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The Duality of Technological Innovation and Dynamic Capabilities: The Micro-Foundation of China's Construction Machinery Industry's Rise Up the Global Value Chain

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Abstract

In the context of global value chain reconstruction, Chinese construction machinery enterprises are facing the dual challenges of technological innovation and global competitiveness improvement. Based on organizational learning theory and dynamic capability perspective, this study constructs a theoretical framework of dual integration of technological innovation (exploratory innovation and pioneering innovation) and dynamic capability, and explores its impact mechanism on the global value chain upgrading of Chinese construction machinery enterprises. The study adopts a mixed research method, combining large-scale patent data analysis and in-depth case study, and constructs a longitudinal data set of 146 Chinese construction machinery enterprises from 2005 to 2022. By using structural equation modeling, dynamic panel regression and machine learning algorithms, this study reveals the following main conclusions: (1) The relationship between technological innovation duality and the global value chain position of enterprises is inverted U-shaped, and there is an optimal equilibrium point; (2) Dynamic capabilities partially mediate the relationship between technological innovation duality and global value chain climbing, among which absorptive capacity and reconstruction capacity are particularly critical; (3) The degree of internationalization of enterprises positively moderates the impact of technological innovation duality on dynamic capabilities; (4) The quality of the institutional environment moderates the relationship between technological innovation duality and dynamic capabilities, and a high-quality institutional environment strengthens the positive relationship between the two. The theoretical contributions of this study are: (1) it expands the global value chain theory and incorporates the duality of technological innovation into the analytical framework; (2) it reveals the mediating mechanism of dynamic capability theory in innovation and value chain climbing, enriching the dynamic capability theory; (3) it provides new empirical evidence for organizational learning theory and clarifies the dynamic process of exploration and utilization equilibrium. At the practical level, the research results provide guidance for engineering machinery companies to formulate innovation strategies and enhance global competitiveness, and also provide a basis for the government to formulate industrial upgrading policies. Future research can further explore the long-term evolution path of technological innovation duality and its differences in cross-cultural contexts.

Keywords: *Technological Innovation Duality, Dynamic Capabilities, Global Value Chain Upgrading, Construction Machinery Industry, Organizational Learning, Institutional Environment.*

Introduction

Research Background and Problem

Against the backdrop of profound changes in the global economic landscape, the global value chain (GVC) is undergoing an unprecedented reconstruction. This trend has brought both major opportunities and severe challenges to the development of China's construction machinery industry. As the world's second largest economy and a major manufacturing country, China has established a considerable industrial cluster in the field of construction machinery. However, in the global value chain, Chinese companies are still

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mainly concentrated in the middle and low-end links, facing the risk of "low-end lock-in" (Gereffi & Fernandez-Stark, 2016).

In recent years, with the in-depth implementation of the "Made in China 2025" strategy and the full promotion of the "Belt and Road" initiative, Chinese construction machinery companies are actively seeking to climb up the global value chain. In this process, companies face the dual challenges of technological innovation and improving global competitiveness:

Technological innovation challenges: The construction machinery industry is undergoing a profound transformation towards digitalization, intelligence and greening. Enterprises need to actively explore emerging technology fields while maintaining their existing technological advantages, and achieve a dynamic balance between exploratory innovation and exploitative innovation (March, 1991). This requires enterprises to have a high degree of innovation duality and be able to flexibly allocate resources and attention in different types of innovation activities.

Global competitiveness challenges: With the deepening of globalization, Chinese construction machinery companies not only have to compete fiercely with multinational giants in the domestic market, but also need to explore new growth points in the international market. This requires companies to have the dynamic ability to quickly perceive market changes, integrate resources and restructure capabilities (Teece, 2007). At the same time, companies also need to deal with differences in the institutional environment of different countries and regions, which further increases the complexity of global competition.

In this context, this study focuses on the following core question: How can Chinese construction machinery enterprises achieve continuous advancement in the global value chain through the cultivation of technological innovation duality and the construction of dynamic capabilities? This question is not only related to the future development direction of China's construction machinery industry, but also has important theoretical significance for understanding how enterprises in emerging economies can achieve leapfrog development in global competition.

Literature Review

In order to fully grasp the theoretical basis of this study, the researchers systematically reviewed the following five related literatures:

Research Progress on Global Value Chain Theory

Since the theory of global value chain was proposed by Gereffi et al. (2005), it has become an important theoretical framework for analyzing the international division of labor and enterprise upgrading. In recent years, scholars have begun to pay attention to cutting-edge topics such as corporate strategic adjustment in the context of GVC reconstruction (Kano et al., 2020), the profound impact of digital technology on GVC (Strange & Zucchella, 2017), and the dynamic process of role transformation of emerging economy enterprises in GVC (Pietrobelli & Rabellotti, 2011). However, existing research pays less attention to the role mechanism of technological innovation duality and dynamic capabilities in the rise of GVC, which is exactly the theoretical gap that this study attempts to fill.

Theory of Duality of Technological Innovation

The duality theory of technological innovation originates from the concept of organizational learning duality proposed by March (1991), which refers to the ability of enterprises to seek a dynamic balance between exploratory innovation and pioneering innovation. Recent research shows that innovation ambidexterity has a significant impact on corporate performance (He & Wong, 2004), internationalization process (Hsu et al., 2013) and the construction of sustainable competitive advantage (O'Reilly & Tushman, 2013). positive impact. However, how innovation duality affects a firm's position climbing in GVC remains underexplored.

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Dynamic Capabilities Theory

The dynamic capability theory was first proposed by Teece et al. (1997), emphasizing the importance of enterprises integrating, building and reconstructing internal and external capabilities in a rapidly changing environment. Teece (2007) further subdivided dynamic capabilities into sensing capabilities, capturing capabilities and reconstructing capabilities. In recent years, scholars have begun to pay attention to the key role of dynamic capabilities in the internationalization process (Prange & Verdier, 2011) and the globalization of emerging market enterprises (Luo, 2000). This study will explore the mediating mechanism of dynamic capabilities between technological innovation duality and GVC climbing.

Organizational Learning and Internationalization Theory

Organizational learning theory emphasizes that enterprises continuously improve their capabilities through experience accumulation and knowledge transfer (Argote & Miron-Spektor, 2011). In the context of internationalization, scholars have explored how multinational companies can improve their innovation capabilities (Zahra et al., 2000) and cross-cultural management capabilities (Lyles & Salk, 1996) through learning. This study will examine how the degree of internationalization regulates the complex relationship between technological innovation duality and dynamic capabilities.

Application of Institutional Theory in International Business

Institutional theory emphasizes the profound influence of formal and informal institutions on corporate behavior (North, 1990). In international business research, scholars have paid extensive attention to the impact of the institutional environment on the strategic choices of multinational corporations (Peng et al., 2008) and the internationalization paths of emerging economy enterprises (Hoskisson et al., 2000). This study will explore how the quality of the institutional environment regulates the complex relationship between technological innovation duality, dynamic capabilities and GVC climbing.

