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The Impact of Digital Technology Innovation on the Supply Chain Position: Micro Evidence from the Chinese New Energy Vehicle Companies

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Abstract: With the rapid development of digital technology and the increasing focus on the global supply chain network, it has become a new challenge for international companies to select digital technology innovation projects in an efficient way, so as to improve their supply chain position and competitiveness. Prior works have identified the effects of digital technology adoption on companies' supply chain positions; however, there has been limited research on the impact of digital technology innovation heterogeneity on companies' supply chain position and the pathways through which this effect plays out. Hence, based on the global supply chain panel data from Chinese new energy vehicle companies, this study used a two-way fixed-effects model and causal stepwise regression analysis to study the impact of digital technological innovation on companies' supply chain position and the dynamic mechanisms between them. The empirical results show that all three types of digital technology innovations, in the design and development process, the production and manufacturing process, and the sales and after-sales process, significantly enhance the company's supply chain position. Further mechanism analysis shows that digital technology innovations enhance the company's managerial efficiency and profitability mainly by reducing costs and increasing revenues, which ultimately improves the company's supply chain position. This paper can provide a reference for policy makers to promote the application and development of a company's digital technology and enhancing the supply chain position.

Keywords: digital technology innovation; supply chain management; social network analysis; new energy vehicle companies

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1. Introduction

In the context of globalization, the position in the supply chain reflects the overall competitiveness of companies. As indispensable players in the global industrial division of labor, Chinese companies are deeply embedded in the international supply chain network, facing significant exposure to external shocks [1]. This risk is particularly pronounced in rapidly growing and transforming sectors like new energy vehicles (NEVs). In 2023, China's NEV sales reached 9.495 million units, accounting for 30% of the global market share and maintaining its position as the global leader for the ninth consecutive year. This underscores China's critical role in driving the global automotive industry towards sustainable development.

However, in recent years, companies have been navigating an increasingly complex global macroeconomic environment, influenced by factors such as the COVID-19 pandemic, subdued international market demand, rising trade protectionism, and escalating anti-globalization trends [2]. These challenges have precipitated 'broken chain' and 'stuck chain' crises within the supply chain [3]. The supply chain position is crucial in coordinating companies' resource utilization, especially in technologically advanced and rapidly developing sectors like NEVs. Therefore, it is crucial for companies to upgrade their positions in the supply chain to effectively cope with the impact of uncertainty in the world economy. At the same time, as the power battery serves as the core component of NEVs, and Chinese firms make up over 60% of the global power battery installation capacity, the strong market competitiveness and innovation of China's NEV industry can be seen. Therefore, examining the impact of innovation by Chinese NEV companies on supply chain dynamics is both crucial and representative.

Digital technological innovation is an important way to enhance the supply chain position of companies and creates a lasting impetus to strengthen their competitive advantages. Since 2017, when China's Government Work Report first proposed "promoting the accelerated growth of the digital economy", the in-depth integration of China's digital technological innovation and the real economy has enhanced companies' competitiveness. China's new energy vehicle companies represent the global supply chain network and have assumed a leading position globally, mainly due to digital technology innovation [4]. Digital technology innovation improves the efficiency of company resource utilization [5], reduces company production costs [6], and promotes the efficiency of supply and demand matching and division of labor cooperation among upstream and downstream companies in the supply chain [7]. Admittedly, the pace of digital technological development today is faster (e.g., the expeditious improvement in AI systems due to the massive amount of data available for machine learning) [8]. How to invest in digital technology innovation in the future is critical for company growth. Therefore, the focus of academic attention has been on clarifying the impact of digital technology innovation on enhancing the competitiveness of companies, as well as the heterogeneous effect of digital technology [9]. It is also a realistic issue that can guide companies in investing innovation funds and selecting digital technology innovation projects.

The existing literature has examined the impact of digital technological innovation on companies' locations in supply chain [10]. Digital technological innovations help companies to realize real-time information exchange and improve cooperation between upstream and downstream companies in the supply chain, thus enhancing the company's network position [11]. First, the existing studies have inaccurately measured digital technology innovation variables. Some scholars measured digital technology using input-output models [12,13]. Zhong et al. [14] textually analyzed the relevant keywords in the annual reports of listed companies as a measure of the digital technological innovation of companies. In addition, some studies utilized qualitative comparative analysis (QCA) [15] and patent data [16]. Relevant studies have concluded that digital technology innovation has played a positive role in improving trade transaction efficiency [17], shrinking trade spatial distance, significantly lowering the threshold for companies to conduct trade, and enabling them to obtain more opportunities to participate in the global supply chain network. However, it is worth questioning whether there is heterogeneity in the digital technology innovations that impact companies' supply chain positions. The mechanism of action behind it is not yet clear. Currently, digital technology innovation lacks a clear and unified definition. Based on existing research [18], we defined digital technology innovation as the process of technological innovation that uses various combinations of digital technologies such as computing, interconnection, information, and communication to improve production processes, change organizational structures and business models, and develop new products. Finally, the existing studies used data for the top five suppliers and top five customers of listed companies to construct the global supply chain network [10,19]. The social network analysis method allows for the calculation of degree and eigenvector indicators which are biased towards company supply chain position measurement.

Based on the global supply chain data for Chinese new energy vehicle companies from 2012 to 2022, this study will empirically test the impact of digital technology innovation on the supply chain position of companies, trying to reveal the mechanism of action and extent of digital technology innovation heterogeneity's impact on the supply chain position of companies. At the same time, it will analyze the role of digital technological innovation in enhancing managerial efficiency and profitability to provide theoretical support and policy recommendations for further determining the economic effects and effectiveness of digital technological innovation in improving the supply chain position of companies. This paper can provide a micro-level reference for analyzing the role of digital technology innovation in enhancing manufacturing and service companies' supply chain positions.

The innovations outlined in this paper are as follows: (1) Taking the new energy vehicles industry as an example, this study classifies digital technological innovation into three segments, namely design and development, production and manufacturing, and sales and after-sales process, based on the content of the patent text applied by companies. The new classification method effectively captures the nuances of digital technology innovation. Based on micro data, this paper explores the impact of the heterogeneity of digital technological innovation on the position of a company in the supply chain. It provides empirical evidence for analyzing the impact of digital innovation on company development. (2) This paper utilizes statistical methods such as the two-way fixed-effects model and causal stepwise regression to explore the impact of two mechanism variables, managerial efficiency and profitability. It explores two paths through which digital technological innovation affects the position of companies in the supply chain. (3) This study divides companies into manufacturing-oriented companies and service-oriented companies. Then, it conducted a regression to analyze the impact of digital technology innovation on the supply chain position of different types of companies. This study deepens our understanding of the effects of innovations and changes in digital technology on companies' supply chain positions and enriches the literature concerning the impact of digitalization on supply chains.

The remainder of this article is structured as follows: Section 1 presents the introduction. Section 2 offers a comprehensive literature review and our research hypotheses. Section 3 describes the methodology and the basic regression model. Section 4 provides the empirical results derived from our analysis. The discussion is presented in Section 5, where we integrate our findings in the context of existing knowledge. Finally, Section 6 outlines the conclusions of our findings and the limitations of our study.

2. Literature Review and Research Hypotheses

2.1. The Impact of Digital Technology Innovation on Companies' Position in the Supply Chain

Scholars have broadly discussed digital innovation as an essential factor in influencing the position of a company's supply chain [1,19,20]. Digital technological innovations such as big data platforms and remote control can efficiently integrate various resources, such as optimizing the combination of labor, raw materials, production tools, and other resources based on their complementarity. This will increase the value of resource utilization and lead to a competitive advantage in the industry, thus consolidating the company's position in the supply chain [21]. Mohammadi and Rashidzadeh [22] suggested that Internet of Things (IoT) technology can help organizations interconnect their equipment to reduce failures and downtime, increase productivity, and improve product quality and safety. Companies utilize IoT digital technology innovations to achieve real-time massive big data comparisons and analyses [23]. Automation, robotics, and other AI digital technology innovations in new energy vehicle companies have improved the flexibility of production lines and shortened the time to market [6]. Companies can predict market demand more timely and accurately, thus optimizing their inventory management, reducing costs, and improving response time [24]. These effectively support companies' production decision making, forming their dynamic capabilities and enhancing their competitive advantages.

