

## Article

# Research on Dynamic Evolution Mechanism of Manufacturing Servitization—Based on the Perspective of Innovation Strategy

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**Abstract:** With the increasingly fierce market competition, customers' needs are gradually becoming more complicated, specialized, customized, and personalized. How manufacturing enterprises adopt innovation strategies to achieve value-added products as well as value co-creation with customers is an important initiative for enterprises to maintain differentiated advantages in market competition. Therefore, the creation of service value has gradually become more and more important. The related research on manufacturing servitization has attracted extensive attention in recent years. Manufacturing servitization is the evolution process of manufacturing enterprises gradually from product-dominant logic to service-dominant logic. The purpose of this study is to explore the dynamic evolution of manufacturing servitization from the perspective of innovation strategy and analyze the dynamic evolution mechanism. This study shows the latest research progress of theories related to manufacturing servitization and lays the theoretical foundation for research on the mechanism of the dynamic evolution of manufacturing servitization. This study proposes a three-stage dynamic evolution model of manufacturing servitization: product production, technological innovation, and service innovation. This study primarily employs the research methods of model construction and computer simulation. Based on the Nelson–Winter model, this study establishes a decision model for manufacturing servitization innovation strategy. This study conducts a computer simulation study on the dynamic evolution of manufacturing servitization from the perspective of innovation strategy and draws conclusions. This study is of great significance for manufacturing enterprises in making appropriate service-oriented innovation strategy decisions in the context of the service-oriented transformation occurring widely in the manufacturing industry.



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**Keywords:** manufacturing servitization; innovation strategy decision-making model; dynamic evolution mechanism; industrial structure; computer simulation

## 1. Introduction

The traditional manufacturing industry is in an intensely competitive market environment, and more and more manufacturers are initiating service-oriented transformation in order to gain differentiated advantages. Manufacturers have shifted their focus from products to product–service systems and integrated solutions, looking for higher returns and additional growth opportunities [1–4]. Scholars describe this shift as servitization [3–6], service infusion [7], or later as digital servitization [8–11]. Manufacturers can shift towards servitization in various advanced service areas related to their products. It is a lengthy and complex process, depending upon the type of advanced services intended. Germany's "Industry 4.0", the U.S.'s "Industrial Internet", and "China's Intelligent Manufacturing", etc., all show the inevitable trend of the transformation from production-oriented manufacturing to service-oriented manufacturing [12]. In terms of business models, the shift is from simply designing, manufacturing, and selling products to a new model of value co-creation through cooperation with customers, intermediaries, and other organizations to develop integrated solutions [7,13]. The manufacturing industry has shifted from focusing on technological innovation to focusing on service innovation and has gradually shifted

from the creation of product use value to the creation of service experience value [14,15]. More fundamentally, it is the shift in the operation and value creation concept of manufacturing enterprises from product-dominant logic to service-dominant logic [12,14,15]. For example, Apple has outsourced all of its smartphone production business, retaining only product development and ecosystem building as its core business and deepening its connection with customers through platforms such as the AppStore and iTunes to improve the customer experience value. The boundaries between the manufacturing and service industries have become blurred. Manufacturing servitization has become the focus of theoretical research and enterprise practice.

Manufacturing servitization is a shift in manufacturing from simply providing tangible products to providing a more complete portfolio of customer-focused service offerings, in which services create more value compared to products [5]. Manufacturing servitization is a dynamic, evolutionary, and continuous transformation process in corporate organizational structure, strategic choices, and behavioral styles. In this process, manufacturing enterprises achieve value-added products through technological innovation and service innovation. Manufacturing servitization changes the role of traditional manufacturing enterprises in the market, from product providers to service providers. Manufacturing servitization focuses on the transformation of manufacturing enterprises from product-oriented and technology-innovation-oriented to product–service systems and combining technological innovation with service innovation [16,17]. Research on how to promote the service-oriented transformation of manufacturing enterprises, business model innovation, and the development of dynamic capabilities needed for servitization have become hot topics in global academic research.

In the context of manufacturing servitization, manufacturing firms adapt to the dynamic changes in the market environment by searching for different innovation strategies. According to Chesbrough, the innovation strategy depends on the internal resources and core competencies that the firm itself possesses on the one hand and, on the other hand, depends on the resources and knowledge that the firm obtains from outside the organization [18]. Goedkoop argues that the innovation strategy of manufacturing servitization transforms manufacturing from a single model of product-oriented technological innovation to one that takes into account both technological innovation and service innovation and from a seller of products to a provider of integrated solutions for products and services [19]. In the context of manufacturing servitization, how enterprises can adapt to changes in the market environment through innovation strategy decision-making and the new characteristics of the evolutionary dynamics of the industry are issues of great concern.

According to the above analysis, this study is mainly focused on addressing the two key questions below. The first question is as follows: How can manufacturing enterprises adapt to the competitive market environment through innovative strategic decisions and their impact on the servitization transformation? The second question is as follows: What is the dynamic evolution process of manufacturing servitization, and what are the characteristics of each stage? By reviewing the relevant studies on manufacturing servitization, this study aims to explore the dynamic evolution of manufacturing servitization from the perspective of innovation strategy. The innovation strategy decision model of manufacturing servitization is constructed to reveal the innovation strategy decision mechanism and dynamic evolution characteristics of manufacturing servitization. The three-stage evolution path of manufacturing servitization is proposed to reveal the dynamic evolution mechanism of manufacturing servitization. Finally, the simulation model of the dynamic evolution of manufacturing servitization is constructed with the manufacturing industry as the research object.

This study mainly has the following two contributions: Firstly, this study explores the dynamic evolution mechanism of manufacturing servitization from the perspective of innovation strategy. Previous research in the servitization literature has mostly focused on the perspective of business model, service-dominant logic, and dynamic resource base view [7,14,15]. Moreover, most studies consider servitization as content but not process [20].

There are significant gaps in research on the dynamic process of servitization and the perspective of innovation strategy. Therefore, this study extends the servitization literature and enriches the servitization research results. Secondly, this study uses the computer simulation analysis method to study the dynamic evolution of manufacturing servitization and constructs a theoretical model of the dynamic evolution. This study adopts a relatively new research methodology that reveals the intrinsic influence mechanism of the innovation strategy decision on the dynamic evolution of manufacturing servitization. This provides a richer and deeper understanding of the dynamic evolution of servitization.

## 2. Theoretical Background

### 2.1. Manufacturing Servitization

Vandermerwe and Rada (1988) first proposed the concept of manufacturing servitization. They defined it as the shift of manufacturing firms from a single producing and selling product to providing a total solution combining products and services in order to create more value for customers and gain competitive advantages [5]. Gebauer (2010) viewed servitization as the process by which manufacturing firms provide added services for their traditional core products and create more value [21]. Malleret (2006) saw servitization as a strategic response of firms to product differentiation and reduced competitiveness [22]. Kowalkowski saw servitization as a strategy for firms to improve their product innovations, cope with the maturity stage of the product life cycle, and escape from the trap of product commoditization [6]. Some studies define servitization in terms of changes within the firm's management processes. Baines and Lightfoot (2009) proposed that servitization is a shift in the role of manufacturing firms in the marketplace from traditional producers and sellers of products to providers of combined product and service solutions [4]. Different terms are used in different studies to characterize manufacturing servitization. Service infusion was proposed by Forkmann [7], service integration solutions by Davies [23], product service systems by Mont [24], and so on.

