technologies, managers might allocate the subsidized funds toward highly visible but operationally useless green assets simply to satisfy institutional pressures or secure the subsidies. Conversely, an enterprise might possess excellent environmental knowledge through robust network connections but lack the capital to act upon this intelligence, resulting in persistent underinvestment. Therefore, we hypothesize a significant moderating effect. High levels of knowledge diffusion enhance the positive impact of green finance on investment efficiency by ensuring that newly available green capital is directed toward strategically sound, positive net present value projects, thereby simultaneously curing underinvestment and preventing overinvestment.

3. Methodology and Research Design

3.1 Data Collection and Sample Selection

To empirically test the proposed theoretical framework, this study constructs a comprehensive panel dataset of manufacturing small and medium-sized enterprises. The sample is derived from national enterprise databases, environmental compliance registries, and patent citation networks over a ten-year observation period spanning from 2012 to 2022. This timeframe captures the implementation of several major macroeconomic policies promoting green finance and industrial upgrading. The initial dataset comprises over eight thousand enterprise-year observations.

To ensure the robustness and reliability of the empirical analysis, several stringent data filtering procedures are applied. First, enterprises operating in the financial and real estate sectors are excluded due to their fundamentally different capital structures and investment behaviors. Second, observations with missing critical financial data, such as total assets, operating revenue, or capital expenditures, are removed from the sample. Third, to mitigate the influence of extreme outliers and recording errors, all continuous financial variables are winsorized at the first and ninety-ninth percentiles. After applying these exclusionary criteria, the final unbalanced panel dataset consists of approximately four thousand five hundred firm-year observations, representing a diverse cross-section of the manufacturing industry, including textiles, chemical processing, machinery, and electronics manufacturing.

3.2 Measurement of Core Variables

The dependent variable in this study is investment efficiency. Following standard corporate finance methodologies, we measure investment efficiency using a residual-based expectations model. The model estimates the optimal level of investment for an enterprise based on its growth opportunities, represented by the annual revenue growth rate. The estimation also controls for firm size, operating cash flow, leverage ratio, and enterprise age, alongside industry and year fixed effects to account for macroeconomic shocks and sector-specific investment cycles. The absolute value of the residual from this regression represents the magnitude of investment inefficiency. A larger absolute residual indicates higher inefficiency. Furthermore, the residuals are segregated into positive and negative components to separately analyze overinvestment and underinvestment behaviors, providing a granular view of capital misallocation.

The primary independent variable is green finance incentives. Measuring green finance at the micro-enterprise level presents significant challenges due to data availability. This study constructs a composite index of green finance incentives by aggregating three distinct data points for each enterprise. The first is the total volume of environmental subsidies and government grants received, extracted from the non-operating income notes in annual financial reports. The second is the proportion of long-term debt categorized as green credit or eco-loans by the issuing financial institutions. The third is a binary indicator of whether the enterprise has participated in state-sponsored green credit guarantee schemes. These three components are normalized and synthesized into a single continuous variable representing the intensity of green financial support.

The moderating variable, knowledge diffusion, is quantified using a spatial and network-based technological spillover index. Specifically, we utilize patent citation data and geographic proximity to innovation hubs. The index measures the extent to which an enterprise cites external patents in its own intellectual property filings, weighted by the geographic distance to the cited enterprise. A higher volume of localized cross-citations indicates deeper embeddedness in knowledge diffusion networks. Additionally, regional industrial agglomeration metrics are incorporated into the index to capture tacit knowledge spillovers that occur through informal social networks and labor mobility within dense manufacturing clusters.

Table 1: Descriptive Statistics of Key Variables for Manufacturing SMEs

Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
Investment Inefficiency	4500	0.045	0.032	0.001	0.150
Overinvestment	1850	0.052	0.038	0.002	0.165
Underinvestment	2650	0.041	0.029	0.001	0.130
Green Finance Index	4500	0.312	0.185	0.000	0.850
Knowledge Diffusion	4500	2.150	1.045	0.100	5.200
Firm Size	4500	21.34	1.150	18.50	24.10
Leverage Ratio	4500	0.425	0.165	0.050	0.890
Cash Flow Ratio	4500	0.085	0.054	-0.15	0.280

3.3 Empirical Strategy and Model Specification

To investigate the direct impact of green finance incentives on investment efficiency, a multivariate fixed-effects panel regression model is specified. The dependent variable, investment inefficiency, is regressed against the green finance index, while controlling for a vector of enterprise-level characteristics. These control variables include firm size, calculated as the natural logarithm of total

assets, which captures economies of scale; leverage ratio, defined as total debt divided by total assets, representing financial risk; operating cash flow ratio, which indicates internal financing capacity; and return on assets, proxying for baseline profitability. The model incorporates both enterprise fixed effects to control for time-invariant unobservable characteristics, such as corporate culture and managerial risk aversion, and year fixed effects to absorb aggregate macroeconomic shocks.