In addition, digital technology promotes company innovation and strengthens technological research and development in the core technology area of new energy vehicles. Tang et al. [25] found that companies strengthened their technological leadership by enhancing power battery innovation through digital technologies. Personalized digital technology products and services, such as assisted driving and VR experiences, can help companies better understand customer needs [26], as well as provide repair services such as rapid fault detection and intelligent maintenance in the after-sales period, which in turn improves customer satisfaction and loyalty. Digital technology improves the efficiency of companies in a way that is more in line with the concept of green and sustainable development and enhances their ESG [27]. In summary, digital technology innovation realizes the fine control of the production process, the full use of resources, and the efficient access to information, all of which can effectively improve the quality of company products and services. It helps companies gain a greater competitive advantage in the market, thus enhancing their position in the supply chain network. Given the above literature, this study proposes the following hypothesis:

Hypothesis 1 (H1). *Digital technology innovation drives the position of a company's supply chain.*

2.2. The Mechanisms of Digital Technology Innovation Affecting Companies' Supply Chain Position

On the one hand, digital technology innovations help allocate quality resources to high-value-added production segments, thus enhancing the productivity of the entire industry. Digital technology reduces the cost of communication between companies and between internal and external parties, effectively solving the problem of information asymmetry [28]. Helping to reduce the flow of information and transaction costs ensures that the supply of production resources is accurately matched to the needs of each production segment. For example, applying digital technologies such as digital production lines, robotic automation, and IoT optimizes production and improves product quality. The Choudhury et al. [29] study found that companies and supply chain partners share data through digital technologies to accurately match R&D, design, manufacturing, and user needs. Online platforms and mobile applications provide a personalized car-buying experience and convenient after-sales service, enhancing customer stickiness [30]. Digital technology helps companies continuously collect and analyze customer feedback to improve product and service quality continually [31]. This close collaboration improves managerial efficiency and helps to enhance the company's position as the center of the supply chain.

On the other hand, digital technology innovations reduce the dependence of traditional manufacturing on labor but increase the demand for talent. This type of talent requires the ability to adapt to the new production model of digital technology and use and maintain advanced production equipment. For example, digital technologies such as VR and AI enable companies to conduct efficient simulation tests and data analyses when developing new technologies and products, shortening the development cycle. Digital technologies allow the interconnection of people, machinery, and organizations to improve managerial efficiency, further enhancing companies' centrality in the supply chain network. Based on these discussions, the following hypothesis is proposed:

Hypothesis 1a (H1a). *Digital technology innovation promotes the position of the company supply chain by improving managerial efficiency.*

According to the theory of technological innovation, if a company can occupy an advantageous position in technological innovation, it can obtain a monopoly within a certain range. Then, it can achieve a high profit return [32]. First, digital technological innovation helps automate and intellectualize the production process and promotes improving company production quality and cost reduction [5]. Chan et al. [33] found that through real-time monitoring of production parameters and logistics flow, companies can quickly respond to market changes, shorten product delivery time, and thus enhance corporate profit returns.

In addition, through digital technology innovation, companies can more accurately grasp consumer demand and market trends, optimize inventory management, and reduce inventory costs [6]. In turn, they can gain a greater competitive advantage in the market and achieve a more central position in the supply chain network. Trinugroho et al. [34] took SMEs (small and medium-sized enterprises) in Indonesia as the research object and found that digital technological innovation improved profitability. Bui and Do [35] found that digital technology reduces the financial constraints of Vietnamese SMEs, and rising profits help them gain a dominant position in the supply chain. Based on these considerations, the following hypothesis is proposed:

Hypothesis 1b (H1b). *Digital technology innovation promotes the position of the company supply chain by improving profitability.*

2.3. The Impact of Digital Technology Innovation Heterogeneity on Companies' Position in the Supply Chain

To study the heterogeneous impact of digital technological innovation on the position of the company supply chain, this paper took the patents applied by new energy vehicle companies as the object. It divided them into three types of digital technological innovation: the design and development process, the production and manufacturing process, and the sales and after-sales process. The digital technology innovation contents corresponding to the three processes were collated, as shown in Figure 1.

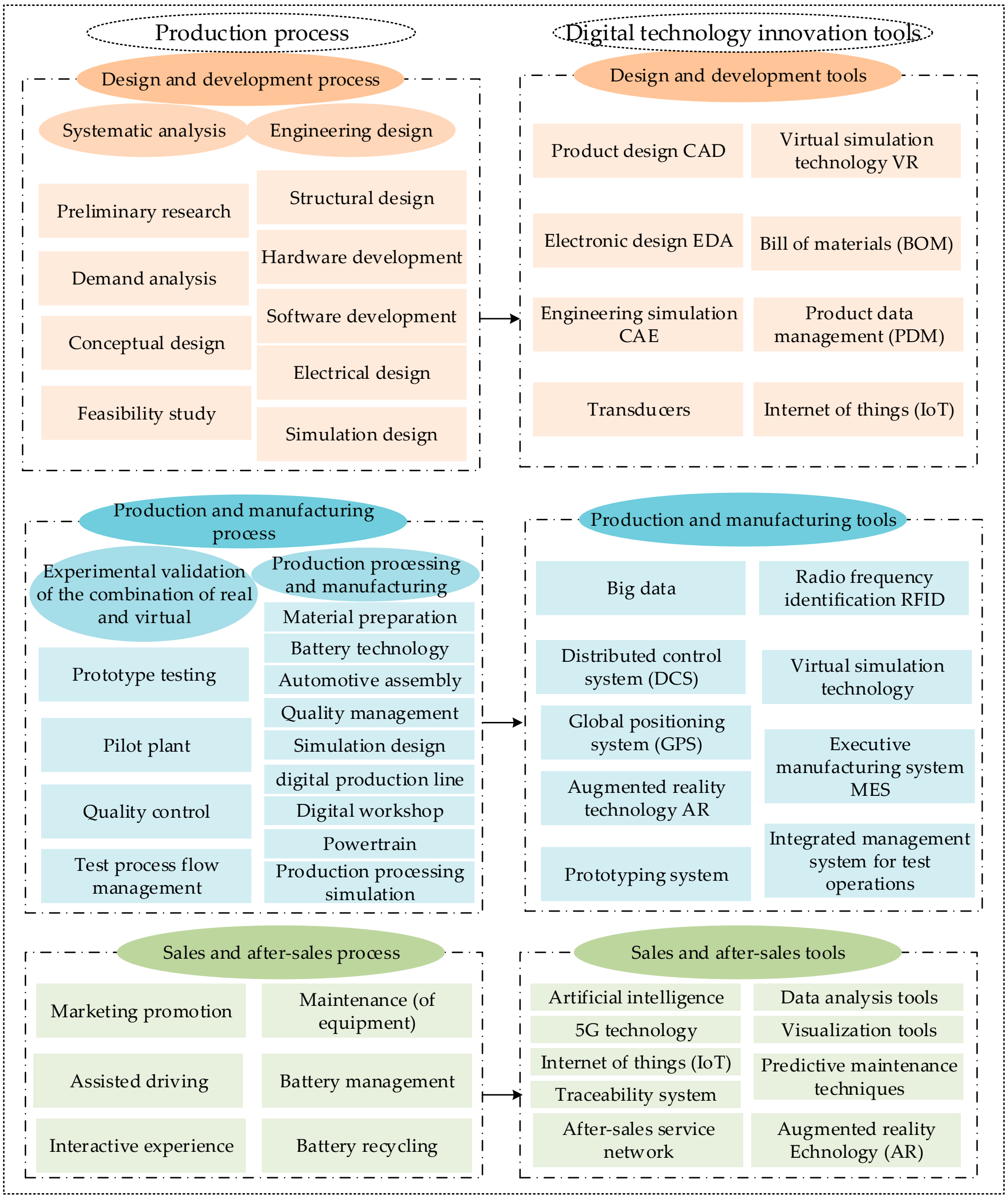

Figure 1. Digital technology innovation in new energy vehicle companies by production process.