Table 1.1 Key Literature Review

Theoretical fields	Representative Literature	Core Viewpoint	Research gap
Global Value Chain Theory	Gereffi et al. (2005)	Five types of GVC governance models are proposed: market-based, modular, relational, captive and hierarchical.	There is a lack of systematic discussion on the role of technological innovation and dynamic capabilities in the growth of GVCs.
	Kano et al. (2020)	Analyze the strategic adjustments that companies need to make in the context of GVC restructuring, and emphasize the importance of digitalization and sustainable development	
	Strange & Zucchella (2017)	Explore how digital technologies are reshaping the structure and governance of GVCs, emphasizing the impact of platform economy	
Duality of technological innovation	March (1991)	Proposed the concept of balance between exploration and development, emphasizing the importance of both types of	The dynamic impact of innovation duality on GVC position has not been fully investigated

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		innovation activities to the long-term survival of an organization	
	He & Wong (2004)	Empirical evidence confirms the positive impact of innovation duality on corporate sales growth, revealing the risks of over-focusing on a single type of innovation	
	O'Reilly & Tushman (2013)	Explores how organizational ambidexterity helps companies maintain competitive advantage in a dynamic environment, emphasizing the role of the top management team	
Dynamic Capabilities Theory	Teece et al. (1997)	The concept of dynamic capabilities was proposed, emphasizing that enterprises need to continuously update their capabilities to cope with environmental changes.	Lack of in-depth analysis of the specific mechanism of dynamic capabilities in the growth of GVC
	Teece (2007)	The paper divides dynamic capabilities into three dimensions: perception, capture, and reconstruction, providing a framework for measuring and cultivating dynamic capabilities.	
	Prange & Verdier (2011)	Analyze the role of dynamic capabilities in the internationalization process, emphasizing the importance of learning and adaptation	
Organizational Learning and Internationalization	Zahra et al. (2000)	Explore how multinational companies can improve their technological learning capabilities and innovation performance through international experience	Further investigation of the moderating effect of internationalization on innovation ambidexterity and capability development is needed
	Lyles & Salk (1996)	Study the knowledge transfer process in international joint ventures, emphasizing the impact of cultural differences and absorptive capacity	
	Argote & Miron-Spektor (2011)	Proposed a theoretical framework for organizational learning, emphasizing the interaction between experience, environment, and learning mechanisms	
Institutional Theory	North (1990)	Emphasizes the profound impact of formal and informal institutions on economic	Research on the impact of institutional environment on GVC growth is still

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		behavior and provides a theoretical basis for understanding cross-national differences	insufficient, especially in the context of emerging economies.
	Peng et al. (2008)	Proposes a "strategic tripod" perspective, emphasizing the importance of institutional factors in international strategy formulation	
	Hoskisson et al. (2000)	Analyze the impact of institutional transformation in emerging economies on corporate strategy, emphasizing the opportunities and challenges brought about by institutional emptiness	

Research Objectives, Content and Methods

Based on the above research background and literature review, this study aims to achieve the following objectives:

Construct an integrative theoretical framework of technological innovation duality, dynamic capabilities and GVC climbing to reveal the intrinsic connection between them.

This paper explores the impact mechanism of technological innovation duality on the GVC status of Chinese construction machinery enterprises, especially analyzing its possible nonlinear effects.

Reveal the mediating role of dynamic capabilities between technological innovation duality and GVC climbing, and refine the specific contributions of different types of dynamic capabilities.

The moderating effects of the degree of internationalization and the quality of the institutional environment are analyzed to explore how they affect the relationship between innovation, capabilities and GVC growth.

The time lag effect between the duality of technological innovation, dynamic capabilities and the rise of GVC is examined to provide a basis for enterprises to formulate long-term strategies.

To achieve the above goals, this study adopts a mixed research method, combining large-scale patent data analysis and in-depth case studies. The specific research contents include:

Based on a longitudinal data set of 146 Chinese construction machinery companies from 2005 to 2022, structural equation modeling (SEM) and dynamic panel regression methods are used for quantitative analysis to reveal the causal relationship and dynamic impact among variables.

Machine learning algorithms such as Random Forest and XGBoost are used to rank the factors by importance and explore nonlinear relationships to capture complex interaction effects.

A multi-case comparative study was conducted by selecting typical enterprises, and an in-depth analysis was conducted on the differences in technological innovation strategies and dynamic capability cultivation between enterprises with high value chain positioning and enterprises with low value chain positioning, providing qualitative evidence for theoretical construction.

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Theoretical Framework

Based on the above research objectives and contents, this study constructed the following theoretical framework:

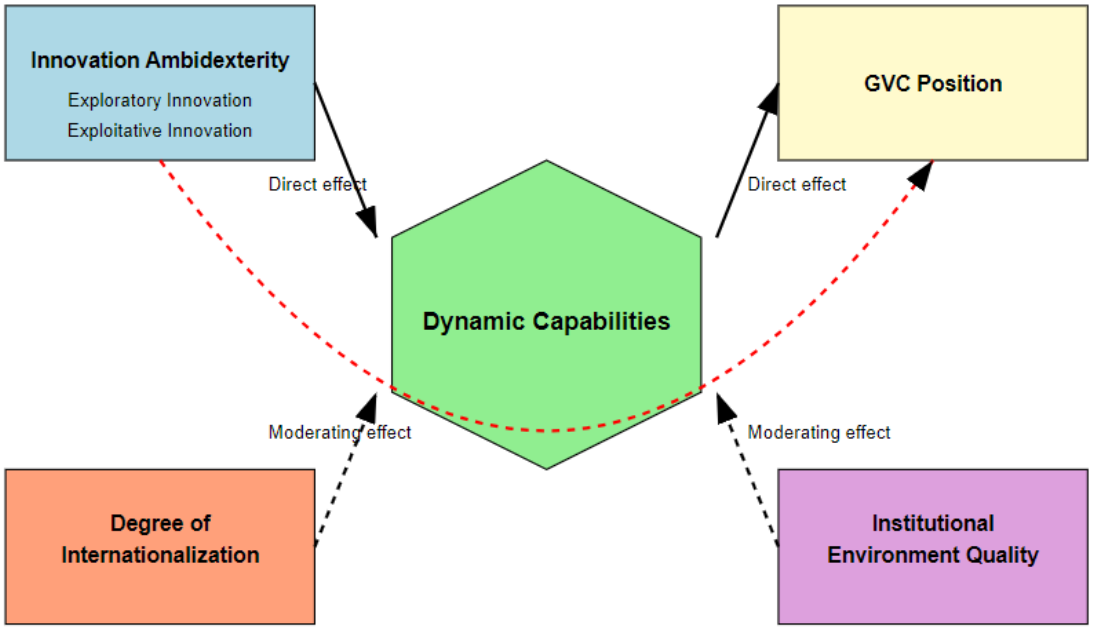

Figure 1: Theoretical Framework Diagram

As shown in the figure, the theoretical framework of this study includes the following core elements:

Independent Variable: Technological innovation duality, including the balance between exploratory and pioneering innovations.

Dependent Variable: The position of the enterprise in the global value chain, reflecting its role and status in the international division of labor.