Recent research in manufacturing servitization emphasizes value co-creation in the servitization process. Manufacturing servitization transformation occurs not only in manufacturing firms but also involves their customers, suppliers, partners, and even competitors [2]. To better understand the value creation process behind servitization, an integration of the roles and relationships of the various players involved is needed [25]. Kohtamäki considered value co-creation by firms and their customers in the context of servitization [26]. Sjödin et al. examined how close relationships and information-sharing activities with clarity and certainty can help firms identify product-service portfolios that better create value for customers [27]. Some scholars have explored the impact of coordination mechanisms [28] and the alignment of interests [2] of multiple participants in the servitization process on value creation in manufacturing firms based on the analysis of the firm-customer dichotomy. Current servitization studies have more often examined the value process in isolation, and relatively few have considered the interactions and dependencies between different participants. In the context of manufacturing servitization, the added value that services bring to product value mainly comes from the participation of customers, who are the core of the service, in the entire process of product design, R&D, production, sales, and delivery [12]. Manufacturing servitization makes the customer a central factor in adding value to the product.

Vargo (2004) expanded on the traditionally product-dominant logic and proposed value co-creation by both firms and customers [29]. In service-dominant logic, the distinction between producers and consumers becomes blurred, both being the subject of value creation. Since service-dominant logic emphasizes skills and capabilities, both producers and consumers are actors in the process of servitization: service providers and recipients [30]. Manufacturing servitization has transformed the enterprise's value creation model from product-dominant logic to service-dominant logic.

## 2.2. The Dynamic Evolution of Manufacturing Servitization

The evolution of manufacturing servitization is divided into several stages. Vandermerwe and Rada divided the process of manufacturing servitization into three stages: firms providing only goods, providing goods with additional services, and providing a bundle of products and services [5]. In the first stage, enterprises produce products only as a provider of products, and the relationship with their customers is a simple transactional relationship. In the second stage, enterprises begin to gradually attach corresponding services to their products and begin to act as product and service providers, expanding the relationship with their customers from sales to after-sales. In the third stage, the enterprises provide an organic combination of products and services together to provide customers with integrated solutions. The relationship with their customers transforms from a transactional relationship to a long-term interaction relationship. Through continuous interaction to meet the heterogeneous needs of customers throughout the entire product life cycle, the customer's experience of the product is continuously improved, facilitating value co-creation between enterprises and customers. Other scholars proposed that servitization is divided into four stages: providing products, providing products with additional services, providing products with advanced services, and providing product-service system total solutions [24,31]. They believed that the fourth stage was the final stage in the evolution of manufacturing servitization. Paiola adopted a qualitative research method to study the evolution of manufacturing servitization and identified three progressive levels of digital servitization complexity: product-, process-, and outcome-oriented [32].

Servitization not only changes the basic business orientation of firms but also implies a substantial reconfiguration of their activities, resources, and partnerships. According to Oliva and Kallenberg [33], manufacturing servitization requires enterprises to develop new competencies, and the acquisition of these competencies requires enterprises to undergo changes in their structures, processes, and organizations. The transformation of manufacturers is not just about adding services and improving products but more about making the integrated services a means to realize a shared vision and continuous value improvement. For firms adopting a servitization strategy, the ultimate goal is to provide products that better meet customer needs. The value creation of enterprises should remain aligned with the dynamic objectives of their customers.

The role of technological factors in the dynamic evolution of manufacturing servitization has received extensive attention from researchers. The development of digital technologies has disrupted traditional business models and value-creation concepts. In the context of digital servitization, the business model is based on the integration of an enterprise-centered value chain, where enterprises, customers, suppliers, and other strategic partners create value together in a complex and dynamic ecosystem. The widespread availability of smart, connected products has led to a redefinition of traditional business partnerships. The scope for value creation shifts from value networks to service ecosystems, where all participants co-create value in service ecosystems through resource integration and service exchanges [14]. Digitization refers to the use of digital technologies to connect people, systems, firms, products, and services. Digital technologies can significantly contribute to the dynamic evolutionary process of manufacturing servitization [34].

## 2.3. Manufacturing Servitization under the Perspective of Innovation Strategy

An innovation strategy is a strategic choice made by an enterprise to maintain its competitive advantage and long-term development in the face of fierce market competition. For the study of innovation strategy, Arrow (1962) and others mainly focused on innovation activities at the level of technology and believed that enterprises needed to make long-term plans for the choice of technological development paths in order to enable them to maintain a relatively favorable position in the competition for innovation [35]. Utterback believed that the technological innovation of enterprises in market competition directly determines the success or failure of the competition [36]. Therefore, the competition strategy of enterprises has a very close relationship with their technological innovation strategy, and

they often are adopted at the same time. For manufacturing enterprises, promoting manufacturing servitization not only means the transformation of enterprises from traditional product centers to service centers but also has a positive effect on their own technological innovation abilities. Manufacturing industries are all technology-intensive industries, and at the same time, they are also the industries where technological innovations are most widely applied. Therefore, it is of great significance to develop service innovations that are compatible with the technological innovations of the manufacturing industry [37].

Baines suggested that the focus of the manufacturing servitization innovation strategy was on the customers. Manufacturing enterprises shift from the traditional product-oriented logic to the new service-oriented logic and provide customers with better experience value through the combination of services and products [4]. Manufacturing servitization innovation strategy changes the characteristics, positioning, and role of enterprises. The traditional product-based transaction relationship shifts to a service-oriented interactive relationship. The relationship between enterprises and their customers gradually becomes an important resource for the enterprises. Mathieu argued that the development of the enterprise's core competence was the key to the transformation of manufacturing servitization [38]. The enterprise needs to move from the original technological innovation strategy to a service innovation strategy and to make organizational and strategic adjustments to provide total integrated solutions [38]. Product innovation capability is the ability to develop new products to meet market needs. The service innovation strategy is essentially a kind of open innovation, specifically one that is embodied in the high degree of customer participation in the enterprise's innovation activities. The customers are actually the source of innovation and the core stakeholders of innovation [15]. Kurdve believed that customer participation in manufacturing servitization is affected by a variety of factors, including the customer's willingness to participate, the customer's ability to participate, and so on [39].

At the same time, the innovation strategy of manufacturing servitization may also have some negative impacts on manufacturing firms. Gebauer introduced the concept of the servitization paradox, arguing that firms adopting a servitization strategy make large investments to expand their service offerings, which sometimes result in higher operating costs, and in many cases, these investments do not lead to a competitive advantage as expected [40]. Some cases have shown that adopting a servitization strategy has been effective in improving the growth and profitability of manufacturing firms, but at the same time, there have been cases where it has been difficult to profit from the service business. Many studies have focused on the barriers to servitization in manufacturing and the key factors to overcome the servitization paradox [41]. Since the implementation of a manufacturing servitization strategy inevitably implies a certain degree of change in the dominant logic, business model, and organizational structure of the firm, it may cause organizational conflict within the organization. Neely argued that manufacturing servitization was, to some extent, a dramatic change in the culture of the firm [42]. Service-centered companies require relatively more flexible staffing and organizational structure, with everything centered on customer needs. This cultural shift may be one of the main difficulties faced by the manufacturing servitization transformation.