New energy vehicle companies mainly carry out systematic analysis and engineering design in the design and development process, including preliminary research and demand analysis, conceptual design, feasibility studies, structural design, hardware and software development, electrical design, and simulation design. The main digital technology innovation is embodied in digital simulation and research and development, including computer-aided design (CAD), computer-aided engineering (CAE), electronic design (EDA), virtual simulation technology (VR), product data management (PDM), and so on.

CAD software helps automotive design engineers to digitally create, modify, and analyze 3D models of their products. CAE software allows engineers to better simulate the performance of their products under different environments and stresses, improving product quality and reliability [36]. Adjustments and optimizations based on real-time feedback reduce the risk of increased manufacturing costs due to poor design considerations to improve profitability and, in turn, enhance the company network position. EDA technology helps companies build a prototype vehicle trial production system, which realizes the interconnection between people, equipment, and systems. Through the real-time collection of equipment information and production progress data at the production site, production problems can be solved promptly, greatly improving vehicle performance testing and production efficiency [37]. VR simulations of vehicle collision, driving, and power consumption scenarios, etc., and testing of intelligent driving systems are necessary to promote the mass production of high-level automatic cars, which has formed the industry standard for new energy vehicles [38]. The PDM digital management platform based on the full life cycle development of the entire vehicle can respond to new market trends such as the diversification of automotive product configurations, the rapid iteration of new cars on the market, and the growing personalized needs of users, thanks to its fast and robust system integration capability, comprehensive and clear process tracking capability, and efficient data management and publishing capability [39]. These digital technology innovations have improved the efficiency and accuracy of design, provided a more open and expansive design space [40], and positively impacted the advancement of companies in the supply chain network. We thus posit the following:

Hypothesis 2 (H2). *Digital technology innovations in the design and development process have a driving effect on the position of the company's supply chain.*

New energy vehicle manufacturers mainly conduct experimental validation through a combination of the real and virtual, as well as production processing and manufacturing in the production and manufacturing process. This includes small-batch trial productions of prototype vehicles, quality control, material preparation, vehicle assembly, production quality management, and digital production lines. Digital technology innovation is mainly embodied by big data analysis, distributed control systems (DCSs), virtual simulation technology, radio frequency identification (RFID), global positioning systems (GPSs), executive manufacturing systems (MESs), integrated management systems for test operations, and so on.

Big data analysis helps new energy vehicle companies establish intelligent production lines, visualize, monitor, and automate production processes with lower labor inputs, and improve production efficiency [6]. DCSs helps to detect and quickly solve any quality problems. Gong et al. [41] found that using automotive virtual simulation technology to operate and manage automotive assemblies and using FlexSim software to build models to solve assembly problems can lead to a significant reduction in assembly time while equipment utilization is significantly improved. Since the production and manufacturing process for new energy vehicles requires a large number of components, such as batteries, motors, control systems, etc., logistics and supply chain management are the key to ensuring production efficiency and product quality. Aggarwal and Das [42] found that tracking and managing the logistics and supply chain process through digital technological innovations such as RFID and GPSs reduces the production process's error rate and transport costs. Prabhu et al. [43] found that MESs and integrated management systems for test operations, by deepening the degree of digital application of each process, can effectively reduce the excess energy consumption and material consumption caused by irrational manual production operations, thus improving the fine degree of manufacturing of new energy vehicles. In summary, digital technology innovation in the new energy vehicle production and manufacturing process helps companies to achieve the automation and intelligence of manufacturing, reducing production costs, improving production efficiency, and ultimately playing a role in promoting the position of companies in the supply chain network. Thus, the above arguments led this study to develop the following hypothesis:

Hypothesis 3 (H3). *Digital technology innovations in the production and manufacturing process drive the position of the company's supply chain.*

New energy vehicle companies mainly include marketing promotion, assisted driving, interactive experience, equipment maintenance, battery management, and recycling in the sales and after-sales process. The main digital technology innovations are the Internet of Things (IoT), Augmented Reality (AR), 5G technology, artificial intelligence (AI), visualization tools, traceability systems, predictive maintenance techniques, and so on.

IoT technology innovation enables the remote monitoring of vehicle performance and status, enabling real-time diagnostics to help customers identify problems and perform maintenance promptly, improving customer satisfaction and loyalty [44]. Cachada et al. [45] found that AR technology innovation helps and guides workers in maintenance operations, which greatly improves the after-sales efficiency of companies. AI technology helps companies better analyze large amounts of user data. By integrating internal user data on car purchases, car use, and automotive Internet connectivity with external market data and other third-party data, it is possible to understand further user needs to scientifically, quickly, and accurately formulate marketing strategies for specific users [30]. In addition, Gong [46] found that AI smart driving technology helps drivers control their vehicles better, improve car driving safety, reduce traffic accidents, and reduce energy consumption through visualization tools. In terms of enhancing the sense of user experience and driving safety, the high speed, low latency, and wide range embodied in 5G technological innovations can be applied to various scenarios, such as intelligent driving, connected cars, and battery maintenance [47]. Karpenko et al. [44] verified the effect of cost optimization and efficiency gains from data sharing provided by traceability system innovations through electric vehicle charging in the EU project bIoTope. Many high-tech components of new energy vehicles, such as batteries and electric motors, require predictive maintenance techniques for regular maintenance and servicing [48], thus improving maintenance efficiency and reducing maintenance costs. In summary, the digital technology innovation mentioned above, on the one hand, plays a role in reducing the management and maintenance costs within the company; on the other hand, it improves user satisfaction [31], helps to increase the company's revenue and competitiveness, and ultimately promotes the enhancement of the company's supply chain position, which all provide groundings for the postulation of the following hypothesis:

Hypothesis 4 (H4). *Digital technology innovations in the sales and after-sales process have a driving effect on the position of the company's supply chain.*

The framework of digital technological innovations affecting supply chain position is visually represented by two colors: blue indicates a direct relationship, while orange indicates an indirect relationship. H1 and H4 represent six hypotheses, respectively, and the relationships among the hypotheses in this paper are shown in Figure 2 below.

The main themes relevant to this study relate to two types of research: the positions of companies in supply chain networks and digital technological innovation. Table 1 presents a comparison between this study and the relevant literature. Firstly, numerous studies have utilized the method of social network analysis to measure the positions of companies within supply chain networks [49,50]. This includes metrics such as structural holes [19], PageRank centrality [10], and harmonic centrality [51]. This paper employs eigenvector centrality to gauge the position of enterprises within the supply chain network. Unlike other centrality measures, eigenvector centrality can reflect the importance of both upstream suppliers and downstream customers with whom the company has trade relationships. This provides a more comprehensive depiction of a company's network position.

Secondly, existing studies identify regional or corporate capabilities for digital technology innovation using methods such as literature induction [52–54], qualitative analysis [55,56], text analysis [57,58], case study methodology [59], and so on. However, there is a lack of detailed discussion on how digital technology innovations are applied to specific production process. This study references existing research that categorizes patents by industry, identifying corporate digital technology innovation capabilities. Furthermore, through the text analysis and co-word analysis, it is determined whether digital technology patents pertain to the design and development process, the production and manufacturing process, or the sales and after-sales process.

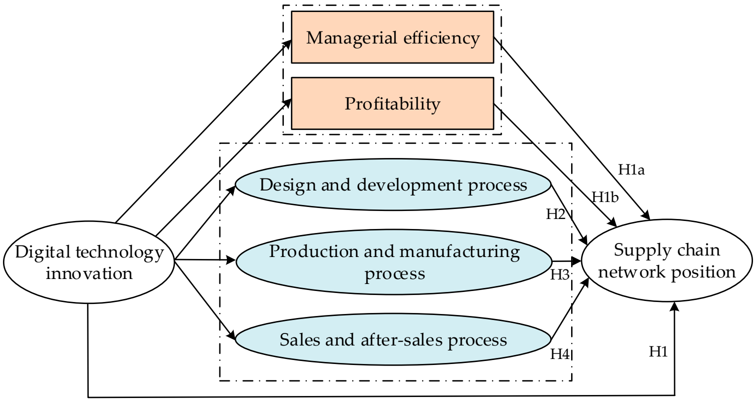

Figure 2. The conceptual diagram and summary of hypotheses.

