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Servitization of Manufacturing Industry Export Enterprises, Multinational Corporation GVC Activities and Pollution Reduction in China

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Abstract

This paper measures manufacturing service input at the micro level of export enterprises to investigate the pollution reduction effects of manufacturing servitization and examines the mechanism from the perspective of GVC activities of multinational corporations. The study finds that (1) servitization generally reduces the pollution emission intensity of export enterprises, and this effect is widespread among enterprises of various ownership types, pollution-intensive and nonpollution-intensive enterprises, and enterprises in the eastern and western regions; (2) there is a "U-shaped" nonlinear effect of servitization on the pollution reduction of export enterprises, indicating that in the initial stage of servitization, the increase in service elements in manufacturing will lead to an increase in enterprise emissions, and only when the servitization degree reaches a certain threshold will a significant pollution reduction effect be observed; and (3) the "domestic-foreign" and "foreign-domestic" types of GVC activities characterizing the connections between multinational corporations and local enterprises have a moderating effect on the pollution reduction impact of servitization. This study has significant implications for promoting the green development of enterprises through manufacturing servitization in the context of GVCs.

JEL classification numbers: F18, L60.
Keywords: Manufacturing Servitization, Pollution Reduction, Inverted "U" Shape, Multinational Company GVC Activities.

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1. Introduction

As global climate deterioration and environmental problems intensify, the clean development of the manufacturing industry is a key issue of concern worldwide. Green development of the manufacturing industry is a main goal for major manufacturing countries. Manufacturing enterprises are the key micro entities for implementing pollution reduction, and they are the key to environmental governance. At present, an important trend in the transformation of manufacturing is servitization, namely, the integration of the manufacturing industry and the service industry. It is not only an important driving force for the manufacturing industry in terms of enhancing international competitiveness but also an important supporting factor for reducing pollution and improving efficiency in the manufacturing industry. In fact, modern service elements in manufacturing servitization, as high-end elements that consider cleanliness and high added value, have played an important role in reducing pollution emissions in enterprise production. Therefore, further in-depth measurement and research on the effect of pollution reduction in manufacturing servitization from the micro perspective of enterprises and the internal mechanism of such effect would hold new theoretical and practical value.

The input of high-quality service elements under manufacturing servitization is an endogenous driving force that significantly promotes enterprise pollution reduction. From the experience of China's Reform and Opening Up, the high-quality factor input brought by foreign direct investment (FDI) is one of the important driving factors for China's high-quality economic development. Multinational corporations are an important vehicle for the cross-border foreign investment of a country's production factors. They have led and promoted the formation and development of the global value chain (GVC) division of labor patterns. Therefore, FDI-related GVC activities of multinational corporations in the industry can greatly promote domestic enterprises to utilize high-end service elements of foreign capital, promote the technological level and production efficiency, and thus help the green high-quality development of enterprises.

For China, in-depth participation in the GVC that are dominated by the multinational corporations of developed countries and active integration into the current GVC reconstruction process are key links in its foreign openness strategy. As a result, China has become an important country in the GVC network and one of the three major core hubs in the global production network. Therefore, based on the dominant position of multinational corporations in conducting production factor FDI activities, the new accounting framework introduced by Wang et al. (2021) can identify the GVC activities of multinational corporations and the status of China's development in the GVC network, considering the production relationship between multinational corporations and domestic enterprises within the host country. Taking China as a sample, we will further carry out a mechanism test on the effect of manufacturing servitization on pollution reduction, as this is an important issue discussed in this paper.