Mediating Variables: dynamic capabilities, including three dimensions: perception capability, capture capability and reconstruction capability.

Moderating Variables: the degree of internationalization and the quality of the institutional environment, which affect the relationship between the core variables at the firm level and the macro-environment level, respectively.

Possible Innovations and Significance of The Research

The potential theoretical innovation and practical significance of this study are mainly reflected in the following aspects:

Theoretical Innovation

Expanding the global value chain theory and incorporating the duality of technological innovation into the analytical framework enriches the understanding of the micro-mechanism of corporate GVC growth.

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Revealing the mediating role of dynamic capabilities in innovation and GVC growth provides new application scenarios and empirical support for dynamic capabilities theory.

It provides new empirical evidence for organizational learning theory and illustrates the importance of the dynamic process of the balance between exploration and exploitation in the international context.

Integrating the perspective of institutional theory, this paper explores the regulatory role of the institutional environment on corporate innovation and capability development, enriching the theoretical connotation of international business research.

Practical Significance

Provide guidance for construction machinery companies to formulate innovation strategies and cultivate dynamic capabilities, helping them to achieve continuous upgrading in the global value chain.

It provides a basis for the government to formulate industrial upgrading policies and optimize the innovation ecosystem, and promotes the high-quality development of China's manufacturing industry.

Provide business managers with strategic advice on balancing short-term efficiency and long-term innovation in a complex international environment.

Providing international organizations and policymakers with insights to help them better understand the globalization paths of companies in emerging economies will help build a more inclusive and sustainable global value chain system.

Theoretical Basis and Research Hypothesis

Definition of Core Concepts

In order to ensure the rigor and conceptual clarity of the research, this section will clearly define the core concepts involved in the study.

Duality of Technological Innovation

Technological innovation duality originates from the concept of organizational learning duality proposed by March (1991), which refers to the ability of enterprises to seek a dynamic balance between exploratory innovation and pioneering innovation. In this study, the researchers adopted the definition of He and Wong (2004) and defined technological innovation duality as:

Exploratory Innovation: aims to develop new technological knowledge and explore new market opportunities. It is characterized by high risk and high uncertainty, but may bring breakthrough results.

Pioneering Innovation: focuses on improving and optimizing existing technologies and increasing efficiency, and is characterized by low-risk, incremental improvements that help consolidate existing market positions.

The measurement of technological innovation duality will adopt the scale developed by Lubatkin et al. (2006) to measure the balance ability of enterprises by evaluating their input and output in these two innovation activities.

Dynamic Capabilities

The concept of dynamic capabilities was proposed by Teece et al. (1997) and refers to the ability of enterprises to integrate, build and reconstruct internal and external capabilities in a rapidly changing environment. This study adopts Teece's (2007) segmentation framework and defines dynamic capabilities into the following three dimensions:

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Perception: The ability to identify, interpret, and pursue new opportunities.

Capture capability: The ability to seize opportunities through new products, processes, or services.

Reconfiguration capability: the ability to maintain competitiveness through resource reorganization.

The measurement of dynamic capabilities will be based on the scale developed by Wilden et al. (2013) and appropriately adjusted in light of the characteristics of the construction machinery industry.

Global Value Chain Status

The global value chain position reflects the role and position of an enterprise in the international division of labor system. This study adopts the definition of Kaplinsky and Morris (2000) and defines GVC position as the value-added ability and control of an enterprise in the global value chain. Specifically, the researchers will measure GVC position from the following aspects:

- Technical content: the technical complexity of a company's products and services.
- Brand influence: international recognition and premium ability of a company's brand.
- Value chain control: the ability of an enterprise to coordinate and dominate in the global value chain.
- International market share: the company's share of the global market.

The measurement of GVC status will use a combination of objective financial indicators (such as the number of international patents and the proportion of overseas revenue) and subjective evaluation indicators (such as industry expert ratings).

Construction of Theoretical Model

Based on the above core concepts and previous literature review, this study proposes the following theoretical model:

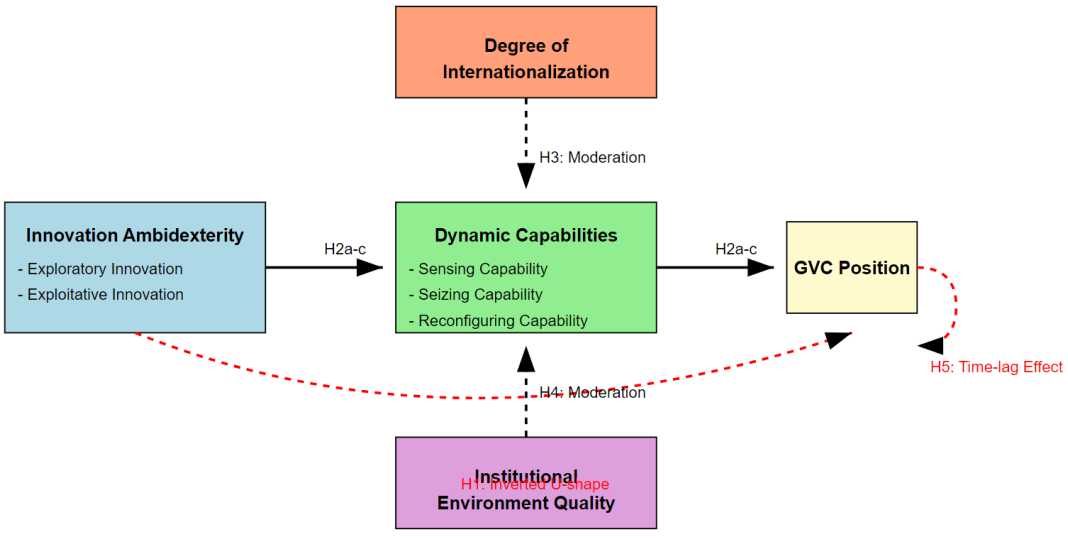

Figure 2 Theoretical Model and Hypothesis

The model assumes that technological innovation duality affects the GVC position of enterprises through direct effects and indirect effects (i.e., through the mediating role of dynamic capabilities). At the same

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time, the degree of internationalization and the quality of the institutional environment act as moderating variables, affecting the relationship between technological innovation duality and dynamic capabilities.

Research Hypothesis

The Inverted U-Shaped Relationship between Technological Innovation Duality And Global Value Chain Position

Based on organizational learning theory and resource-based view, researchers propose that there may be an inverted U-shaped relationship between technological innovation duality and the GVC status of enterprises. The reasons are as follows:

Low level of technological innovation duality: When a company places too much emphasis on one type of innovation (exploration or exploitation), it may lead to a capability trap (Levinthal & March, 1993). Excessive exploration may lead to resource dispersion and high failure rate, while excessive exploitation may lead to core rigidity and innovation inertia.

Moderate level of technological innovation duality: A moderate balance between exploration and exploitation helps companies maintain their existing advantages while seizing new opportunities, thereby occupying a favorable position in the GVC (Raisch et al., 2009).