Table 1. A comparison of this study with relevant studies.

Research Object	Methodologies and Models	Indicators and Data	Authors (Year)
Supply Chain Position	Social network analysis methodology (network centrality and structural holes)	Data on the top five suppliers and customers of the company	Shi et al. (2020) [49]; Du and Zhang (2022) [19]
	Social network analysis methodology (pagerank centrality)	Data on the top five suppliers and customers of the company	Jing et al. (2023) [10]
	Social network analysis methodology (network centrality)	Questionnaire methodology to obtain company transaction data	Seiler et al. (2020) [50]
	Meta analyses	Questionnaire data	Chang et al. (2016) [60]
	Social network analysis methodology (harmonic centrality)	Global companies' equity ownership structure	Riccaboni et al. (2021) [51]
	Social network analysis methodology (eigenvector centrality)	Global supply chain data on the company's suppliers and customers	This paper
Digital technological innovation	Literature induction method	-	Holmström (2018) [52]; Purnomo et al. (2021) [53]; Kohli and Melville (2019) [54]
	Qualitative analysis methods	Questionnaire methodology	Nambisan et al. (2017) [55]; Wanof (2023) [56]
	Text analysis method	Patent text	Rodriguez and Piccoli (2018) [57]; Goyal (2024) [58]
	Principal component analysis (PCA) method	Evaluation indicator system	Zhai et al. (2020) [61]; Jing et al. (2023) [10]
	Case study methodology	Questionnaire data	Blichfeldt and Faullant (2021) [59]
	IPC and industry classification	Patent data	Nagaoka et al. (2010) [62]; Ponta et al. (2021) [16]
	IPC and industry classification, text and co-word analysis method	Patent data and patent text	This paper

3. Materials and Methods

3.1. Modeling

3.1.1. Baseline Regression Model

This section constructs a two-way fixed-effects model of digital technology innovation and supply chain position to empirically test the impact of digital technology innovation on companies' supply chain positions. The specific model is as follows.

$$SCNP_{it} = \alpha + \beta Diginno_{it} + \gamma Controls_{it} + \mu_i + \varphi_t + \varepsilon_{it} \quad (1)$$

where $SCNP_{it}$ represents the supply chain position of the company i in year t; $Diginno_{it}$ represents the digital technology innovation capabilities of company i in year t; β is used to measure the impact of digital technology innovation on companies' supply chain position; $Controls_{it}$ represents the control variable; μ_i is the company fixed effect; φ_t is the time fixed effect; ε_{it} is the error term.

3.1.2. Mediating Effect Model

The two channels through which a company's digital technology innovation affects its position in the supply chain network are managerial efficiency and profitability, respectively. This section refers to Wen et al.'s causal stepwise regression [63] to test the mediating effect to explore their specific mechanisms of influence further.

$$SCNP_{it} = a_0 + a_1 Diginno_{it} + \beta Controls_{it} + \mu_i + \varphi_t + \varepsilon_{it} \quad (2)$$

$$Medi_{it} = b_0 + b_1 \beta Diginno_{it} + \beta Controls_{it} + \mu_i + \varphi_t + \varepsilon_{it} \quad (3)$$

$$SCNP_{it} = c_0 + Medi_{it} + a_1 Diginno_{it} + \beta Controls_{it} + \mu_i + \varphi_t + \varepsilon_{it} \quad (4)$$

$Medi_{it}$ represents the mediator in year t of company i, including managerial efficiency (ME_{it}) and profitability (PA_{it}).

3.2. Variables and Descriptions

3.2.1. Dependent Variable: Supply Chain Position

First, a global supply chain network of new energy vehicle companies should be built based on the data from their upstream suppliers and downstream customer lists. A supply chain network, as one kind of social network, is essentially composed of a node and the edge relationships between nodes. It includes the core company nodes and the collection of companies with direct or indirect supply and marketing relationships.

Second, network centrality is chosen as a proxy variable for a company's position in the supply chain network [64]. A company's position in the supply chain network is determined by the importance of the company in the network. Usually, companies at the network's core have a high centrality, while those at the network's edge have a low centrality. Centrality is a common indicator to measure the node's network position, which reflects the company's ability to access and control resources in the supply chain network. Network centrality measures include Degree Centrality, Closeness Centrality, Betweenness Centrality, Eigenvector Centrality, PageRank, etc. Among these indicators, Eigenvector Centrality (Egc) is different from other centrality degrees in that it reflects the company's position in the supply chain network and the relationship between the company and other companies in the supply chain network. Therefore, this paper adopts eigenvector centrality to measure a company's network position. The larger the value, the closer the company is to the center of the supply chain network. The rest of the centrality indicators are used as proxy variables for the explanatory variables in the robustness test. The specific calculation formula is as follows.

Degree Centrality refers to the number of nodes that are directly linked to other nodes within the network and is calculated as:

$$Degree = \frac{\sum_{j=1}^{N} X_{ij}}{N-1} \tag{5}$$

where $\sum_{j=1}^{N} X_{ij}$ is the number of other nodes that node i is connected to in the network, and N is the total number of nodes in this network.

Eigenvector Centrality refers to the position of the eigenvector in a space. The eigenvector is based on the overall structure of the network. The formula is calculated as follows to find the most significant contribution to the core of the participants.

Assuming that x_i represents the centrality of the eigenvector of node i, then

$$Egc_i = x_i = c\sum_{j=1}^{n} a_{ij}x_j \tag{6}$$

where c is a constant of proportionality and a_{ij} is 0 if and only if i is connected to j.

3.2.2. Independent Variable: Digital Technology Innovation

Based on previous research [65], this article chooses to use the number of digital technology patents applied by companies in the current year to measure their digital technology innovation. Firstly, the national economic industry code and the International Patent Classification (IPC) match the industry classification to which the patent belongs based on the IPC number of the company's patent application. Secondly, the *Statistical Classification of Digital Economy and Its Core Industries* (2021) released by the National Bureau of Statistics of China identifies the industry classification of digital technology. Finally, it is possible to determine which patents applied by the company belong to digital technology patents. Taking 01 digital product manufacturing industry as an example, the specific matching methods are shown in Table 2.

Table 2. Example of correspondence between digital technology patent IPC and industry classification.

Statistical Classification of the Digital Economy and Its Core Industries			Industry Codes and Names of the National Economy	International Patent Classification Number
Major Class	**Middle Class**	**Subclass**		
01 Digital Product Manufacturing Industry	10101 Computer Manufacturing	010101 Computer Manufacturing	3911 Computer Manufacturing	G06F1 * G06F5 * G06F7 * G06F15 * G06F17 * G06F21 * H05K *
		010102 Computer Component Manufacturing	3912 Computer Component Manufacturing	G06F1 * G06F3 * G06F5 * G06F7 * G06F15 * G06F17 * G06F21 * H05K * H02J7 * H02M *
		010103 Manufacturing of computer peripheral equipment	3913 Computer Peripheral Equipment Manufacturing	G06F1 * G06F3 * G06F5 * G06F7 * G06F15 * G06F17 * G06F21 * H05K * G10L15 * G11B3 * G11B5 * G11B7 * G11C *

Table 2. *Cont.*

Statistical Classification of the Digital Economy and Its Core Industries			Industry Codes and Names of the National Economy	International Patent Classification Number
Major Class	**Middle Class**	**Subclass**		
01 Digital Product Manufacturing Industry	10101 Computer Manufacturing	010104 Industrial Control Computer and System Manufacturing	3914 Industrial Control Computer and System Manufacturing	G06E * G06F1 * G06F3 * G06F5 * G06F7 * G06F15 * G06F17 * G06F21 * G06J * H05K * G05B19/418
		010105 Manufacturing of Information Security Equipment	3915 Manufacturing of Information Security Equipment	G06F1 * G06F3 * G06F5 * G06F7 * G06F11 * G06F15 * G06F17 * G06F21 * H05K *
		010106 Other computer manufacturing	3919 Other computer manufacturing	G06F1 * G06F3 * G06F5 * G06F7 * G06F11 * G06F15 * G06F17 * G06F21 * H05K * G06N10 *

Notes: * indicates all subcategories of patent classification under the patent IPC classification number.