To test the moderating role of knowledge diffusion, the baseline model is extended by introducing an interaction term between the green finance index and the knowledge diffusion index. To prevent issues of multicollinearity, both main variables are mean-centered prior to generating the interaction term. Standard errors are clustered at the enterprise level to account for potential autocorrelation and heteroskedasticity within the panel data structure.

4. Empirical Results and Discussion

4.1 Baseline Analysis of Green Finance and Investment Efficiency

The empirical analysis commences with an examination of the direct relationship between green finance incentives and investment inefficiency. The regression results indicate a statistically significant negative coefficient for the green finance index across all model specifications. Because the dependent variable represents inefficiency, this negative coefficient demonstrates that an increase in green finance incentives is associated with a reduction in investment inefficiency, thereby improving overall capital allocation. From an economic perspective, a one standard deviation increase in the green finance index correlates with a roughly twelve percent reduction in the average level of investment inefficiency among the sampled manufacturing enterprises.

To provide deeper insights, the baseline analysis is partitioned to separately examine the effects on overinvestment and underinvestment. The results reveal that green finance exerts a profound and highly significant mitigating effect on underinvestment. This aligns with the theoretical premise that dedicated environmental funding alleviates the severe liquidity constraints that historically prevented small and medium-sized enterprises from pursuing capital-intensive green upgrades. Interestingly, the impact of green finance on overinvestment is also negative and statistically significant, though the magnitude of the coefficient is slightly smaller than that observed for underinvestment. This suggests that the stringent monitoring, project vetting, and post-lending audits associated with green financial instruments successfully restrict managers from diverting funds into negative net present value projects, thus serving a vital corporate governance function.

4.2 The Moderating Role of Knowledge Diffusion

The core theoretical contribution of this study lies in analyzing the interactive effects of green finance and knowledge diffusion. The regression results for the moderation model reveal that the coefficient of the interaction term between green finance and knowledge diffusion is negative and highly statistically significant. This confirms our central hypothesis: knowledge diffusion acts as a potent positive moderator. Specifically, the capacity of green finance incentives to reduce investment inefficiency is significantly amplified in enterprises that operate within robust knowledge diffusion networks.

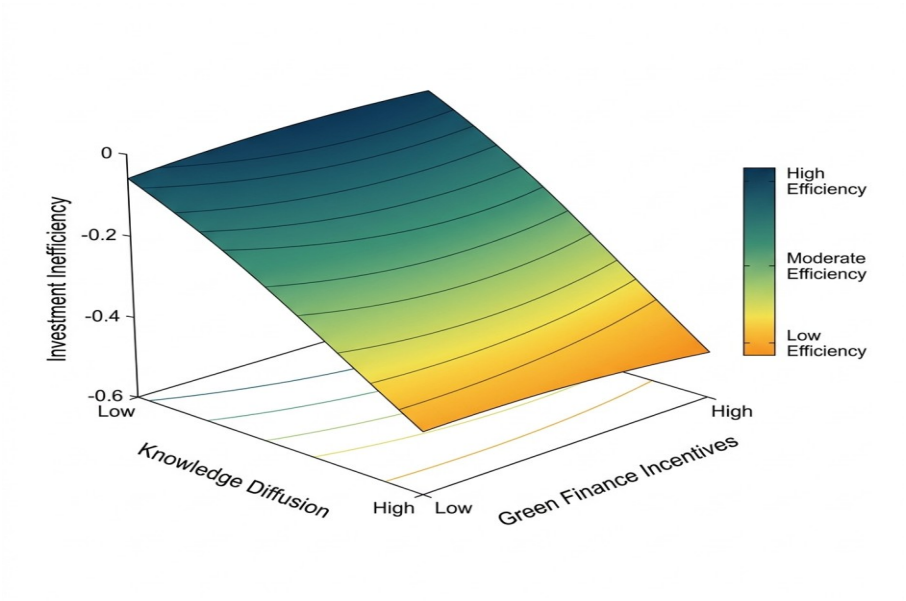

Figure 2: Moderation Analysis Schematic

When enterprises possess high levels of external knowledge access, they demonstrate superior absorptive capacity. The tacit knowledge gained through regional industrial clusters and the explicit technical knowledge acquired through patent networks enable managerial teams to accurately evaluate the technological feasibility and market demand for green innovations. Consequently, when these highly knowledgeable enterprises receive green subsidies or loans, they deploy the capital with surgical precision, targeting optimal environmental projects that yield genuine operational efficiencies. Conversely, for enterprises situated in knowledge vacuums with low diffusion scores, the marginal benefit of green finance on investment efficiency diminishes considerably. Without the guiding mechanism of external technological intelligence, the risk of misallocating green funds increases, underscoring that financial capital cannot act as a complete substitute for intellectual capital.