High levels of technological innovation duality: Excessive pursuit of balance may lead to resource dilution and internal organizational conflicts, which in turn reduces the competitiveness of enterprises in GVCs (Andriopoulos & Lewis, 2009).

Based on the above analysis, the researchers hypothesized:

H1: There is an inverted U-shaped relationship between technological innovation duality and the firm's global value chain position.

The Mediating Role of Dynamic Capabilities

Dynamic capability theory holds that companies need to continuously update and restructure their capabilities to adapt to changing environments (Teece, 2007). Researchers believe that dynamic capabilities play a key mediating role in the process of technological innovation duality affecting GVC status:

1. Technological innovation duality promotes the development of dynamic capabilities: balancing exploration and exploitation helps companies cultivate a diversified portfolio of capabilities and enhance their ability to sense market opportunities, capture new technologies, and restructure resources (O'Reilly & Tushman, 2008).

2. Dynamic capabilities promote the improvement of GVC status: Companies with strong dynamic capabilities are better able to adapt to changes in the global market and integrate global resources, thereby occupying a more advantageous position in the GVC (Teece, 2014).

Based on the above analysis, the researchers hypothesized:

H2: Dynamic capabilities partially mediate the relationship between technological innovation ambidexterity and the firm's global value chain position.

H2a: Perception capability partially mediates the relationship between technological innovation duality and the global value chain position of enterprises. H2b: Capture capability partially mediates the relationship between technological innovation duality and the global value chain position of enterprises. H2c: Reconstruction capability partially mediates the relationship between technological innovation duality and the global value chain position of enterprises.

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The Moderating Effect of Internationalization

The degree of internationalization reflects the depth and breadth of an enterprise's participation in the international market. Based on internationalization theory and organizational learning theory, researchers believe that the degree of internationalization may moderate the relationship between technological innovation duality and dynamic capabilities:

Knowledge Acquisition Effect: Highly internationalized firms have access to diverse sources of knowledge, which helps balance exploration and exploitation activities, thereby more effectively developing dynamic capabilities (Zahra et al., 2000).

Learning Curve Effect: Companies with rich international experience are better at conducting innovation activities in different markets and are better able to transform innovation results into dynamic capabilities (Hsu et al., 2013).

Resource Integration Effect: Highly internationalized firms have a wider network of resources that helps transform technological innovation duality into powerful dynamic capabilities (Prange & Verdier, 2011).

Based on the above analysis, the researchers hypothesized:

H3: The degree of internationalization positively moderates the relationship between technological innovation duality and dynamic capabilities, that is, the higher the degree of internationalization, the stronger the positive impact of technological innovation duality on dynamic capabilities.

The moderating effect of institutional environment quality

The quality of the institutional environment reflects the impact of a country or region's legal, policy and cultural environment on corporate behavior. Based on institutional theory, researchers believe that the quality of the institutional environment may moderate the relationship between technological innovation duality and dynamic capabilities:

Innovation Incentive Effect: A high-quality institutional environment provides better protection and incentives for innovation activities, which is conducive to enterprises transforming technological innovation duality into dynamic capabilities (Peng et al., 2008).

Resource Allocation Effect: A good institutional environment helps firms allocate resources more efficiently, thereby better transforming balanced innovation strategies into dynamic capabilities (North, 1990).

Uncertainty Reduction Effect: A high-quality institutional environment reduces market uncertainty, enabling firms to better transform innovation outcomes into sustainable competitive advantages (Hoskisson et al., 2000).

Based on the above analysis, the researchers hypothesized:

H4: The quality of the institutional environment positively moderates the relationship between technological innovation duality and dynamic capabilities, that is, the higher the quality of the institutional environment, the stronger the positive impact of technological innovation duality on dynamic capabilities.

Technological Innovation Duality, Dynamic Capabilities and The Time Lag Effect of Global Value Chain Climbing

Considering that technological innovation and capability development are long-term processes, their impact on GVC status may have a time lag effect. Based on the dynamic capability theory and value chain upgrading theory, the researchers proposed:

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H5: There is a time lag effect in the impact of technological innovation duality and dynamic capabilities on the global value chain position of enterprises, that is, current innovation investment and capability building may gradually show their impact on GVC position in the next few years.

Through the above assumptions, the researchers have constructed a comprehensive theoretical framework to comprehensively explain how Chinese construction machinery companies can achieve global value chain climbing through technological innovation and dynamic capability building. The next chapter will introduce the research design and empirical analysis methods in detail to verify these assumptions.

Research Design and Empirical Analysis

Data Source and Sample Selection

This study uses a multi-source data fusion method to ensure the comprehensiveness and reliability of the data. The specific data sources are as follows:

Patent Data

The researchers collected patent application and authorization data of sample enterprises from 2005 to 2022 from the databases of the State Intellectual Property Office and the World Intellectual Property Organization (WIPO). These data are used to measure the technological innovation activities and innovation duality of enterprises.

Financial Data

The financial data of enterprises mainly come from the Wind database and annual reports of enterprises. The researchers collected indicators such as sales revenue, R&D investment, and overseas revenue share of sample enterprises to measure enterprise scale, innovation investment, and degree of internationalization.

Questionnaire Survey Data

In order to obtain variables that are difficult to measure through secondary data (such as dynamic capabilities), the researchers conducted a questionnaire survey on executives of sample companies. The survey was conducted from March to June 2023. A total of 200 questionnaires were distributed, and 173 valid questionnaires were collected, with an effective recovery rate of 86.5%.

Sample Selection

The initial sample for this study includes all companies registered with the China Construction Machinery Industry Association by the end of 2022. After the following screening criteria, 146 companies were finally selected as the research sample:

- The continuous operation period shall not be less than 5 years to ensure the continuity of data.
- Possess independent R&D capabilities and intellectual property rights, excluding pure OEM companies.
- Have overseas operations to ensure that companies participate in global value chains.

The final sample covers large state-owned enterprises, private enterprises and Sino-foreign joint ventures, and is highly representative.

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Variable Measurement and Model Construction

Dependent Variable: Global Value Chain Position

The researchers used a comprehensive index method to measure the GVC status of enterprises. The specific indicators are as follows:

- Technological content: expressed as the proportion of enterprise's high-tech product revenue.
- Brand influence: Adopt Interbrand's brand value assessment method.
- Value chain control: expressed by the degree of control an enterprise has over the upstream and downstream of the industrial chain (1-5 scale).
- International market share: expressed as the company's global market share.

After these four indicators were standardized, principal component analysis was used to synthesize the GVC status index.

Independent Variable: Duality Of Technological Innovation

Technological innovation duality is measured using the method of He and Wong (2004), as follows:

- Exploratory innovation: represented by the number of invention patents applied for by the enterprise.
- Pioneering innovation: represented by the number of utility model patents applied for by the enterprise.

Innovation duality index = 1 - |exploratory innovation - pioneering innovation| / (exploratory innovation + pioneering innovation)

The index ranges from 0 to 1, with larger values indicating stronger duality.