This article determines that digital technology patents belong to the design and development process, production and manufacturing process, or sales and after-sales process based on the keywords in the patent abstract. Recognizing multiple IPCs per patent, we utilized a keyword approach to avoid information omissions, with a co-word analysis identifying the most frequently used keywords for classification, as detailed in Table 3.

Table 3. Keyword correspondence in the production process.

Production Process	Keywords
Design and development process	Preliminary research, requirement analysis, conceptual design, feasibility study, hardware development, software development, structural design, computer-aided design
Production and manufacturing process	Prototype production, Internet of Things, artificial intelligence, machine learning, execution manufacturing, radio frequency identification, battery technology, powertrain, big data analysis
Sales and after-sales process	Sales, customer relationship management, supply chain management, maintenance, marketing promotion, battery recycling, battery management, charging stations

Additionally, due to the inherent ambiguity when multiple high-frequency keywords indicate different production processes, manual judgments were required. The manual judgments were carried out by a panel consisting of four researchers: a professor of innovation management, a patent text researcher from the civil engineering faculty, and two PhD students specializing in innovation management. This rigorous review process considered each patent's IPC, title, abstract, and first claim. To ensure reliability, we conducted an inter-rater reliability test, achieving a Cohen's Kappa coefficient of 0.95, confirming the high agreement among raters. Consequently, patents are accurately divided into the specified production processes.

3.2.3. Mediating Variables

The mediating variables in this paper are managerial efficiency and profitability. Digital technological innovation promotes management efficiency by optimizing the efficiency of internal and external communication and the overall production process of a company. Ang et al. [66] measured the management efficiency (ME) of a company by dividing the sum of the overhead and selling expenses by the total revenue, taking the inverse of this for empirical regression. In addition, the robustness of operating profit margin, net profit margin and turnover ratio as proxies for managerial efficiency (ME) is also tested separately and the results are shown in Appendix A, Table A1. The smaller the value of ME is, the more efficient the management is, and thus, the more the company is able to participate in more connections in the network and have a higher network position.

Good profitability (PA) improves the core competitiveness of a company, and the higher the profitability of a company, the more favorable position it can occupy in the global supply chain [67]. Return on assets, also known as return on investments, measures how much net profit can be generated per unit of assets, which serves as a proxy variable for company profitability and is calculated in Equation (7). The greater the return on investments, the greater the profitability, and thus, the more connections the company is able to make in the network, i.e., the higher the supply chain position.

$$Return\ on\ Assets = Net\ Profit/Average\ Total\ Assets \times 100\% \tag{7}$$

3.2.4. Control Variables

The study includes several econometrics specifications related to a company's supply chain position to control other aspects affecting their network position. Mayer et al. proposed that the larger the company size, the more obvious the effect of promotion on improving the company supply chain position [68]; this paper selected the total assets as a proxy variable for company size (Size). Shareholders' equity (Se) can provide a stable operating base for companies and help maintain the long-term stability of supply chain partnerships, and this paper chooses owners' equity as a proxy variable for shareholders' equity. In addition, companies that have been registered for a longer period of time are able to have a longer business history and are perceived as being more stable and reliable partners, which in turn leads to a more central position in the supply chain, hence the choice of company age (Age) as a proxy variable. Capital intensity (Cap) reflects the extent of a company's reliance on capital in the production process, which directly affects its cost structure and profitability [69]. The ratio of intangible assets (Ias) refers to the proportion of intangible assets to total assets, and this index can reflect the importance of intangible assets in the company's asset structure. In the era of the knowledge economy, intangible assets such as patents, trademarks, and brands often become the core competitiveness of companies, which helps to enhance their supply chain position. The history of patents within a company not only reflects its innovative capacity but also suggests that companies with a substantial number of patents are more likely to possess advanced knowledge and superior infrastructure. This enhances their ability to effectively embrace and implement new digital technologies compared to companies with fewer patents. Consequently, we have decided to use the number of patents held by a company (Pat) as a proxy for its innovation orientation, providing a quantitative measure that captures this aspect of corporate capability. Previous studies have largely informed the selection of control variables. Descriptive statistics of the variables under consideration are shown in Table 4.

Table 4. Descriptive statistics of the main variables.

Variable	Variable Description	Sample Size	Mean	Standard Deviation	Minimum	Maximum
SCNP	Supply chain network position	1051	0.038	0.102	0	0.916
Diginno	Digital technology innovation	1051	83.160	237.815	1	2671
ME	Managerial efficiency	1051	0.216	2.620	0	85.302
PA	Profitability	1051	0.020	0.048	−0.468	0.316
Size	Company size	1051	3.01	15.7	0	447
Se	Shareholders' equity	1051	11.1	30.1	−0.761	36.4
Age	Age of company	1051	19.496	5.869	1	42
Ia	Intangible assets ratio	1051	0.030	0.030	0	0.479
Cap	Capital intensity	1051	10.262	50.103	0	1205.661
Pat	Number of company patents	1051	333.761	1024.390	1	11,506

3.3. Data Sources

The data for the sample of new energy vehicle companies came from four main sources. First, the sample of new energy vehicle companies was mainly from the Qichacha database. The new energy vehicle industry chain studied in this paper includes vehicle, equipment production, and supporting facilities (charging piles, new energy vehicle design, etc.). Therefore, the companies' main business disclosed in the Qichacha database and the upstream and downstream related companies in the new energy vehicle industry chain were used as samples, to obtain 349 companies. Meanwhile, considering that China's new energy vehicle industry has witnessed rapid development since 2011, the period of 2012–2022 was selected as the study period. Second, the company supply chain data came from Factset Revere, a global supply chain database, which discloses the list of upstream suppliers and downstream customers. We took the companies as nodes and the supply chain relationships as edges and utilized Gephi software 0.10.0 to construct a global supply chain network of new energy vehicle companies. A series of network centrality indicators were calculated. Third, the company patent data came from the IncoPat global patent database. Searching with 349 new energy vehicle company names as applicants yielded 559,496 patents. Then, 230,412 digital technology innovation patents were obtained by the method described in Section 3.2.2. Fourth, the financial data of companies are sourced from the Qichacha, CSMAR, and Wind databases, and the stock code is utilized for multi-source data matching. Based on the completeness of financial data disclosure of listed companies, this paper identified 255 listed companies among 349 new energy vehicle companies as empirical samples. The industry classification standard references the "Industry Classification Guidelines for Listed Companies" published by the China Securities Regulatory Commission. To mitigate the influence of outliers on the empirical results, we conducted winsorization at the 1st and 99th percentiles of the data. The companies with delisting warnings or missing financial data were excluded. The final sample was composed of 255 company-year observations for 1051 companies.

4. Empirical Results

4.1. Estimation Results of the Baseline Model

Based on the data from 2012 to 2022, the regression model was subjected to the Hausman test, and it was determined that a two-way fixed effects model should be selected for the baseline regression. Table 5 reports the results of the baseline regressions on the impact of digital technology innovation on a company's supply chain position for the overall process, the design and development process, the production and manufacturing process, and the sales and after-sales process, respectively. The results of the tests for the main regressor variables and the inclusion of control variables were conducted separately in the regression process.

As shown in Table 5, digital technological innovations significantly increase the position of companies in the supply chain network. This result is necessary for testing our mediation premise in Hypothesis 1, 2, 3, and 4. Digital technology innovation in the sales and after-sales process and the design and development process have a more significant effect on improving the position of companies in the supply chain network. The new energy vehicles industry conforms to the smile curve characteristics of the manufacturing value chain, and the upstream and downstream parts of the industry chain have a high value added [70], so the effect of digital technological innovation on them is stronger. Analyzed from the perspective of control variables, the company size and the liquid assets ratio significantly contribute to the company's supply chain position enhancement. The shareholders' equity, company age, and intangible assets ratio negatively affect company supply chain position enhancement.