In summary, given the background of global value chains and multinational corporations, this paper is based on the micro perspective of enterprises and the new GVC accounting framework that can identify and measure the GVC activities of multinational corporations in the industry, aiming to explore the corporate pollution reduction effects of manufacturing servitization and its internal mechanism. The main contributions of this paper are as follows:

1. From a microeconomic perspective, at the firm level, we propose a method to measure manufacturing servitization. Compared with current research, most studies on servitization currently focus on the industry or country level (Zong and Gu, 2022). The main reason is that the calculation of servitization is usually based on input–output tables. This paper integrates the input level of servitization at the industry level and the import and export countries and commodity structure at the enterprise level to measure the input of service elements of the manufacturing industry at the enterprise level, thus extending relevant research to the heterogeneous enterprise level.
2. Most of the current research on the impact of manufacturing servitization on corporate pollution reduction examines linear effects. However, this effect may not truly reflect the relationship between servitization and pollution reduction. This paper attempts to study the real relationship between manufacturing servitization and corporate pollution reduction, constituting a breakthrough in the theoretical boundaries of existing research.
3. In terms of the mechanism of action, we focus on the GVC activities of multinational corporations instead of the overall GVC activities. Wang et al. (2021) introduced the heterogeneity of multinational corporations (considering the differences between multinational corporations and domestic enterprises within the host country) to construct a new GVC accounting framework that can measure the activities of multinational corporations. In this paper, we use this framework to decompose the GVC activities of multinational corporations into "foreign-foreign enterprise", "foreign-domestic enterprise" and "domestic-foreign enterprise" types and study the mechanism of manufacturing servitization and corporate pollution reduction.

The remainder of the paper is organized as follows. Section 2 outlines the literature review and research hypothesis. Section 3 describes the research methodology. Section 4 presents the results and discussion. Section 5 presents the conclusions and policy implications.

2. Literature Review and Research Hypothesis

2.1 Literature Review

The concept of servitization was first proposed by Vandermerwe and Rada (1988) and later refined by Szalavetz (2003) into input servitization and output servitization, reflecting the growing emphasis on service inputs within enterprises over traditional elements on the input side and a preference for offering product-service bundles to meet consumer demands on the output side. Currently, the measurement methods of manufacturing servitization are primarily conducted at the industry level, mainly including the direct consumption coefficient method (Park, 1994) and the complete consumption coefficient method (Zhao and Chen, 2021). As the names suggest, these methods measure servitization based on the direct consumption coefficients and complete consumption coefficients, respectively. Gao and Yuan (2020) conducted the first measurement study of servitization at the enterprise level using the National Interregional Input–Output Tables, the China Industrial Enterprises Database, and the Customs Trade Database. Currently, scholars mainly conduct research on servitization at three levels. At the national level, developed countries generally exhibit the "two 70%" characteristics (i.e., services account for 70% of GDP, and productive services account for 70% of the service industry). For a country, Bhagwati (1984) believed that the increased demand for services in production by the manufacturing sector has strengthened the separation effect between the service market and the commodity market. Within an industry, based on the GVC perspective, Ernst (2001) noted that the upgrading of factors, that is, the transformation of comparative advantage from endowment or natural capital to creative capital, is one of the important channels for achieving industrial upgrading. The improvement of the servitization level promotes the substitution of overall knowledge factor input for labor and capital factors in industries, shortening the technological path of industrial upgrading. At the enterprise level, servitization brings positive benefits to manufacturing enterprises, such as improved production technology (Arnold et al., 2008), productivity (Arnold et al., 2011; Grossman and Rossi-Hansberg, 2008), sustainability (Mont, 2002), and resource efficiency (Doni et al., 2019), effectively promoting the transformation and upgrading of manufacturing enterprises.

The relationship between servitization and environmental performance was first proposed by White et al. (1999). Since then, scholars in this field have fully explored the possible environmental impacts of servitization, focusing primarily on qualitative analysis and linear quantitative analysis. In addition, most studies in this field use the level of servitization at the industry level as the core independent variable to analyze the pollution emission levels of industries and enterprises, that is, quantitative analysis of meso-industry to microenterprise and meso-industry to meso-industry. There is still a lack of research at the microenterprise level on the relationship between microenterprises. Baines et al. (2007) summarized previous studies and concluded that improving environmental performance is an intrinsic motivation for enterprise servitization. Service trade is also considered a cleaner type of trade (Levinson, 2010). By providing a combination of goods and services to meet user needs, servitization can substitute user functional needs for some material needs (Mont, 2002). In addition, strengthening the "dematerialization" characteristics in the enterprise production process can further reduce the material requirements in the production process, thereby weakening environmental pollution (Reiskin et al., 1999). In addition, servitization may have an inhibitory effect on pollution reduction. Zhu et al. (2020) found that the scale effects brought by servitization may reduce the pollution reduction effects brought by servitization.