Table 2: Baseline Regression and Moderating Effect Results

Variables	Baseline Model	Moderation Model	Robustness Model
Green Finance	-0.025	-0.018	-0.022
Knowledge Diffusion	-0.012	-0.009	-0.011
Interaction Term		-0.034	-0.031
Firm Size	-0.005	-0.004	-0.006
Leverage Ratio	0.042	0.039	0.045
Cash Flow Ratio	-0.055	-0.051	-0.058
Firm Fixed Effects	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes
R-squared	0.285	0.324	0.315

4.3 Robustness Tests and Endogeneity Considerations

To ensure the validity of the empirical findings, this study conducts several rigorous robustness checks and addresses potential endogeneity concerns. A primary concern in corporate finance research is reverse causality; it is plausible that enterprises with inherently higher investment efficiency are more adept at securing green finance, rather than green finance driving the efficiency. To address this endogeneity, we employ an instrumental variable approach using the two-stage least squares methodology. The instrument selected is the regional density of green financial institutions, measured at the provincial level. This macro-level variable satisfies the relevance criterion as regional institutional density directly influences enterprise access to green funds, while satisfying the exclusion restriction as

it does not directly impact the micro-level investment efficiency of individual enterprises except through the financing channel. The instrumental variable regression results remain consistent with the baseline findings, confirming the causal direction of our hypotheses.

Furthermore, alternative proxies for the core variables are utilized to verify the stability of the results. The measure of investment efficiency is recalculated using a different expectations model that incorporates sales revenue rather than asset growth. Similarly, the knowledge diffusion index is replaced with a simpler metric based solely on inter-firm collaborative research and development expenditures. Across these alternative specifications, both the direct mitigating effect of green finance on investment inefficiency and the significant moderating role of knowledge diffusion remain robust and quantitatively similar to the primary models. Finally, the sample is subsampled by technological intensity, dividing enterprises into high-tech and low-tech manufacturing. The results indicate that the interaction between green finance and knowledge diffusion is particularly pronounced in high-tech manufacturing, where technological uncertainty is highest and the demand for specialized knowledge is most acute.

5. Conclusion and Policy Implications

5.1 Summary of Main Findings

This paper has systematically investigated the complex mechanisms through which green finance incentives and knowledge diffusion interact to explain the investment efficiency of manufacturing small and medium-sized enterprises. The empirical analysis, grounded in a comprehensive panel dataset and rigorous econometric modeling, yields several pivotal findings. First, the provision of green finance incentives significantly reduces overall investment inefficiency. By injecting targeted liquidity and imposing external monitoring, green finance effectively mitigates both the underinvestment caused by capital constraints and the overinvestment driven by agency conflicts. Second, and more importantly, the study establishes that knowledge diffusion serves as a critical boundary condition for optimal capital allocation. The capacity of green finance to enhance investment efficiency is substantially amplified for enterprises deeply embedded in knowledge networks. Access to external technological intelligence and managerial best practices equips these enterprises with the necessary absorptive capacity to accurately evaluate and execute complex environmental projects, thereby maximizing the utility of subsidized green capital.

5.2 Theoretical and Managerial Implications

Theoretically, this research contributes to the intersection of corporate finance and innovation literature by proposing and validating a dual-channel framework [28]. It moves beyond the traditional view that financial constraints are the sole barrier to sustainable upgrading, highlighting that cognitive and technological constraints are equally restrictive. By integrating absorptive capacity theory with investment efficiency models, the study demonstrates that financial capital and intellectual capital are complementary rather than substitutable forces in the green transition. From a managerial perspective, the findings emphasize the necessity for enterprise leaders to actively cultivate external network linkages. Managers must recognize that securing green financing is only the first step; building relationships with academic institutions, engaging in industry consortia, and monitoring regional patent landscapes are essential activities for developing the foresight required to allocate green funds effectively.

5.3 Limitations and Directions for Future Research

While this study offers robust insights, it is subject to certain limitations that provide avenues for future academic inquiry. The empirical analysis is primarily based on quantitative financial and patent data, which may not fully capture the nuances of informal, tacit knowledge sharing that often occurs through interpersonal managerial relationships [29]. Future research could employ mixed-methods approaches, incorporating in-depth qualitative interviews or survey data, to map the micro-mechanisms of tacit knowledge diffusion in greater detail. Additionally, the study focuses on a generalized measure of green finance. As the sustainable finance market matures, subsequent studies should investigate the differential impacts of specific instruments, contrasting the investment efficiency outcomes of green equity financing against green debt financing or examining the distinct behavioral responses to regional environmental tax incentives versus direct federal subsidies. Exploring these granular distinctions will further refine the design of policy interventions aimed at fostering sustainable industrial development.

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