Table 5. Estimated results of the baseline model.

Variable	**Overall Process**		**Design and Development Process**		**Production and Manufacturing Process**		**Sales and After-Sales Process**	
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Diginno	0.0169 ***	0.0829 ***	0.0313 ***	0.0164 ***	0.0168 ***	0.0775 **	0.0528 ***	0.0276 ***
	(8.77)	(4.65)	(7.48)	(4.04)	(3.56)	(2.18)	(5.55)	(3.48)
Size		0.599 ***		0.592 ***		0.647 ***		0.614 ***
		(6.96)		(5.91)		(6.79)		(6.08)
Se		0.635 ***		0.686 ***		0.745 ***		0.716 ***
		(3.70)		(3.39)		(3.91)		(3.51)
Age		0.612 ***		0.891		0.605 ***		0.899
		(6.85)		(0.61)		(5.81)		(0.64)
Ia		0.283 ***		0.279 **		0.354 ***		0.319 **
		(3.01)		(2.23)		(2.98)		(2.35)
Cap		0.739 **		0.858 **		0.822 **		0.927 **
		(2.32)		(2.22)		(2.26)		(2.38)
Pat		0.924 ***		0.952 ***		0.813 ***		0.892 ***
		(19.95)		(16.48)		(18.21)		(17.28)
Constant	−0.027 **	0.770 ***	−0.035 **	0.041	−0.035 **	0.740 ***	−0.037 **	0.042
	(−2.37)	(6.61)	(−2.26)	(1.34)	(−2.53)	(5.49)	(−2.46)	(1.44)
Fixed effect	YES	YES	YES	YES	YES	YES	YES	YES
R^2	0.242	0.589	0.297	0.604	0.231	0.607	0.257	0.612
N	1051	1051	732	732	831	831	727	727

Notes: t-statistics shown in parentheses are clustered at the country level. ***/** indicate significance at the 1% and 5% levels. The following are the same. Odd columns are the test results for the main explanatory variables for the sample of companies with different production processes; even columns are the results of tests that incorporate the control variables.

4.2. Heterogeneity Analysis

The impact of digital technology innovation on the position of companies in the supply chain networks is heterogeneous in the industry. Based on China's National Economic Industry Classification (GB/T-4754-2017), this subsection classifies companies into two categories: manufacturing and non-manufacturing. Among them, 463 (44.05%) companies were manufacturing companies. The results are shown in Table 6, with the odd columns being regression results for the sample of manufacturing companies. From the perspective of the overall process of companies, digital technology innovation significantly improves the supply chain position of manufacturing companies compared to non-manufacturing companies. Two types of digital technology innovations, the design and development process and the production and manufacturing process are significant in enhancing the supply chain position of manufacturing companies. The digital technology innovation of the sales and after-sales process significantly promotes the supply chain position of non-manufacturing companies. Most non-manufacturing companies are categorized into information transmission, software and information technology services, wholesale and retail trade, scientific research and technology services, and financial services. The main value-adding creations for these industries are located downstream of the industrial chain, so the digital technological innovation of the sales and after-sales process has a more significant effect on improving their supply chain position.

Table 6. A heterogeneous analysis of the impact of digital technology innovation on the company's supply chain position.

Variable	**Overall Process**		**Design and Development Process**		**Production and Manufacturing Process**		**Sales and After-Sales Process**	
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Diginno	0.0696 *** (3.03)	0.0166 *** (5.95)	0.0156 *** (3.08)	0.0112 *** (5.53)	0.0388 *** (5.82)	0.0234 * (1.76)	0.0232 * (1.64)	0.0324 *** (3.33)
Fixed effect	YES	YES	YES	YES	YES	YES	YES	YES
R^2	0.651	0.569	0.669	0.614	0.618	0.674	0.607	0.689
N	463	588	322	410	374	457	348	379

Note: Heteroscedasticity robust t-statistics in parentheses. * $p < 0.1$, *** $p < 0.01$. Odd columns are regression results for manufacturing companies with different production processes; even columns are regression results for non-manufacturing companies with different production processes.

4.3. Robustness Testing

Considering that many complex factors will affect the supply chain position, we conducted a robustness test to verify the robustness of the conclusions.

Change the Measure of Supply Chain Position: This paper employs the eigenvector as a proxy variable for a company's supply chain network position in the baseline regression analysis. Many indicators can measure the position of companies in the supply chain network, as detailed in Section 3.2.1. dependent variable: supply chain position. Therefore, in the robustness test section, we chose Degree and PageRank as the proxy variables of network position for regression, respectively. After reconstructing the metrics of the constructed model, the estimation results in columns (1)–(2) of Table 7 indicate that digital technological innovations can still significantly contribute to the supply chain position. The findings of this paper are generally robust. The regression results of the impact of digital technology innovation on Degree and PageRank for each of the three production processes are detailed in Appendix A, Table A2.

Table 7. Robustness tests results.

Variable	**(1)**	**(2)**	**(3)**	**(4)**
Diginno	0.0154 *** (2.65)	0.0579 *** (5.43)	0.0829 *** (5.40)	0.0706 *** (3.72)
Size	0.141 *** (5.01)	0.125 *** (4.30)	0.599 *** (8.08)	0.735 *** (8.45)
Se	0.310 *** (5.51)	0.101 *** (17.38)	0.635 *** (4.30)	0.878 *** (5.14)
Age	0.944 *** (3.22)	0.490 (1.63)	0.610 *** (7.95)	0.614 *** (7.09)
Ia	0.422 (1.37)	0.123 *** (3.88)	0.283 *** (3.49)	0.150 (1.41)
Cap	0.461 (0.44)	0.114 (1.06)	0.739 *** (2.70)	0.195 (0.37)
Pat	0.233 *** (15.34)	0.101 *** (6.49)	0.924 *** (23.17)	0.966 *** (19.26)
Fixed effect	YES	YES	YES	YES
R^2	0.668	0.519	-	0.623
N	1051	1051	1051	833

Note: Heteroscedasticity robust t-statistics are in parentheses. *** $p < 0.01$. Columns (1) and (2) replace the original main explanatory variable Eigenvector, an indicator of supply chain network position, with Degree and PageRank, respectively. Column (3) shows the estimation results of the Tobit model. Column (4) shows a sample of companies whose main business is non-new energy vehicle manufacturing and were excluded.

Change the Estimation Model: Since the explanatory variable eigenvector centrality takes values ranging from 0 to 1, it satisfies the limited dependent variable model condition. Therefore, the baseline model was re-estimated using the Tobit model. The results are shown in column (3) of Table 7, where the Tobit model is consistent with the regression results of the fixed effects model. Digital technology innovation has a significant positive impact on the company's supply chain position at the 1% level, taking into account the possible bias in sample selection. The conclusions of this paper hold robustly.

We excluded samples of companies whose main business is not new energy vehicle manufacturing. With the deepening of the global division of labor in production, a company, especially a listed large-scale company, may have multiple industrial chain production lines. As the company's industry classification is based on the industry with the most revenue from the company's main business, companies whose main business is not new energy vehicle manufacturing are excluded. Specifically, samples of companies in the water and electricity, gas, public government services, and financial services industries were included, and a total of 118 samples were excluded. The results are shown in column (4) of Table 7, and the coefficients of the obtained regression results become larger, indicating that the conclusions of this paper are relatively robust.

4.4. Endogeneity Tests

In this paper, we used the two-way fixed effects model in the empirical study to analyze the impact of digital technology innovation on a company's supply chain position. Endogeneity problems may be caused by omitted variables and reverse causality in the research process. The companies at the center of the supply chain network are more capable of innovation in digital technology. The centrality of the supply chain network may be the cause rather than the effect of companies' digital technology innovation. The influences on a company's position in the supply chain network are more complex and are affected by many other factors in addition to the control variables already selected in this paper. To overcome the endogeneity problem, an instrumental variable is constructed in this section to re-estimate the model.