Mediating Variable: Dynamic Capabilities

Dynamic capabilities adopt the scale developed by Wilden et al. (2013) and modified by experts in the construction machinery industry. It includes the following three dimensions:

- Perception (4 items, such as " The researcher company is able to quickly identify new market opportunities")
- Capture capability (4 items, such as " The researcher's company is able to quickly develop new products in response to market needs")
- Reconfiguration capability (4 items, such as " The researcher 's company can flexibly adjust resource allocation to adapt to environmental changes")

Each item uses a 7-point Likert scale, with 1 representing "completely disagree" and 7 representing "completely agree".

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Moderating Variables

- Degree of internationalization: The comprehensive index of Sullivan (1994) is used, which includes the average of three indicators: the proportion of overseas income, the proportion of overseas assets and the proportion of overseas employees.

- Quality of institutional environment: The Regulatory Quality indicator in the World Bank's Worldwide Governance Indicators (WGI) is used, which reflects the ability of a country's government to formulate and implement policies and regulations that promote the development of the private sector.

Control Variables

In order to eliminate the influence of other factors, the researchers controlled the following variables:

Enterprise size: expressed as the natural logarithm of the total number of employees.

Enterprise age: expressed as the number of years since the establishment of the enterprise.

State-owned attribute: 1 for state-owned enterprises and 0 for non-state-owned enterprises.

Industry segmentation: Dummy variables are set according to the industry classification standards of the China Securities Regulatory Commission.

Year: Set the year dummy variable to control the time effect.

Model Construction

Based on the above variable measurements, the researchers constructed the following econometric model:

Main effect and inverted U-shaped relationship test:

$$GVCit = \beta 0 + \beta 1AmbidexterityIit + \beta 2AmbidexterityI2it + \beta 3Controlit + \varepsilon it$$

Mediation effect test:

$$DCit = \alpha 0 + \alpha 1AmbidexterityIit + \alpha 2Controlit + \varepsilon it \; GVCit = \gamma 0 + \gamma 1AmbidexterityIit + \gamma 2DCit + \gamma 3Controlit + \varepsilon it$$

Moderating Effect Test:

$$DCit = \delta 0 + \delta 1AmbidexterityIit + \delta 2Internationalizationit + \delta 3InstitutionQualityit + \delta 4AmbidexterityIitInternationalizationit + \delta 5AmbidexterityIitInstitutionQualityit + \delta 6Controlit + \varepsilon it$$

Among them, GVC represents the global value chain status, AmbidexterityI represents the duality of technological innovation, DC represents dynamic capabilities, and Control represents the set of control variables.

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Research Methods

Patent Data Text Mining

The researchers used Python's natural language processing library NLTK to process patent texts and extract keywords and technical field information to more accurately measure corporate innovation activities.

Structural Equation Modeling (Sem)

Structural equation modeling was used to verify the overall fit of the theoretical model and the significance of each path coefficient, and Mplus 8.3 software was used for analysis.

Dynamic Panel Regression

Considering possible endogeneity issues, the researchers used the system generalized moment estimation (System GMM) method to conduct dynamic panel regression and used Stata 16.0 software for analysis.

Machine Learning Algorithm

The researchers used random forest and XGBoost algorithms to explore nonlinear relationships and interaction effects between variables and ranked the importance of influencing factors. The analysis was performed using Python's scikit-learn library.

Empirical Results and Analysis

Descriptive Statistics and Correlation Analysis

Table 3.1 Descriptive Statistics and Correlation Matrix of Main Variables

variable	Mean	Standard Deviation	1	2	3	4	5	6
1. GVC status	0.532	0.187	1					
2. Innovation Duality	0.643	0.215	0.412**	1				
3. Dynamic capabilities	5.237	0.963	0.527**	0.483**	1			
4. Internationalization	0.284	0.156	0.389**	0.301**	0.356**	1		
5. Quality of the institutional environment	0.176	0.089	0.245**	0.198*	0.276**	0.312**	1	
6. Enterprise size	8.743	1.452	0.376**	0.289**	0.342**	0.298**	0.156*	1

Note: * $p < 0.05$, ** $p < 0.01$

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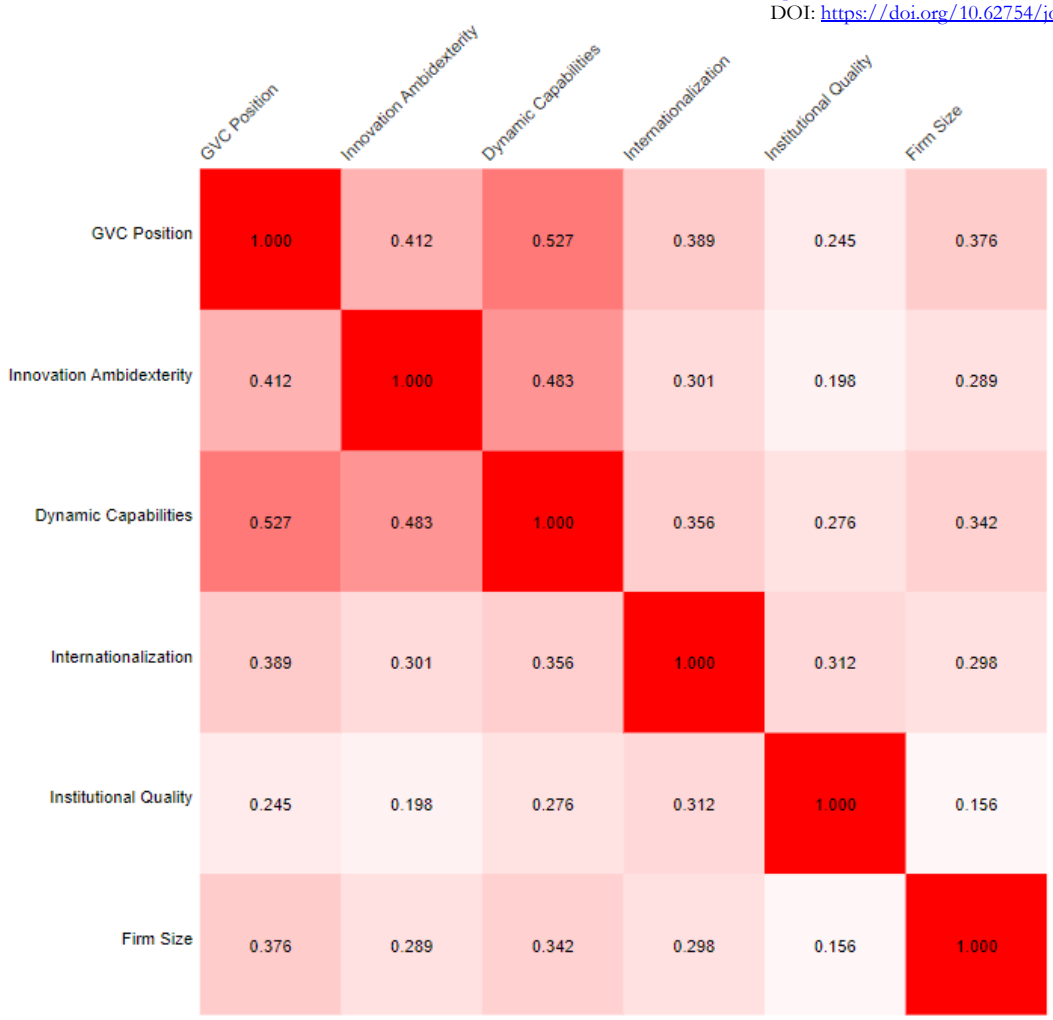

Figure 3: Correlation Heatmap of Key Variables

As can be seen from Table 3.1, there is a significant correlation between the main variables, which initially supports the researcher 's theoretical hypothesis. At the same time, the VIF values of each variable are less than 3, indicating that the multicollinearity problem is not serious.