In summary, this study investigates the phenomenon of manufacturing servitization from the perspective of innovation strategy, analyzes the dynamic evolution characteristics of manufacturing servitization, constructs the innovation strategy decision model, and reveals the dynamic evolution mechanism of manufacturing servitization.

### 3. Theoretical Analysis and Model Construction

#### 3.1. Overview of Innovation Strategies for Manufacturing Servitization

The manufacturing servitization innovation strategy is an open innovation strategy. The manufacturing servitization innovation strategy requires enterprises not only to carry out product innovation but also to carry out technological innovation and service innovation at the same time. The technological innovation strategy requires enterprises to

fully absorb the opinions of customers, master the needs of customers, and establish a customer-oriented technological innovation system. The service innovation strategy requires enterprises to establish close relationships with customers, continuously exchange information and interact with customers, and co-create value with them to provide integrated solutions that create more value for customers.

### 3.1.1. Technological Innovation Strategy

The technological innovation strategy of servitization manufacturing is reflected in the continuous improvement of technology and the quality of products. Improving the performance of the product itself means that the enterprise needs to invest appropriate resources in all aspects of the product, from R&D to production, in order to improve its effectiveness. For manufacturing enterprises, adopting a technological innovation strategy means, first of all, increasing investment in research and development (R&D). In the context of manufacturing servitization, the reasons for manufacturing enterprises to carry out R&D are often based on users' feedback and potential demand for products.

Technology R&D investment tends to have a positive relationship with R&D performance, i.e., the increase in profitability resulting from technological progress. Due to the cumulative nature of manufacturing enterprises in terms of technological experience and knowledge, R&D investment and R&D performance tend to have an exponential rather than linear relationship, i.e., the greater the investment in technological R&D, the greater its corresponding input–output ratio. For manufacturing enterprises, the progress of their manufacturing technology often has a technological ceiling. The technological ceiling determines the upper limit that can be reached by the technological development of manufacturing enterprises. When the enterprise's technology continues to improve, in the process of approaching the technological ceiling, the rate of technological progress will continue to slow down. When the technology owned by the enterprise is very close to the ceiling, the rate of technological progress tends to be close to zero, making it difficult to improve the enterprise's performance through technological progress. In an already well-developed manufacturing industry, the existence of a technological ceiling has led many firms to adopt innovations in their service businesses and internal processes to maintain their competitive advantage.

### 3.1.2. Service Innovation Strategy

The service innovation strategy of manufacturing servitization is reflected in the increasing proportion of service elements in value creation, the increasing impact of service businesses on the operation performance of enterprises, and the accompanying changes in the relationship between enterprises and the upstream and downstream subjects of the value chain.

Service innovation strategies have come to be seen as an important source of competitive advantage for firms in all industries and a key driver of economic change in recent years. Service innovation strategies follow a different logic compared to technological innovation strategies. Services are intangible and heterogeneous, while they are co-created by firms and customers. Therefore, service innovation strategies have many unique characteristics [43]. The close interaction between the firms and the customers in the service process and the fulfillment of the actual needs of the customers allow service innovation to be considered as an innovation model [44].

### 3.1.3. Synergistic Development of Technological Innovation Strategy to Service Innovation Strategy

Under the perspective of manufacturing servitization innovation strategy, enterprises have transformed from the traditional product-oriented logic to the service-oriented logic, which puts more focus on customers' demand. On the one hand, enterprises need to communicate and interact with customers continuously to fully understand their needs and make corresponding changes to their products based on those needs. Enterprises

improve the performance and quality of their products through technological innovation and enhance their reliability, stability, and adaptability. On the other hand, enterprises also need to help customers further discover the potential of the products, as well as further help customers find out the possible existence of other needs, i.e., in the process of continuous interaction to create demand for customers. In the context of manufacturing servitization, the enterprise's technological innovation and service innovation complement each other, and service innovation plays a more and more important role.

### 3.2. Innovation Strategic Decision Model for Manufacturing Servitization

Typical features of manufacturing servitization are the increasing importance of service elements in the enterprise's business strategy and the simultaneous development of the enterprise's technological innovation strategy and service innovation strategy. For manufacturing servitization enterprises, in order to adapt to the continuous dynamic changes in the market competition environment, they must continuously adjust their enterprise strategy according to the environment and their own situation in each period of their life cycle. At the same time, there is a certain degree of objective limitation on the enterprise's capital scale and resource capacity, so it cannot invest unlimited resources in all strategic choices and must carry out reasonable capital allocation between different strategies. Based on the classical Nelson–Winter model [45], this study combines the basic assumptions of evolutionary economics and considers the characteristics of innovation strategy to construct a model of innovation strategy decision-making for manufacturing servitization. The design of the model reflects the influence of environmental factors on enterprises and the choice of innovation strategies of enterprises in different periods.

The firm's production is determined by a combination of the technology it currently possesses and the size of its capital. Any factor that can bring about a change in the firm's rate of return can be seen as an advancement of the firm's technological level and the firm's ability to produce output. In evolutionary theory, firms discover new technologies in the technological space by searching, trying out new technologies, and observing the firm's adaptation to the market and its own performance after adopting new technologies. In the context of manufacturing servitization, the search of the enterprise is to find the appropriate weights for both the strategic mix of technological innovation and service innovation.

In the production model, this study follows the design of the classical evolutionary model, which views the output of the firm as the product of the strategy chosen by the firm and the firm's current amount of capital. The firm's strategy is the sum of the weights of the technological innovation strategy and service innovation strategy currently adopted by the firm. The total capital stock of manufacturing firm  $i$  at period  $t$  is  $K_{it}$ , the output per unit of capital is  $h_{it}$ , and the firm's total amount of output in the current period is  $Q_{it}$ :

$$Q_{it} = h_{it}K_{it} \quad (1)$$

According to Vandermerwe and Rada (1988), the evolution of manufacturing servitization can be divided into three stages. Therefore, the model construction in this study follows this form, viewing the different stages of manufacturing servitization as stage changes in the respective weights of corporate technological innovation and service innovation in the evolution of manufacturing servitization. The manufacturing factor and service factor inputs at each stage are determined by the weights of technological and service innovations, respectively. The total amount of output in the market in a period is the sum of the output volumes of all firms.

$$Q_t^M = \sum_{i=1}^N Q_{it} \quad (2)$$

This study determines the price per unit of output in the market using the pricing approach in the classical evolutionary model, i.e., the price per unit of output is positively proportional to the current market demand and inversely proportional to the total amount

of output in the current market. Let the price in the market be  $P_t^M$  and be determined by the total market demand  $R_t^M$  and the total output of all firms in the market  $Q_t^M$ .