According to Ye et al. [71], topographic relief is used as an instrumental variable. On the one hand, geography affects the digital infrastructure in the region where the company is located, thus satisfying the correlation. On the other hand, topographic relief has no direct effect on the location of a company in the supply chain, which satisfies the exogeneity condition. Table 8, column (1) presents the primary estimation outcomes where topographic relief is utilized as an instrumental variable. We performed an endogeneity test on the model, which yielded a p-value below 0.01, thereby confirming the need for this test. The F-value for the first stage, derived from the use of the instrumental variable, exceeds 10, indicating that the variable meets the necessary correlation criteria and does not constitute a weak instrument variable. The empirical results show that digital technology innovations significantly enhance companies' supply chain position. The conclusions of this paper are still substantial after using instrumental variables to deal with endogeneity issues further.

Table 8. Endogeneity test results.

Variable	**(1)**
Diginno	0.1246 *** (4.87)
R^2	0.6211
N	1051
Control variables	YES
Weak instrumental variable F-value	127.013
Endogenous p-value	0.000

Note: Heteroscedasticity robust t-statistics are in parentheses. *** $p < 0.01$.

4.5. Mechanism Analysis

This section uses causal stepwise regression to test the mediating effects of managerial efficiency and profitability. Columns (1) and (3) of Table 9 analyze the relationship between a company's digital technological innovation and these two mechanism variables, respectively. As seen from Table 9, at the 5% nominal level, companies' digital technological innovation significantly affects managerial efficiency and profitability. Digital technological innovation enhances companies' managerial efficiency and profitability, and hypotheses H1a and H1b are valid.

Table 9. Mediation model regression tests.

Variable	(1)	(2)	(3)	(4)
Diginno	0.485 *** (7.03)	0.0842 *** (7.88)	0.768 *** (4.82)	0.0986 *** (4.74)
Managerial efficiency		2.409 ** (3.68)		
Profitability				0.118 * (5.96)
Control variables	YES	YES	YES	YES
Fixed effect	YES	YES	YES	YES
R^2	0.034	0.381	0.094	0.407
N	1051	1051	1051	1051

Note: Heteroscedasticity robust t-statistics are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Column (1) shows the regression results for digital technology innovation and its impact on managerial efficiency. Column (2) shows the effects of managerial efficiency on the supply chain position. Column (3) shows the regression results for digital technology innovation and its impact on profitability. Column (4) shows the effects of profitability on the supply chain position.

The relationship between digital technological innovation, each of the mechanism variables, and the companies' supply chain position is shown in Table 9. As can be seen in columns (2) and (4) of Table 9, in the baseline regression, the coefficient of digital technological innovation on supply chain position is less than 0.0131, so there is a partial mediation effect. The managerial efficiency, profitability, and supply chain position coefficients are significantly positive. This indicates that digital technology innovation can enhance supply chain position by improving organizational efficiency and increasing profitability. The use of digital technology in companies solves the problem of information asymmetry more efficiently by accelerating the rapid flow of data and information within the company and between the company and the outside world and improving management efficiency. At the same time, digital technology realizes the connection between the company's employees, machines, and leadership organization. New energy vehicle companies' automation and intelligent development have improved their management efficiency. Digital technology has helped automate companies' production processes, which has improved the quality of their products and reduced production costs. This, in turn, improves the profitability of the company. Together, they enhance the center position of companies in the supply chain network.

5. Discussion

Within the context of company supply chain management, digital technology innovation is most important. To address the influences of digital technology innovation on companies' supply chain position, we analyzed the direct and managerial efficiency/profitability-mediated indirect effects. In addition, we compared the direct effects of three types of digital technology innovations, including the design and development process, the production and manufacturing process, and the sales and after-sales process. The findings extend the current understanding of the impact of digital technology innovation on a company's supply chain position in several ways. The study shows that a company with stronger digital technology innovation can improve its management efficiency and profitability, thus helping it become a core supply chain company.

The results indicate that digital technology innovation positively contributes to enhancing companies' supply chain positions. However, digital technology innovations have different magnitudes of supply chain position-enhancement effects on different main business companies. Firstly, for service-oriented companies upstream and downstream of the new energy vehicles industry, including upstream design and downstream terminal automobile sales, maintenance and repairs, the two types of digital technological innovations, the design and development process, and the sales and after-sales process, play a more significant role in upgrading the position of companies in the supply chain network. This is related to the way the companies create value. The value added by service-oriented companies is reflected in the value created by human capital, and most of the digital technology innovations of this type of companies involve software, which is based on R&D and design tools that serve people [72]. Relative to the manufacturing sector, they are asset-light, and the payback time for digital technology innovation projects is relatively short [73]. Therefore, especially for small and medium enterprises (SMEs), it is crucial to accurately identify digital technologies and invest in digital technology innovation projects. This is a key path for SMEs to seize the opportunity to upgrade their position in the industry chain. Digital technology innovation has led to a gradual shift in the value relationship between companies and their customers from a product dominant logic of value transaction to a service dominant logic of value co-creation, which focuses on services as the fundamental basis of exchange and how knowledge and skills can be at the center of competitive advantage [74]. There are two processes by which innovative companies can move from value trading to value co-creation [75]. The first is the connection iteration process, companies break the resource constraints through foresighted cognition, adaptive reconfiguration, and creative search to form digital resource advantages, and realize the transformation from product suppliers to digitally enabled company functions, and from product-centric to customer-centric. The second is the endowing iteration process, in which companies break through the advantageous choices through the aggregation of digital resources and capabilities, the diffusion of digital industry chain, and the symbiosis of digital ecology, develop intelligent ecology, and realize the transformation from satisfying customers' existing needs to exploring customers' potential needs, and from product dominant logic to service dominant logic.

Secondly, the digital technology innovation of manufacturing-oriented companies within the new energy vehicles industry mostly focuses on the intermediate vehicle manufacturing production link, including the energy efficiency improvement of specific production technology or production equipment. Relative to service-oriented companies, the return on investment cost of digital technology innovation for manufacture-oriented companies is higher [76], with a high investment amount and a long payback cycle. Therefore, it is less popular among SMEs. Large manufacturing-oriented companies tend to monopolize the production and manufacturing process, a category of digital technology innovation [77]. Therefore, large manufacturing-oriented companies should invest more R&D and innovation resources into digital technology innovation's production and manufacturing process. Continuously consolidate and maintain their core and monopoly position in the supply chain network.

Existing studies on the measurement of digital technological innovation mainly include the literature induction method [52–54], the qualitative analysis method [55,56], the text analysis method [57,58], and the construction of an indicator system method [61]. This research, however, posits a more nuanced view. Consistent with the prior studies [16,62], this study utilizes patent data to measure innovation capability. It further splits digital technological innovations into three categories: the design and development process, production and manufacturing process, and sales and after-sales process, identifying the heterogeneity of digital technological innovations that contribute to companies' supply chain position enhancement. Furthermore, While previous studies that utilized data from the top five suppliers and top five customers of listed companies to construct supply chain networks [10,19], this study uses the Factset global supply chain database to build a more complete supply chain network of new energy vehicle companies. In addition, we find that using digital technology for a relational search has a positive effect on open innovation benefits, which is aligned with prior findings (e.g., [59,78]). However, this paper further utilizes social network analysis to measure supply chain network centrality, which provides a more comprehensive assessment of company competitiveness compared to studies that use a single metric of return on assets (ROA) or return on equity (ROE).

In addition to digital innovations driving China's new energy vehicle (NEV) industry, substantial governmental support through targeted industrial policies has been pivotal. These policies align with the United Nations Sustainable Development Goals, particularly Goals 7 (Affordable and Clean Energy) and 13 (Climate Action). The Chinese government has launched initiatives including significant subsidies for NEV manufacturers and buyers, tax exemptions, and stringent fuel economy standards aimed at phasing out conventional vehicles. These are part of broader efforts encapsulated in the 'Made in China 2025' plan, which emphasizes green technology innovations to integrate sustainability into the national industrial agenda. Key policy milestones include the 'Automotive Industry Green and Low-Carbon Development Roadmap 1.0' issued in December 2023 by the Ministry of Industry and Information Technology, targeting a peak in automotive carbon emissions by 2030. Furthermore, the State Council's January 2024 'Opinions on Comprehensively Advancing the Construction of a Beautiful China' aims for new energy vehicles to comprise 45% of new car sales by 2027. These strategic directions not only advance China's NEV sector in terms of economic growth and technological innovation but also contribute to environmental sustainability and urban air quality improvement, reflecting China's commitment to a green and low-carbon automotive future.