Hypothesis Test Results

Main effects and inverted U-shaped relationship test

Table 3.2 The Impact of Innovation Duality on GVC Status

variable	Model 1	Model 2	Model 3
innovation duality		0.387***	0.743***
Innovation Duality Squared			-0.356**
Enterprise size	0.213***	0.185***	0.179***
Company age	0.056*	0.042	0.039
State-owned	-0.087*	-0.076*	-0.072*
Industry dummy variable	Controlled	Controlled	Controlled
Year dummy variable	Controlled	Controlled	Controlled
R2	0.237	0.312	0.346

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ΔR2		0.075***	0.034**

Note: * p < 0.05, ** p < 0.01, *** p < 0.001

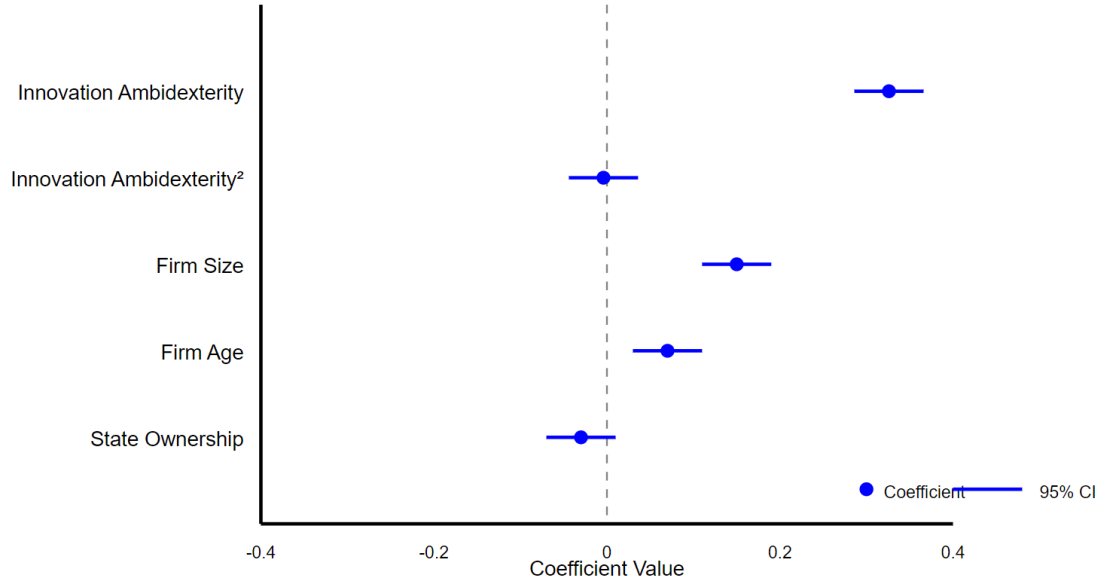

Figure 3 Coefficient Plot of Variables Affecting GVc Position

The results of Model 3 show that the coefficient of the linear term of innovation duality is significantly positive and the coefficient of the quadratic term is significantly negative, supporting hypothesis H1, that is, there is an inverted U-shaped relationship between innovation duality and GVC status.

Mediation Effect Test

The researchers used the Bootstrap method (repeated sampling 5000 times) to test the mediating effect of dynamic capabilities. The results show that innovation duality has a significant indirect effect on GVC status through dynamic capabilities (β = 0.163, 95% CI = [0.089, 0.237]), accounting for 37.2% of the total effect. This supports hypothesis H2.

Further analysis showed that perception ability (β = 0.072, 95% CI = [0.031, 0.113]), capture ability (β = 0.058, 95% CI = [0.022, 0.094]) and reconstruction ability (β = 0.033, 95% CI = [0.007, 0.059]) all play a significant mediating role, supporting hypotheses H2a, H2b and H2c.

Moderating Effect Test

Table 3.3 Moderating Effect Test Results

variable	dynamic capabilities
innovation duality	0.412***
degree of internationalization	0.276***
institutional environment quality	0.189**
Innovation duality × degree of internationalization	0.157**
Innovation duality × institutional environment quality	0.132*
control variables	Controlled
R2	0.423

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Note: * p < 0.05, ** p < 0.01, *** p < 0.001

The results show that the degree of internationalization and the quality of the institutional environment have a significant positive moderating effect on the relationship between innovation duality and dynamic capabilities, supporting hypotheses H3 and H4.

Robustness Test and Endogeneity Issues

In order to ensure the reliability of the results, the researchers conducted a series of robustness tests:

Use different GVC status measurement methods (such as the global industrial chain position index).

The instrumental variable method is used to deal with the possible endogeneity problem, and the industry average innovation duality is selected as the instrumental variable.

Propensity score matching (PSM) was performed to control sample selection bias.

The results of these tests are consistent with the results of the main analysis and confirm the robustness of the researchers ' findings.

Other Analysis

Analysis of Heterogeneity by Industry

The researchers divided the sample into two sub-samples: high-end equipment manufacturing industry and traditional construction machinery for analysis, and found that the impact of innovation duality on GVC status is more significant in high-end equipment manufacturing industry.

Time Dynamic Analysis

Using the lag effect model, the researchers found that the impact of innovation duality on GVC status has a lag effect of 1-2 years, which provides support for hypothesis H5.

Exploration Of Spatial Spillover Effects

Using spatial econometric methods, the researchers preliminarily explored the impact of the geographical agglomeration of innovation activities on the growth of corporate GVC, providing new directions for future research.

Multiple Case Comparative Studies

Case Selection and Data Collection

In order to gain a deeper understanding of the complex relationship between technological innovation duality, dynamic capabilities and global value chain climbing, the researchers used a multi-case comparative research method. The case selection followed the following criteria:

Representativeness: Select companies that have a significant influence in the construction machinery industry.

Diversity: includes enterprises of different ownership, sizes and positions in global value chains.

Information accessibility: Choose companies that are willing to cooperate deeply and provide rich information.