$$P_t^M = R_t^M / Q_t^M \quad (3)$$

The profit of a firm is the difference between the firm's revenue and the firm's costs. A firm's current revenue is the product of price and output, and its revenue per unit is the product of price and the current rate of return, i.e., the strategic portfolio. The costs of a firm are divided into three main components: the firm's fixed costs, the firm's variable costs, and the firm's innovation inputs. The firm's innovation inputs in the cost model are mainly the firm's expenditures on its portfolio of innovation strategies. The firm's cost rate is the firm's expenditure per unit of capital on a portfolio of innovation strategies, which is jointly determined by the cost rate of the technological innovation strategy and the service innovation strategy. The cost rate of a firm's expenditure on two different innovation strategies is constant, but the actual expenditure of a firm on its innovation strategies is directly proportional to the firm's capital scale. Whenever a firm achieves a positive financial performance in the market, it uses the profit gained for capital expansion. At the same time, the firm increases its investment in technological innovation strategy and service innovation strategy proportionally to its capital scale expansion. Let  $h_{it}$  be the output rate of firm  $i$  at time  $t$ ,  $c_i$  be the fixed cost,  $r_i^{TK}$  be the firms' rate of investment per unit of capital in technological innovation, and  $r_i^{SV}$  be the firms' rate of investment per unit of capital in service innovation, then the profit margin  $g_{it}$  is given by the following formula:

$$g_{it} = h_{it} - c_i - r_i^{TK} - r_i^{SV} \quad (4)$$

In the evolutionary economic model, the extent to which a firm invests in different innovation strategies is determined by the size of its own capital. Therefore, in order to adapt to the highly competitive market environment, firms need to continuously expand their capital size in order to obtain enough resources for their different business and innovation strategies. Firms earn profits in each period of operation and expand their capital size based on profits. The firm's target markup rate in each period is affected by two factors: the elasticity of demand in the current market and the firm's market share. Let the elasticity of demand be  $\mu^M$  and the firm's market share be  $s_{it}$ , then the firm's target markup rate  $k_{it}^{TG}$  is:

$$k_{it}^{TG} = \mu^M / (\mu^M - s_{it}) \quad (5)$$

The firm's actual markup rate  $k_{it}^{AC}$  is determined by a combination of the firm's fixed costs  $c_i$ , the current period's price  $P_t^M$ , and the output rate  $h_{it}$ :

$$k_{it}^{AC} = P_t^M h_{it} / c_i \quad (6)$$

If the actual markup of the current firm is higher than the target markup, it means that the current firm's price is higher than its target price. As a result, the firm will need to expand its capital scale and its output to bring down the price. Firms cannot immediately reach the target price level through a single capital expansion. According to Winter (1986), the rate of investment used for capital expansion is considered to be proportional to the difference between the target rate of markup and the actual rate of markup, and based on this, the firm's target rate of investment  $I_{it}^{TG}$  is determined.  $\delta_i$  is the depreciation rate of the firm's capital, and the expected investment rate of the enterprise  $I_{it}^{HP}$  is as follows:

$$I_{it}^{HP} = \delta_i + (k_{it}^{AC} - k_{it}^{TG}) / k_{it}^{AC} \quad (7)$$

There are two main sources of investment enterprises use to carry out their own capital expansion. One part comes from the profits of the enterprise's operations  $F_{it}$ , and the other part comes from external investment  $I_{it}^{BK}$ , i.e., usually in the form of bank loans. The external investment in each period depends on the profitability of the firm in the current

period. If the current profitability of the firm is negative, the firm is unable to obtain external investment B. If the current profitability is positive, the investment institutions are optimistic about the business prospects of the firm, and the firm is more likely to obtain financial support from the investment institutions. Set  $F_{it}$  as the profitability of the enterprise, if the firm's profitability in the previous period  $t - 1$  is positive, then the firm's target investment rate  $I_{it}^{TG}$  at period  $t$  is:

$$I_{it}^{TG} = F_{it}(1 + B_t) + \delta_i \quad (8)$$

If the firm's profitability in the previous period  $t-1$  is negative, then the company needs to downsize, and the firm's target investment rate  $I_{it}^{TG}$  at period  $t$  is:

$$I_{it}^{TG} = F_{it} \quad (9)$$

If  $I_{it}^{TG} < I_{it}^{HP}$ , then the actual investment rate  $I_{it}$  of firm  $I$  at period  $t$  is:

$$I_{it} = I_{it}^{HP} \quad (10)$$

If  $I_{it}^{HP} < I_{it}^{TG}$ , then the actual investment rate  $I_{it}$  of firm  $I$  at period  $t$  is:

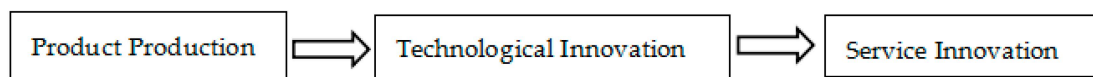
$$I_{it} = I_{it}^{TG} \quad (11)$$

The extent of capital expansion of firm  $i$  at period  $t$  is ultimately determined by the actual investment rate  $I_{it}$ , the depreciation rate  $\delta_i$ , and the capital size in the previous period  $K_{i,t-1}$ . Firms' actual investment in technological innovation and service innovation increases proportionally with the growth of firms' capital size. The capital size of firm  $i$  at period  $t$   $K_{it}$  is:

$$K_{it} = K_{i,t-1}(1 - \delta_i + I_{it}) \quad (12)$$

### 3.3. A Three-Stage Dynamic Evolutionary Model of Manufacturing Servitization

According to the literature review and the choice of enterprises' innovation strategy, this study divides the whole evolution cycle of manufacturing servitization into three stages based on the perspective of innovation strategy. The three stages are product production, technological innovation, synergistic development of technological innovation, and service innovation strategy. In the third stage, it is difficult to make great progress in technological innovation strategy, so enterprises are more dominated by service innovation strategy, as shown in Figure 1. The three-stage evolutionary path of manufacturing servitization is determined by the different innovation strategies adopted by manufacturing firms at different stages. During the dynamic evolution process, the roles of technological innovation capability and service innovation capability in value creation also change with the stage of the evolution of manufacturing servitization.



**Figure 1.** Manufacturing servitization evolution from the perspective of innovation strategy.

In the first stage of the dynamic evolution of manufacturing servitization, also known as the initial stage, manufacturing enterprises only adopt product production strategies. All enterprises develop along their own original paths, and the difference in competitive ability between different enterprises is not obvious. Manufacturing enterprises simply gain profits through manufacturing and selling products. However, new entrants are constantly emerging in the market, and the market is becoming more and more competitive. In order to reduce production costs and establish competitive advantages, some manufacturing enterprises begin to search for technological innovation and adopt technological innovation strategies. Thus, the dynamic evolution of manufacturing servitization enters the second

stage. In the second stage, manufacturing enterprises realize the reduction in production costs and improvement of production processes. Therefore, they can improve their product quality and create more product value-in-use; they can also provide some basic after-sales service. Different enterprises have different technological innovation capabilities, and thus, the technological progress and output rate improvement brought about by technological innovation vary greatly. Enterprises with advantages in technological innovation capability continue to expand their market shares and gradually become leaders in the industry. However, technological innovation in the manufacturing industry generally has a technological ceiling. With the accumulation of technological advances in enterprises, their technological level is closer to the technological ceiling, technological R&D and innovation become more and more difficult, and the marginal output of innovation continues to decrease. Enterprises have to turn to exploring new strategy choices to obtain competitive advantage and create new sources of profits. Therefore, more and more manufacturing enterprises begin to develop more advanced services through the adoption of the service innovation strategy. Thus, the dynamic evolution of manufacturing servitization enters the third stage.