6. Conclusions

6.1. Conclusions

Digital technology is bound to become the core driver of competitiveness in modern company development. Based on the micro perspective, this paper uses the global supply chain data of Chinese new energy vehicle companies from 2012 to 2022 to test the impact of digital technology innovation on the enhancement of companies' positions in the supply chain network (and its mechanisms). The empirical results reveal the complex and significant interrelationships among digital technology innovation, managerial efficiency, profitability, and supply chain position, providing empirical evidence for companies to enhance their influence and competitiveness. The main conclusions of this study are as follows:

(1) Our empirical results emphasize the crucial role of digital technology innovation in promoting companies' supply chain position. In the economic sense, the coefficient of the impact of digital technology innovation on a company's supply chain position is 0.0131, which is significant at the nominal level of 1%. This indicates that for every 1-unit increase in a company's digital technology patents, the supply chain position will increase by 0.0131 units. This aligns with the findings of Jing et al. [10] and Du et al. [19], which state that digital technology innovation significantly increases companies' supply chain position. After a series of robustness tests in this paper, the conclusion is still valid.

(2) Managerial efficiency and profitability are key to the complex link between digital technological innovation and the supply chain position of companies. Further, the specific mechanisms of these effects have been examined, indicating that digital technological innovation mainly improves production efficiency through digitized production technology and equipment, and that digital information technology reduces communication costs and improves supply and demand matching efficiency, which ultimately promotes their supply chain position. As a result, it reduces companies' management costs and expenses, increases their profits, and ultimately improves their supply chain position.

(3) The effect of digital technology innovation on enhancing companies' supply chain positions is heterogeneous. The analysis again reveals that the promotion effect of digital technology innovation on the supply chain position of manufacturing-oriented companies is significantly greater than that of service-oriented companies, especially production and manufacturing process digital technology. The sales and after-sales processes linked you digital technology have a stronger effect on enhancing the supply chain position of service-oriented companies.

6.2. Limitations of the Research and the Future Outlook

This study is still subject to certain limitations, and future research should consider these. Firstly, the rapid evolution of digital technology means that our analysis captures only a snapshot of its impact on company supply chains within a specific industry and timeframe. Future studies could consider adopting a case study to trace the evolving impacts of digital technology innovations over time, offering a more dynamic view of these changes. Secondly, digital technology innovations are not homogeneous and vary significantly across different sectors. Our research focuses on new energy vehicle companies in mainland China, which provides insights into how developing countries can develop emerging industries to gain a competitive advantage globally, such as in the industries of power batteries and drones. Due to variations in regulatory and economic environments, future research should expand to a broader range of industries and regions to determine whether our findings are applicable in different developmental stages of national environments. Additionally, as digital technologies continue to develop, future studies should consider utilizing advanced methodologies like large AI model training to refine the classification of digital technologies across industries. This approach could enhance the granularity of research into how digital innovations impact supply chain positions. Furthermore, while the company's supply chain position should take into account the heterogeneities of digital technology innovation, it would be rather interesting to identify the multidimensional concept of digital innovation in the future.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Mediation model regression tests.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Diginno	0.2491 *** (3.27)	0.0842 *** (4.74)	0.6501 *** (3.81)	0.0613 *** (6.90)	0.9140 ** (19.81)	0.0681 *** (7.03)
Managerial efficiency(operating margin)		0.601 *** (7.03)				
Managerial efficiency(net profit margin)				0.261 ** (2.22)		
Managerial efficiency(turnover ratio)						0.878 ** (2.03)
Control variables	YES	YES	YES	YES	YES	YES
Fixed effect	YES	YES	YES	YES	YES	YES
R^2	0.037	0.594	0.093	0.407	0.043	0.632
N	1051	1051	1051	1051	1051	1051

Note: Heteroscedasticity robust t-statistics are in parentheses. ** $p < 0.05$, *** $p < 0.01$. Columns (1), (3), and (5) show the regression results of the effect of digital technology innovation on operating margin, net profit margin, and turnover ratio, respectively. Columns (2), (4), and (6) show the effect of operating margin, net profit margin, and turnover ratio on supply chain position.

Table A2. Robustness tests results.

Variable	Design and Development Process		Production and Manufacturing Process		Sales and After-Sales Process	
	(1) Degree	(2) PageRank	(3) Degree	(4) PageRank	(5) Degree	(6) PageRank
Diginno	0.0124 ***	0.0528 ***	0.0725 **	0.0266 ***	0.0220 ***	0.0206 ***
	(4.04)	(3.98)	(2.18)	(25.29)	(3.48)	(25.29)
Size	0.522 ***	0.144 ***	0.642 ***	0.302 ***	0.624 ***	0.302 ***
	(5.91)	(4.40)	(6.79)	(4.60)	(6.08)	(4.60)
Se	0.626 ***	0.293 ***	0.743 ***	0.127 ***	0.726 ***	0.127 ***
	(3.39)	(4.44)	(3.91)	(9.67)	(3.51)	(9.67)
Age	0.892	1.865 ***	0.603 ***	0.415 ***	0.890	0.415 ***
	(0.61)	(3.90)	(5.81)	(6.14)	(0.64)	(6.14)
Ia	0.271 **	0.386	0.354 ***	0.203 ***	0.311 **	0.203 ***
	(2.23)	(0.95)	(2.98)	(2.87)	(2.35)	(2.87)
Cap	0.851 **	0.154	0.825 **	0.834 ***	0.926 **	0.834 ***
	(2.22)	(0.12)	(2.26)	(3.49)	(2.38)	(3.49)
Pat	0.922 ***	0.251 ***	0.830 ***	0.367 ***	0.891 ***	0.367 ***
	(16.48)	(13.28)	(18.21)	(11.01)	(17.28)	(11.01)
Fixed effect	YES	YES	YES	YES	YES	YES
R^2	0.604	0.689	0.607	0.768	0.612	0.768
N	732	831	727	732	831	727
Variable	**(7) Tobit**	**(8) SCNP**	**(9) Tobit**	**(10) SCNP**	**(11) Tobit**	**(12) SCNP**
Diginno	0.0164 ***	0.0144 ***	0.0775 **	0.0640	0.0276 ***	0.0316 ***
	(4.74)	(3.29)	(2.57)	(1.42)	(4.12)	(4.08)
Size	0.529 ***	0.732 ***	0.647 ***	0.801 ***	0.614 ***	0.787 ***
	(6.93)	(7.23)	(8.01)	(8.45)	(7.22)	(8.01)
Se	0.686 ***	0.942 ***	0.745 ***	0.101 ***	0.716 ***	0.102 ***
	(3.97)	(4.68)	(4.62)	(5.42)	(4.16)	(5.19)
Age	0.891	0.426	0.605 ***	0.608 ***	0.899	0.165
	(0.71)	(0.27)	(6.86)	(6.12)	(0.76)	(0.12)
Ia	0.279 ***	0.815	0.354 ***	0.186	0.319 ***	0.897
	(2.61)	(0.56)	(3.52)	(1.39)	(2.78)	(0.58)
Cap	0.858 ***	0.382	0.822 ***	0.270	0.927 ***	0.609
	(2.60)	(0.51)	(2.67)	(0.42)	(2.82)	(0.82)
Pat	0.952 ***	0.997 ***	0.813 ***	0.871 ***	0.892 ***	0.984 ***
	(19.31)	(15.96)	(21.50)	(17.80)	(20.49)	(17.76)
Fixed effect	YES	YES	YES	YES	YES	YES
R^2	-	0.644	-	0.651	-	0.664
N	732	831	831	833	727	833

Note: Heteroscedasticity robust t-statistics are in parentheses. ** $p < 0.05$, *** $p < 0.01$.

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