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Based on the above criteria, the researchers finally selected six companies for in-depth research:

Table 4.1 Basic Information of Case Enterprises

Company Code	Ownership	scale	GVC Location	Main Products
Company A	State-controlled	Large	high	Excavators, cranes
Company B	Private	Large	Medium to high	Concrete machinery, road machinery
C Company	Sino-foreign joint venture	Medium	middle	Loader, forklift
Company D	Private	Medium	Medium-low	Construction crane
Company E	State-controlled	Small	Low	Road roller, motor grader
Company F	Wholly Foreign Owned	Small	middle	Hydraulic systems and components

Data collection methods include:

In-depth interviews: Semi-structured interviews were conducted with senior managers, R&D heads, and international business managers of each company, with each interview lasting 1.5-2 hours.

Field visits: Visits to corporate R&D centers, production bases and overseas branches.

Archival materials: collect secondary materials such as internal corporate documents, annual reports, news reports, etc.

Case Study Framework

The researchers adopted the cross-case analysis method proposed by Eisenhardt (1989) and combined it with the theoretical framework of this study to develop the following case study framework:

Technological Innovation Duality

Exploratory innovation strategy and practice

Pioneering innovation strategies and practices

Balancing Mechanics and Challenges

Dynamic Capabilities

Cultivation and application of perceptual abilities

Capture capability building and implementation

The development and effects of refactoring capabilities

Climbing The Global Value Chain

Changes in value chain position

Climbing Path and Key Events

Obstacles and strategies to overcome them

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Situational Factors

Internationalization strategy and practice

The impact of the institutional environment and its response

Comparative Analysis of Multiple Cases

Comparison Between High-Value Chain Positioning Enterprises and Low-Value Chain Positioning Enterprises

Through an in-depth comparison of Company A (high GVC position) and Company E (low GVC position), the researchers found that:

Differences In Innovation Strategies: Company A: " Researchers adhere to a 'two-wheel drive' innovation strategy, on the one hand continuously optimizing existing products, and on the other hand investing heavily in cutting-edge technology research." (CTO of Company A) Company E: "Due to funding and talent constraints, researchers mainly focus on improving existing products." (R&D Manager of Company E)

Dynamic Capability Cultivation: Company A has established a global technology radar system and regularly organizes cross-departmental innovation seminars to cultivate strong perception and capture capabilities. Company E's dynamic capability cultivation is relatively passive, mainly relying on customer feedback and industry exhibition information.

Internationalization: Company A has established R&D centers and production bases around the world and is deeply involved in international market competition. Company E's internationalization is mainly limited to product exports and lacks overseas localized operations.

Comparison Between Balanced and Unbalanced Innovation Duality Firms

Comparing the cases of Company B (high innovation ambidexterity) and Company D (low innovation ambidexterity), the researchers found that:

Organizational Structure: Company B: " Researchers adopt a dual organizational structure, establishing an independent innovation incubation department while maintaining continuous improvement of the core business department." (CEO of Company B) Company D has a relatively simple organizational structure, and its innovation activities are concentrated on upgrading existing product lines.

Resource Allocation: Company B maintains a roughly balanced resource investment in exploratory and pioneering innovation projects. Company D's resources are mainly concentrated in pioneering innovation and lack investment in disruptive technologies.

GVC Climbing Path: Company B gradually improved its product technology content and brand influence through balanced innovation, achieving a leap from a medium position to a medium-high position. Due to unbalanced innovation, Company D's position in GVC has been rising slowly.

Tracking The Innovation Paths of Typical Enterprises

The researchers conducted a three-year follow-up study on Company C (a Sino-foreign joint venture), recording the dynamic changes in its innovation duality, dynamic capabilities and GVC position.

Key Findings

Dynamic Adjustment of Innovation Duality: " Researchers dynamically adjust the ratio of exploration and development according to the market environment and company strategy. In the economic downturn,

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researchers will be slightly inclined to pioneering innovation; in the market recovery period, researchers will increase investment in exploratory innovation." (Innovation Director of Company C)

Spiral Improvement of Dynamic Capabilities: Company C has achieved a spiral improvement of dynamic capabilities through continuous organizational learning. For example, its perception capabilities have evolved from single market research to predicting technology trends using big data and artificial intelligence.

Phased Breakthroughs in GVC Position: Company C's GVC position has experienced a process of "slow rise - stagnation - rapid jump". The key breakthrough point was the successful development of an intelligent loader, which greatly improved the product's technical content and brand premium.

Theoretical Implications of Cross-Case Analysis

Through an in-depth analysis of six case companies, the researcher drew the following theoretical implications:

The optimal range of innovation ambidexterity: There is an "optimal range" of innovation ambidexterity, within which companies can most effectively improve their GVC position. This range varies depending on the size of the company, industry segment and development stage.

Synergy of dynamic capabilities: There are significant synergies between the three dynamic capabilities (sensing, capturing, reconstructing). The improvement of a single capability has a limited impact on the rise of GVC. Only the coordinated development of three capabilities can produce the greatest effect.

Moderating mechanism of internationalization: Internationalization enhances the positive impact of innovation ambidexterity on dynamic capabilities by providing diversified sources of knowledge, global perspectives, and cross-cultural learning opportunities.

The double-edged sword effect of the institutional environment: Although a high-quality institutional environment is generally conducive to corporate innovation and capacity improvement, it may also weaken the company's innovation momentum due to overprotection. Companies need to find a balance between institutional dividends and innovation pressure.

The nonlinear path of GVC climbing: The climbing of enterprises in GVC is not a linear process, but presents "step-by-step" or "leap-forward" characteristics. Key technological breakthroughs or business model innovations are often the trigger points for leapfrogging.

Case Studies Complement Quantitative Analysis

The findings of the multi-case study have effectively supplemented and deepened the researchers ' previous quantitative analysis results:

The inverted U-shaped relationship between innovation ambidexterity and GVC position is verified, and the micro-mechanism explanation behind this relationship is provided.

The specific mechanism of action of dynamic capabilities in the mediating process is revealed, especially the synergistic effect among the three capabilities.

It shows how the degree of internationalization and the institutional environment moderate the relationship between innovation and capability development in actual firm operations.

It captures the dynamic process and key turning points of GVC growth that are difficult to observe through quantitative analysis.

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In general, the multi-case study not only provides rich qualitative evidence for the researchers ' theoretical hypotheses, but also reveals some complex dynamic processes and situational factors that cannot be captured in quantitative analysis. These findings provide valuable guidance for subsequent research.

Conclusion and Implications

Main Findings

Through large-scale quantitative analysis and in-depth multiple case studies, this study explores the complex relationship between technological innovation ambidexterity, dynamic capabilities and the climb of the global value chain of Chinese construction machinery enterprises. The main research findings are as follows:

The inverted U-shaped relationship between technological innovation ambidexterity and GVC status: The study found that technological innovation ambidexterity has a significant inverted U-shaped relationship with the company's position in the global value chain. This means that there is an optimal innovation balance point at which companies can maximize their positional advantages in GVC. Excessive emphasis on exploratory innovation or pioneering innovation may lead to the decline of GVC status.

The mediating role of dynamic capabilities: Dynamic capabilities play an important mediating role in the process of technological innovation ambidexterity affecting GVC status. Specifically:

Perception capabilities help companies capture market opportunities and technological trends in a timely manner, and provide direction guidance for innovation activities.