In the third stage of the dynamic evolution of manufacturing servitization, manufacturing enterprises focus most on service innovation strategies. They provide not only basic after-sales service but also put more emphasis on advanced services. Advanced services are a complex bundle of product–service offerings involving long-term contractual agreements and cost-down commitments [46]. Such as offering advanced outcome services and contracts based on performance; an example is Xerox’s pay-per-click scanning, copying, and printing of documents. The introduction of advanced services makes it possible for technologically lagging enterprises to establish close cooperative relationships with customers, suppliers, etc., through service innovation. Thus, they obtain differentiated competitive advantages and the opportunity to catch up with the leaders.

#### 4. Research Methods and Research Processes

##### 4.1. Research Methods

This study primarily employs the research methods of model construction and computer simulation. Drawing upon the Nelson–Winter model, we developed an innovation strategy decision-making model for manufacturing servitization. Key considerations include environmental factors, corporate choices, and the servitization process. Furthermore, we used computer simulation to model the dynamic evolution of manufacturing servitization under different market structures, analyzing the characteristics and competitive dynamics at each stage.

In this study, the computer simulation mainly involves the use of Matlab software and the Monte Carlo method to model the complex interactions and outcomes of manufacturing servitization strategies. Compared to system dynamics simulation [47] and other simulation methods, we chose the Monte Carlo simulation mainly because our research problems involve significant uncertainty and variability. Further, Monte Carlo simulation can be computationally intensive, especially when dealing with a large number of samples or complex models.

In this study, the computer simulation method was applied according to the following steps: Model Development: an innovation strategy decision-making model of manufacturing servitization and the factors influencing manufacturing servitization. Parameterization: The model is populated with data and parameters that reflect real-world conditions and variables, such as market demand, technological progress, and the strategic choices of firms. Simulation Execution: The model is run using simulation software. This involves iterating the model over numerous time steps to capture the dynamic nature of the process. Analysis: The output from the simulation is analyzed to identify the impacts of various factors on servitization strategies. Next, we provide a detailed account of the computer simulation process and its outcomes.

## 4.2. Research Processes

### 4.2.1. Initial Parameter Settings for Computer Simulation

In order to carry out computer simulation on the dynamic evolution of manufacturing servitization, it is necessary to set the initial value of the innovation strategy decision-making model. The initial value setting should be in line with industrial reality and characteristics on the one hand, and the processing capability of the computer simulation itself should be taken into account on the other hand. Combined with previous experience and practical needs, the initial value setting of the computer simulation is shown in Table 1.

**Table 1.** Computer simulation initial setting of the evolution of manufacturing servitization.

| Item                          | Symbolic      | Initial Value |
|-------------------------------|---------------|---------------|
| Market demand                 | $R_0^M$       | 60            |
| Elasticity of market demand   | $\mu^M$       | 0.9           |
| Enterprise capitalization     | $K_{i0}$      | 25            |
| Innovation output rate        | $h_{i0}$      | 30            |
| Enterprise outputs            | $Q_{i0}$      | 27.5          |
| Enterprise unit cost          | $c_i$         | 0.25          |
| Enterprise depreciation rates | $\delta_i$    | 0.03          |
| TI output rate                | $h_{i0}^{TK}$ | 30            |
| SI output rate                | $h_{i0}^{SV}$ | 30            |
| Coefficient of TI capacity    | $\gamma_{i0}$ | N (1, 0.01)   |
| Coefficient of SI capacity    | $\omega_{i0}$ | N (1, 0.01)   |

TI: technological innovation; SI: service innovation.

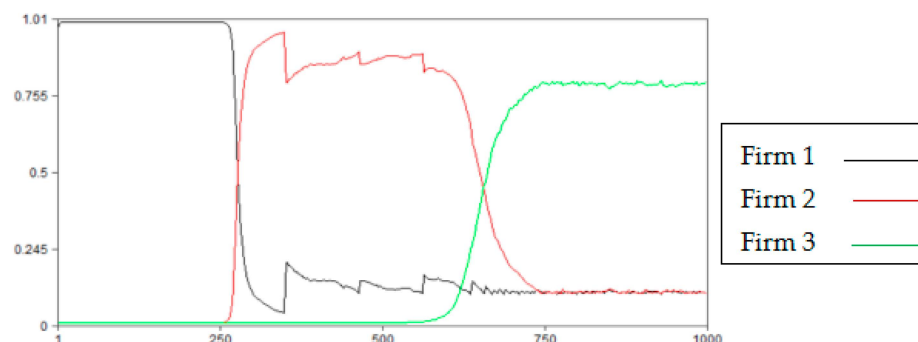
### 4.2.2. Computer Simulation Execution Process

In this study, the inverse Herfindahl index is used to represent the degree of industrial competition, and the simulation results are processed by adopting the Monte Carlo method. Multiple simulations are conducted under the same initial parameters, and the results of each period are averaged in order to more accurately and more intuitively reflect the dynamic characters of industrial competition under the dynamic evolution of manufacturing servitization. In this study, we set up 50 simulations under the same initial parameter conditions and plotted them based on the simulation result data, as shown in the figures below.

At the initial stage of the simulation, there is only one incumbent firm (Firm 1) in the market, which is in the first stage of the dynamic evolution of manufacturing servitization. Firm 1 possesses a technology that allows it to occupy a monopoly position in the market. As time passes, in the 150th period, the new technology TK1 appears in the existing technology space. At this point, due to the dominant position of Firm 1 in the market, there is no existential crisis of any kind, and the original technological path is still maintained. The appearance of technology TK1 provides a window of opportunity for other firms to catch up with Firm 1. After the emergence of technology TK1, Firm 2, which has mastered technology TK1, enters the market. Due to path dependence, Firm 1 cannot react to the changes in the current market dynamics in time. This allows Firm 2 to catch up with the dominant position that incumbent Firm 1 previously held in the market in a very short period through the strategic advantage offered by technology TK1. As we can see in Figure 2, Firm 2 enters the market and quickly captures most of the market share.

When the market dominance of Firm 1 is overtaken by Firm 2 with technology TK1, the survival of Firm 1 in the market faces a great threat under the influence of the market selection mechanism of the dynamic evolution of manufacturing servitization. Therefore, following the motivational mechanism of the dynamic evolution of manufacturing servitization, Firm 1 starts to react to its current environment and responds to the changes in market dynamics with new innovative strategic decisions. Firm 1 thus enters the second stage of the dynamic evolution of manufacturing servitization, with its dominant strategy shifting to technological innovation. At the same time, in order to compete with the emerg-

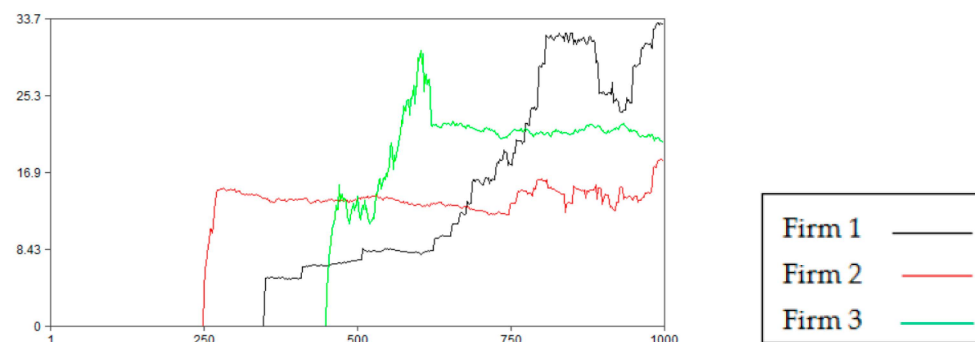
ing Firm 2, Firm 1 has to continue to invest in technological research and development on the basis of the acquisition of TK1 and continue to search in the technological space in order to increase its market share. However, the emerging Firm 2 also falls into the path of depending on TK1 due to its dominant position in the market. And Firm 2 loses the motivation to continue searching in the technology space. Meanwhile, Firm 1, after its technological search, reoccupies part of the market share.