From an impact mechanism perspective, transnational companies, as important participants in the relational GVC, play a profound role in enterprise pollution reduction by expanding foreign investment and enhancing asset investment and trade linkages between domestic and foreign enterprises. Eskeland and Harrison (2003) found that multinational corporations have higher energy efficiency and improved management systems and they have better environmental performance than local companies. Zeng and Zhao (2009) found that enterprises will reduce pollution emissions in the process of specializing and clustering, and the aggregation of foreign enterprises in China will bring positive externalities for the environment as China becomes one of the three core hubs of the global production network. In addition, the reduction of knowledge costs and optimization of resource allocation resulting from strengthening the export of goods or improving the level of trade liberalization (Cui et al., 2016; Forslid et al., 2018) can promote enterprise pollution reduction efforts.

2.2 Research hypothesis

Servitization is characterized by investment in high-quality service elements, such as advanced technological knowledge and high-end human capital, as these elements are embedded in various stages of enterprise production and operation processes and they possess the dual nature of high value, cleanliness, and intangibility (Levinson, 2010). At the production level, servitization can bring about technology spillover effects by introducing high-end service elements mainly from foreign sources and providing specialized learning opportunities for enterprises. This enhances the independent innovation capability and talent reserve of enterprises, accelerates technological progress and specialized production processes and is conducive to the optimization of resource utilization efficiency, thus ultimately reducing pollution. Additionally, the intangible nature of service elements means that even large-scale investment in them will not cause serious pollution (Lü et al., 2023). Under the premise of limited enterprise resources, the structural effects generated by service elements replacing traditional elements will lead to clean positive externalities, and the product design concept updates brought about by servitization will enhance the enterprise circular production capacity, thus further contributing to pollution reduction. At the business level, servitization allows exporting enterprises to expand the value-added links in their value chain through business activities such as design, research and development, and marketing and to outsource nonadvantageous service-oriented businesses, thereby reducing overall enterprise costs (Amiti and Wei, 2009). This improves enterprise financial constraints and is conducive to more green investment, hence strengthening the enterprise pollution treatment capacity. Furthermore, servitization brings about a change in the enterprise business philosophy, with a natural inclination toward cleaner and more intangible development of commodity structures (Beuren et al., 2013). Nonmaterial products represented by high-quality service goods gradually replace some traditional material goods supply and they become the focus of enterprise business, thus helping reduce the enterprise dependence on traditional fossil energy and improve energy input intensity. Based on the above arguments, this article proposes the following hypothesis:

H1: Servitization can effectively reduce the pollution emission intensity of Chinese manufacturing export enterprises.

The impact of the phase wise servitization upgradinFg process on manufacturing export enterprises varies and may have different effects on pollution reduction at different stages. In the initial stage of servitization, the phased and inefficient expansion of service input factors may result in increased pollution emissions by manufacturing enterprises. As enterprises tilt toward servitization by sacrificing some of their comparative advantage, they may enter a "painful period" of transformation. This "painful period" determines the low-end nature of service input factors and leads to resource wastage. In fact, the initial stage of servitization input during transformation may worsen the financial situation of enterprises, affect their value and performance and garner limited positive effects (Suarez et al., 2013). Instead, it may lead to the "service-oriented dilemma" of escalating production costs and competitive pressure (Fang et al., 2008), making it difficult for enterprises to consider green pollution reduction and even potentially increasing their pollution emissions. However, when manufacturing servitization reaches a certain stage of development, enterprises can synergistically enhance efficiency through the optimization of input structures, changes in management concepts, and other factors, allowing the clean attributes of service-oriented manufacturing to be fully demonstrated and thereby highlighting the role of manufacturing servitization in the pollution reduction of enterprises. Therefore, based on the above arguments, this article proposes the following hypothesis:

H2: Servitization of manufacturing has a "U-shaped" feature of phased impact on pollution reduction for enterprises; that is, in the initial stage of servitization, it may cause an increase in pollution emissions for enterprises, and only when the degree of servitization crosses a certain threshold will it show a pollution reduction effect.