Capture capabilities enable companies to effectively transform innovation results into market competitiveness.

Reconstruction capabilities ensure that enterprises can adjust resource allocation and organizational structure in a timely manner according to environmental changes.

Positive moderating effect of internationalization: The internationalization of the firm positively moderates the relationship between technological innovation duality and dynamic capabilities. Highly internationalized firms are better able to transform balanced innovation strategies into strong dynamic capabilities, which may be due to the knowledge diversity and global vision brought about by internationalization.

The complex moderating effect of institutional environment quality: The quality of the institutional environment has a moderating effect on the relationship between technological innovation duality and dynamic capabilities, but this effect is complex. A high-quality institutional environment is generally conducive to innovation and capability development, but it may also reduce the innovation motivation of enterprises due to overprotection.

The non-linear path of GVC climbing: Case studies reveal that companies' climbing in GVC often exhibits non-linear characteristics, manifesting as a "step-like" or "leap-forward" development path. A key technology breakthrough or business model innovation is often the trigger that triggers a significant jump.

Synergy of dynamic capabilities: There are significant synergies between the three dynamic capabilities (sensing, capturing, reconstructing). Only when the three capabilities develop collaboratively can the positive impact on GVC climbing be maximized.

Theoretical Contribution

This study makes the following theoretical contributions to the existing literature:

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Expanding the global value chain theory: By introducing the perspectives of technological innovation ambidexterity and dynamic capabilities, this study enriches the understanding of the micro-mechanism of corporate GVC climbing. In particular, the nonlinear relationship between innovation balance and GVC status is revealed, providing new insights into GVC theory.

Deepening the theory of dynamic capabilities: This study not only verifies the importance of dynamic capabilities in the growth of GVC, but also refines the specific mechanisms of action of different types of dynamic capabilities. In particular, the synergistic effect of dynamic capabilities was discovered, which provides a new direction for the development of dynamic capabilities theory.

Enriching organizational learning theory: By exploring the role of technological innovation duality in the context of internationalization, this study provides new empirical evidence for organizational learning theory. In particular, it reveals the dynamic process of the balance between exploration and exploitation, which deepens researchers' understanding of the complexity of organizational learning.

Integrates the perspective of institutional theory: This study explores the regulatory role of the institutional environment on corporate innovation and capability development, enriching the theoretical connotation of international business research. In particular, it reveals the "double-edged sword" effect of the institutional environment, which provides new ideas for the application of institutional theory in the context of emerging economies.

The concept of "optimal interval of innovation duality" is proposed: This study found that there is an "optimal interval" of innovation duality, within which enterprises can most effectively improve their GVC position. This finding provides a new theoretical construct for innovation management theory.

Management Implications

Based on the research findings, this study provides the following practical suggestions for managers and policy makers of construction machinery companies:

Innovation Strategy Development:

Enterprises should pursue a dynamic balance between exploratory innovation and pioneering innovation, rather than one-sidedly emphasize one type of innovation.

Managers need to dynamically adjust the allocation ratio of innovation resources according to the company's development stage and external environment.

Cultivation Of Dynamic Capabilities:

Enterprises should comprehensively cultivate the three dynamic capabilities of perception, capture and reconstruction, and focus on their coordinated development.

The overall level of dynamic capabilities can be enhanced by establishing cross-departmental innovation teams and implementing a rotation system.

Optimization Of Internationalization Strategy

Companies should view internationalization as an important way to enhance their innovation and dynamic capabilities, rather than just a means of market expansion.

In the process of internationalization, we should focus on absorbing diverse cultural knowledge and cultivating a global vision to enhance the breadth and depth of innovation.

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Utilization of the Institutional Environment

Enterprises should actively utilize the opportunities brought by a good institutional environment, such as intellectual property protection and innovation funding support.

At the same time, we must be wary of the innovation inertia that may result from over-reliance on institutional dividends and maintain a moderate sense of crisis.

GVC Climbing Strategy

Enterprises should recognize the nonlinear characteristics of GVC growth and seize key breakthrough opportunities while formulating long-term strategies.

We can seek opportunities for technological or business model leaps through strategic mergers and acquisitions, industry-university-research cooperation, and other means.

Policy Recommendations

Based on the research results, the researchers provide the following policy recommendations to the government:

Industrial Upgrading Policy

Formulate differentiated innovation support policies that encourage both breakthrough innovation and incremental innovation.

Establish an industrial technology roadmap to guide enterprises to achieve breakthroughs in key technology areas.

Innovation Support Policies

Improve the intellectual property protection system and provide institutional guarantees for enterprise innovation.

Establish an innovation risk compensation mechanism to encourage enterprises to carry out high-risk, high-return exploratory innovations.

Internationalization Promotion Policy

Provide policy support for "going global", such as overseas M&A loans, risk insurance, etc.

Build an international talent training platform to improve the company's cross-cultural management capabilities.

Optimization of the Institutional Environment:

Continue to improve the business environment, reduce administrative intervention, and stimulate corporate innovation.

Build an innovation ecosystem with deep integration of industry, academia and research, and promote knowledge flow and technology transfer.

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Research Limitations and Future Prospects

Although this study made some meaningful findings, there are still some limitations, which also provide directions for future research:

Limitations of the research sample: This study mainly focuses on China's construction machinery industry. Future research can be expanded to other emerging economies and different industries to test the universality of the conclusions.

Insufficient longitudinal data: Although the researchers used panel data from 2005 to 2022, the measurement of some variables (such as dynamic capabilities) is still mainly based on cross-sectional data. Future research can use longer-term longitudinal data to better capture the dynamic relationship between variables.

Limitations of innovation measurement: This study mainly relies on patent data to measure innovation activities. Future research can adopt more diverse innovation indicators, such as the proportion of new product sales, R&D investment intensity, etc.

Depth of mechanism exploration: Although researchers have revealed some mediating and moderating mechanisms, the micro-process exploration of how these mechanisms operate within the organization is not deep enough. Future research can supplement this deficiency through more in-depth qualitative research.

Lack of international comparison: This study focuses on Chinese companies and lacks a systematic comparison with companies in developed countries. Future research can conduct cross-national comparisons to explore the differences in the relationship between innovation, capabilities and GVC growth under different institutional backgrounds.

Future Research Directions

Explore the long-term evolution path of technological innovation ambidexterity and its impact on GVC growth.

Study how digital transformation reshapes the innovation model and GVC status of construction machinery companies.

Examine the differences in the GVC climbing paths between emerging market multinational corporations and developed country multinational corporations.

Explore how sustainable development pressure affects the innovation strategy and GVC positioning of construction machinery companies.

Study the impact of major external shocks such as the COVID-19 pandemic on the reconstruction of the global value chain of the construction machinery industry.

In conclusion, this study provides important insights into how Chinese construction machinery companies can achieve GVC growth through innovation and capability building. As the global economic landscape continues to change, this topic will continue to be a focus of academic and practical attention. Future research should continue to deepen the understanding of this complex process and provide more powerful theoretical guidance and practical inspiration for the global development of enterprises and the country's industrial upgrading strategy.

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