**Figure 2.** Market share of structure A in technological regime.

A new technology, TK2, appears in the current technological space when Firms 1 and 2 are competing in the market. Unlike technology TK1, the new technology TK2 does not directly improve the firm's production capacity or product quality. However, technology TK2 can enhance the firm's service capability. At this time, Firm 3 enters the market. Firm 3, which has both technology TK1 and technology TK2, is in the third stage of the dynamic evolution of manufacturing servitization. However, the incumbent Firms 1 and 2 both hold a more substantial market share, and both are in a path-dependent state. Therefore, they do not respond immediately to the changes in market dynamics after the entry of Firm 3. Within a very short period of time, Firm 3 captures a significant portion of the market share.

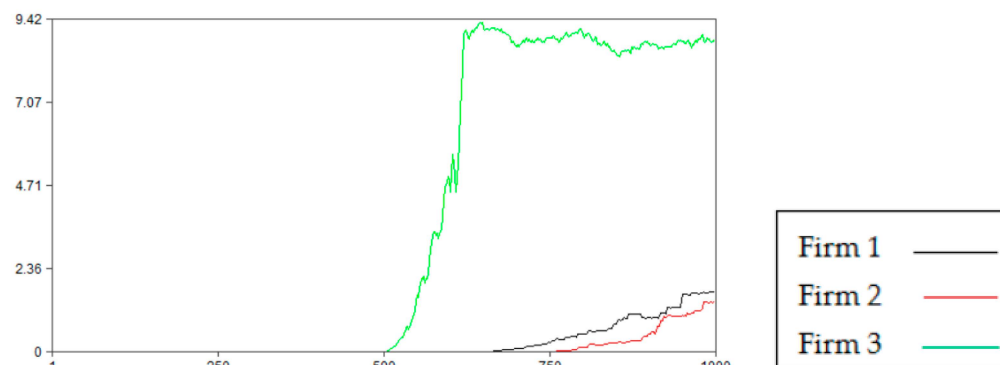
As we can see in Figure 3, when Firm 2 enters the market and enters the second stage of the dynamic evolution of manufacturing servitization, its technology search intensity is very high. Therefore, the technological innovation output rate rises rapidly, which is an important reason why Firm 2 is able to catch up with Firm 1 in a relatively short period of time. After Firm 2 dominates the market, the intensity of its search in the technology space is greatly reduced, and the output rate of technological innovation tends to level off. After being overtaken by Firm 2, under the influence of the motivational mechanism of manufacturing servitization, Firm 1 also strengthens its search intensity in the technology space.



**Figure 3.** Technology productivity of structure A.

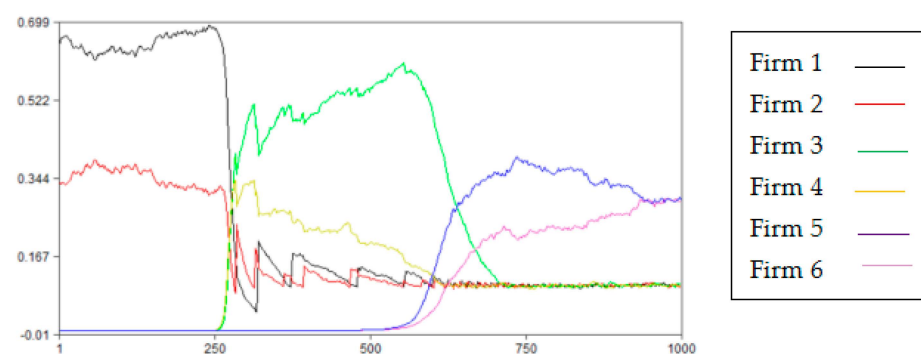
As we can see in Figure 4, when Firm 3 enters the market and enters the third stage of the dynamic evolution of manufacturing servitization, it catches up with the existing incumbent Firms 1 and 2. Firm 3, which possesses technology TK2, has a huge advantage in

terms of service innovation capability, so after catching up with Firms 1 and 2, the intensity of Firm 3's search in the technology space based on technology TK2 is decreasing, and its service innovation output quickly levels off. Firms 1 and 2, on the other hand, have entered the third stage of the dynamic evolution of manufacturing servitization with the catching up of new entrant 3, and each conducts intense searches in technological space in order to recapture market share.



**Figure 4.** Service productivity of structure A.

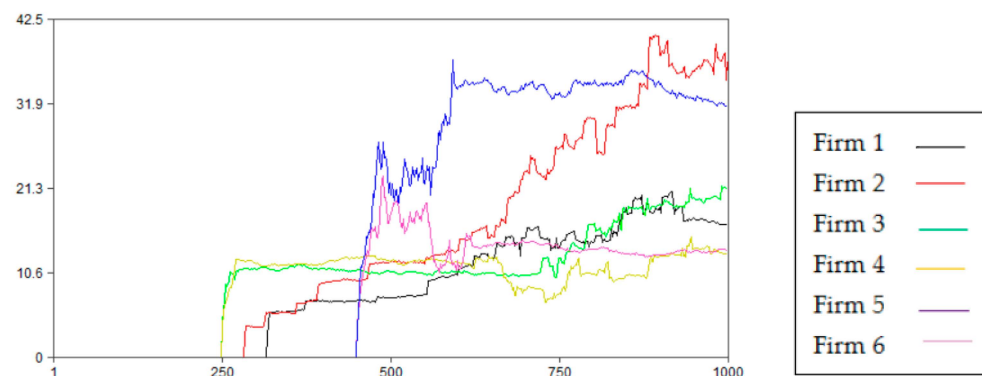
Based on the model of market structure A, further research is being conducted on the dynamic evolution of manufacturing servitization in market structure B, which has six firms and two new technologies. In market structure B, the manufacturing-facilitating technology TK1 and the service-facilitating technology TK2 appear in the 200th and 450th periods, respectively. As we can see in Figure 5, there are two initial firms in the market, Firm 1 and Firm 2, where Firm 1 occupies a larger market share and is the dominant firm in the current market. Before the emergence of technology TK1, the market shares occupied by Firm 1 and Firm 2, although different, were relatively stable, and there was no existential crisis for both firms. So, neither firm intensifies its search in the technology space and only utilizes the existing technology for its production and operation.



**Figure 5.** Market share of structure B.

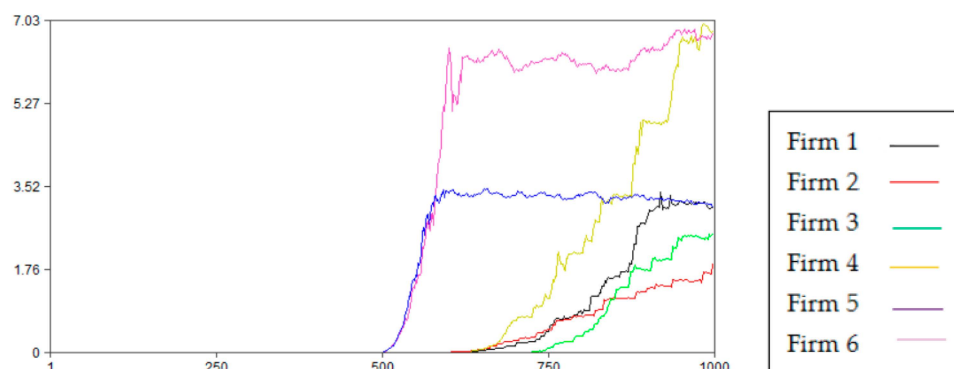
The new technology TK1 appeared in the 200th period, and Firms 3 and 4 with technology TK1 entered the market in the 250th period. As we can see in Figure 5, due to the advantage in the output rate of technological innovation brought about by technology TK1, new entrants Firms 3 and 4 quickly catch up with the market share of incumbent Firms 1 and 2. New entrant 3 overtakes the leadership of incumbent Firm 1 and becomes the dominant firm with the largest market share. New entrant 4 also overtakes incumbents 1 and 2 but is lower than Firm 3. Meanwhile, Firms 1 and 2 also respond to the challenge of new entrants. As we can see in Figure 6, the technological innovation output rates of Firms 1 and 2 also begin to increase. Firms 1 and 2 begin to intensify their technological search in the technological space and advance their technological innovation strategies. Thus, they start to enter the second stage of the dynamic evolution of manufacturing servitization.

After a period of technological search, although the market shares of Firms 1 and 2 have not yet recovered to the level before the entry of Firms 3 and 4, they have gradually reached the level of neck-and-neck in terms of technological innovation output rate. Therefore, they recapture some market shares. On the contrary, due to their dominant position in the market and scale effect, Firms 3 and 4 do not threaten their survival even if they temporarily lose their technological advantage, so they do not respond to the high-intensity technological search of Firms 1 and 2.



**Figure 6.** Technology productivity of structure B.

In the 450th period, the new technology TK2 appeared, which can enhance the service capability of enterprises. In the 500th period, Firms 5 and 6, which have both the mature technologies TK1 and TK2, enter the market and promote their respective technological innovation strategies and service innovation strategies. They are stated in the third stage of the dynamic evolution of manufacturing servitization. As seen in Figure 5, after Firms 5 and 6 enter the market, the market share of Firm 3 is substantially eroded by Firms 5 and 6, and Firm 5 gradually becomes the new dominant firm. Although Firms 5 and 6 both simultaneously promote the technological innovation strategy and the service innovation strategy, the two new entrants react differently to the current market dynamics. As shown in Figure 6, Firm 5 focuses more on its technological innovation strategy and searches intensively in the technology space, so its technological innovation output rate increases rapidly. At the same time, after a period of high-intensity search in the technology space, Firm 6 begins to gradually reduce the intensity of technological search. As shown in Figure 7, Firm 6 has a very high search intensity in the technology space where technology TK2 is located, vigorously promotes its service innovation strategy and even reaches about twice the output rate of Firm 5.



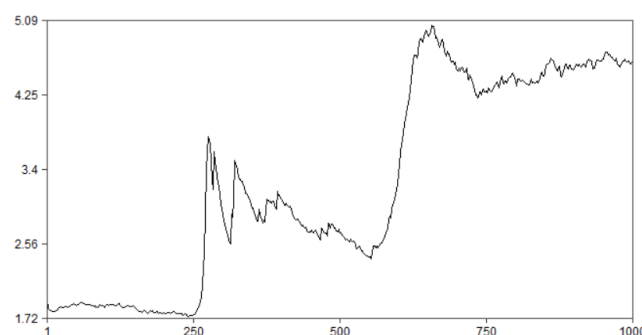
**Figure 7.** Service productivity of structure B.

Firm 5 adopts a strategy that emphasizes both technological innovation and service innovation when it first enters the market. As seen in Figures 6 and 7, Firm 5 simultaneously conducts high-intensity searches in the different technology spaces. When its market share

has reached a certain level, and it does not have an existential crisis, it begins to reduce its investment in service innovation. Even so, at this time, the service innovation output rate of Firm 5 is still second only to that of Firm 6 and much higher than that of other incumbent firms. However, Firm 6 starts to stabilize its technological innovation strategy and intensify its service innovation strategy soon after entering the market. Although it does not have an advantage in technological innovation, it still catches up with the dominant Firm 5 by virtue of its huge advantage in service capability and eventually reaches or even occasionally exceeds the market share of Firm 5.

When the evolution of manufacturing servitization enters the third stage, with the introduction of service elements, the competitive situation of the manufacturing industry has changed significantly. When the number of enterprises is small, the adoption of technological innovation strategy and service innovation strategy at the same time makes the enterprises that are at a disadvantage in the technological innovation stage regain greater competitiveness and even realize the counter-attack on market share. The degree of competition in the industry also turns down to up. When the number of enterprises is larger, although the situation of realizing market share reversal is less, the introduction of service elements still terminates the trend of decreasing industrial competition, and the degree of competition in the market gradually enters a dynamic equilibrium. It can be seen that the introduction of service elements has a very important impact on improving the competitiveness of enterprises, increasing their adaptability to the environment, and maintaining their survival and development in industrial competition.

As we can see in Figure 8, during the dynamic evolution process, the concentration of industry shows a decreasing trend with the continuous emergence of new technologies. At the same time, the birth of new technologies and the entry of new enterprises have a brief impact on industry concentration in a short period of time. For example, the emergence of technologies TK1 and TK2 can lead to the entry of new firms into the market, which in turn affects industry concentration. Although the overall industry concentration is decreasing, there is still a transient increase in market concentration due to the catching-up effect of the new entry firms. When the overtaken incumbents begin to react to new market dynamics, market concentration will fall again.



**Figure 8.** Inverse Herfindahl index.

#### 4.3. Computer Simulation Results Analysis

The results of the multi-subject simulation show that the industrial dynamics of the evolution of manufacturing servitization are significantly different in manufacturing industries dominated by technological innovation capabilities and those dominated by service innovation capabilities. The service innovation capability-led industrial environment usually occurs when the key technology of the industry is close to the ceiling, i.e., relatively mature manufacturing industries. At this point, the growth in the rate of innovation output from technology has started to slow down. After enterprises enter the third stage of evolution, the introduction of service elements plays a very crucial role in increasing the innovation output rate and expanding the competitive advantage of enterprises. Under an industrial environment dominated by service innovation capability, the proportion of service innovation strategy in the enterprise's innovation strategy portfolio continues to

increase, the benefits brought by the service innovation strategy grow gradually, and the enterprise is gradually transformed into a service-oriented enterprise.

In the dynamic evolution of manufacturing servitization, technological innovation and service innovation, due to the emergence of new technologies in the industry, create a window of opportunity for lagging firms to catch up with incumbent firms; the service innovation capability of firms is an important factor for lagging firms to catch up with incumbent firms.

At the initial stage of the dynamic evolution of manufacturing servitization, the technological levels of all firms converge, and all firms maintain a stable market share and, therefore, have no incentive to engage in a more intense technological search. In the process of dynamic evolution, however, new technologies that help to improve the technological level and production capacity of firms naturally emerge. The emergence of new technologies opens a window of opportunity for new entrants and lagging firms to catch up with existing incumbents. On the one hand, new entrants and lagging firms can strengthen their technology search to acquire new technologies and advance their technological innovation strategy, therefore entering the second stage of the dynamic evolution of manufacturing servitization. On the other hand, incumbent firms, due to path dependence, will not actively conduct targeted searches after the emergence of new technologies, which further increases the opportunities for new entrants and lagging firms to catch up with incumbent firms. In the third stage of the dynamic evolution of manufacturing servitization, service elements are introduced, and enterprises in the industry begin to adopt both technological innovation and service innovation strategies. The introduction of service elements changes the relationship between manufacturing enterprises and the upstream and downstream of the value chain. On the one hand, the service innovation strategy makes the relationship between enterprises and downstream customers change from a simple transaction relationship to an interactive, cooperative relationship, realizing the value co-creation of both sides. On the other hand, the service innovation strategy enables enterprises and upstream suppliers to communicate more effectively about their product and technology needs, making it easier for enterprises to obtain the technologies and resources they need and thus enhancing their technological and service innovation capabilities.

For lagging firms with insufficient technological innovation capacity, service innovation capacity provides a way for them to catch up. The service innovation strategy emerging from the third stage of the dynamic evolution leads to a significant increase in their competitive advantage. As a result, the introduction of service elements changes the dynamics of industry evolution. The market shares of some lagging firms increase rapidly and even exceed the market shares of the industry leaders. The original competitive situation in the industry is broken, and the degree of competition in the industry stops its downward trend and rises again. In the second stage, i.e., the technological innovation stage, the gap between industry leaders and laggards in terms of technological innovation ability is often not very big, and the relative competitive advantage is also smaller. In the third stage, i.e., the stage of combining technological innovation and service innovation, the introduction of service elements enables some laggards to integrate their relationship with the upstream and downstream of the value chain more effectively. They focus on enhancing their service innovation capability to make up for the lack of their technological innovation capability so as to catch up with the industry leaders.

## 5. Conclusions

This study reveals the dynamic evolution mechanism of manufacturing servitization based on the perspective of innovation strategy and analyzes the stage characteristics of the dynamic evolution of manufacturing servitization. A series of research methods, such as literature research, theoretical analysis, model construction, and computer simulation, are comprehensively applied to carry out in-depth research. This study proposes a three-stage dynamic evolution model of manufacturing servitization. Based on the perspective of

innovation strategy, the whole evolution cycle of manufacturing servitization is divided into three stages: the product production stage, the technological innovation strategy stage, and the service innovation strategy stage, according to the choice of enterprise innovation strategy. After the transformation of servitization, the leading logic of the enterprise is service-oriented logic; the role of the enterprise in the market is the overall solution provider of product and service combinations, and the enterprise and the customer carry out comprehensive and in-depth interactions to realize value co-creation.

The research extends its exploration into the mechanisms governing the transformation of manufacturing servitization via innovation strategy, developing a decision-making model for such strategies. This model adeptly mirrors and exposes how, in response to market competition, manufacturing enterprises in the throes of servitization select appropriate innovation strategies and allocate sparse resources to bolster their technological and service innovation capabilities, thus ensuring their survival and growth. The introduction of service elements in the third stage presents a significant opportunity for firms with weaker technology innovation capabilities to catch up and even surpass industry leaders. This finding underscores the transformative potential of service innovation in creating competitive advantages and disrupting existing market structures.

In this study, the dynamic evolution mechanism of manufacturing servitization is investigated through computer simulation and emulation. Based on the decision-making model of manufacturing servitization innovation strategy proposed in the paper, the model established on the computer simulation platform by the programming method carries out the different industrial dynamics under the three-stage evolution path of manufacturing servitization, and on the basis of which, the simulation analysis of the dynamic evolution of manufacturing servitization under the industrial structure with different numbers of enterprises is carried out. The results find that there are similar competitive dynamics in the three-stage evolution of manufacturing servitization under different industrial structures.

The study's findings are consistent with the existing literature on manufacturing servitization, emphasizing the importance of both technology innovation and service innovation in the evolution of manufacturing industries. While some studies highlight the challenges and risks associated with service innovation, this study demonstrates that service innovation can be a powerful tool for lagging firms to catch up and regain competitiveness. Additionally, the study confirms the role of new technologies in driving the dynamic evolution of manufacturing servitization. The emergence of new technologies creates opportunities for both new entrants and incumbent firms to innovate and improve their competitive position.

## 6. Implication, Limitations, and Future Research

This study investigates the dynamic evolution of manufacturing servitization from the perspective of innovation strategy. The research findings contribute to both theoretical and practical understanding of manufacturing servitization.

In terms of theoretical implications, firstly, current servitization studies are predominantly content-oriented but rarely servitization processes, which researchers recently called for more attention [20]. This study explores the dynamic evolution processes of manufacturing servitization and proposes the three-stage dynamic evolution model. Therefore, this study extends the servitization research by focusing on servitization processes. Secondly, this study explores the dynamic evolution mechanism of manufacturing servitization from the perspective of innovation strategy. This provides a new perspective for understanding the complex and evolving nature of manufacturing servitization. This study extends the theoretical research on manufacturing servitization and provides certain references for the subsequent related research.

In terms of practical implications: Firstly, the innovation strategy decision-making model proposed in this study provides manufacturers with a basis and reference for strategy decision-making. This model can be used to analyze how manufacturing enterprises choose and implement innovation strategies in different stages of the servitization process. Sec-

ondly, the three-stage dynamic evolution model of manufacturing servitization proposed in this study is of great significance for manufacturers. This makes manufacturers gain a better understanding of servitization transformation and servitization strategy. This facilitates a successful servitization transition for manufacturers. Lastly, the study demonstrates that service innovation can serve as a catch-up strategy for lagging firms in manufacturing industries. By focusing on enhancing service innovation capabilities, lagging firms can overcome their disadvantages in technology innovation and regain market share from incumbent firms. So, manufacturers can increase investment in service innovation in order to obtain differentiated competitive advantages and achieve catch-up with the leaders.

In terms of limitations and future research, the computer simulation approach adopted in this study is oriented toward the industrial characteristics of the manufacturing industry. Because of the limitations of the research, which is only for a specific industry, future research can further expand the relevant research to other industries. Secondly, this study investigates the dynamic evolution of manufacturing servitization from the perspective of innovation strategy, and future research can study this research from other perspectives, such as the innovation ecosystem [9,48], value co-creation [27,49,50], and so on.

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