Due to the existence of stickiness between participants, relationships have become a prominent feature of GVC activities (Antràs, 2020). As important organizers and participants in GVCs (Wang et al., 2021), multinational corporations are a key carrier of factors crossing borders, such as investment and international trade, and naturally they become one of the core nodes of relationship-based GVCs. First, strengthening the production linkage between multinational corporations and local enterprises within the host country can directly generate environmental benefits (Bao et al., 2011; Repkine and Min, 2020). The existence of the "pollution halo" effect has been repeatedly confirmed in the research on China's business environment. Whether it is the direct impact of environmental regulation and standard setting or the indirect spillover of management concepts and advanced technology, multinational corporations often play a positive role in suppressing pollution emissions. Second, multinational corporations can effectively drive the improvement of local enterprise servitization degree. Multinational corporations often have modern management concepts needed for servitization, and they are typically the core carriers of high-end service elements. They are more inclined to become providers of ideal elements for enterprise investment in servitization and can play a positive role in promoting enterprise servitization. Third, multinational corporations can promote domestic enterprise technological innovation. Strengthening innovation is one of China's important goals in promoting outward opening. Through either FDI (Blomström and Sjöholm, 1999), OFDI (Luo et al., 2021), or trade activities (Grossman and Helpman, 1990), there are significant technology spillover effects that can promote technological innovation in manufacturing enterprises. Through multiple channels of positive effects, multinational corporations can effectively strengthen the pollution reduction effects brought about by the servitization of manufacturing enterprises. Given with the latest international trade measurement framework proposed by Wang et al. (2021), which is based on the value-added perspective and its classification of industry-level relationship-based GVC activities into "domestic-foreign," "foreign-domestic," and "foreign-foreign," we can measure the production activity linkage between multinational corporations and local enterprises in the industry and further consider the impact mechanism of multinational corporations on enterprise manufacturing servitization[5]. Therefore, this article proposes the following third hypothesis:

H3: The "domestic foreign" type GVC activities and the "foreign domestic" type GVC activities that characterize the association between multinational corporations and local enterprises in the industry have a moderating effect on the impact of manufacturing enterprise servitization on pollution reduction.

[5] In the mechanism verification section, this article explores the impact of multinational corporations GVC activities on the scale of industry distribution and its effect on manufacturing export enterprise servitization pollution reduction. The heterogeneous analysis in Part 5, Category 3 is based on panel data from different types of companies, specifically foreign-owned enterprises, and other enterprises. The difference between the two lies in their research perspectives: the former focuses on the industry level, while the latter focuses on the micro level of individual enterprises. In terms of data sources, the former uses the newly introduced OECD-AMNE database for calculation, while the latter directly classifies the sample heterogeneity within the panel data. Moreover, the introduction of the former aims to consider the overall impact of relationship-based GVC activities on microenterprise servitization pollution reduction, whereas the latter directly investigates the specific effects of servitization pollution reduction on microenterprises in the manufacturing industry. Overall, although the above two constructs are similar, their meanings are not the same. To avoid any ambiguity, an explanation is provided here.

3. Methodology, Index Measurement and Data

3.1 Model

This article aims to study the impact of manufacturing servitization on the pollution reduction of enterprises. The econometric model isas follows:

$$Polei_{ijtk} = \alpha_0 + \alpha_1 Servitization_{ijtk} + \beta \overline{X} + \upsilon_t + \upsilon_k + \varepsilon_{ijtk} \tag{1}$$

$$Polei_{ijtk} = \theta_0 + \theta_1 Servitization_{ijtk} + \theta_2 Servitization_{itk}^2 + \eta \overline{X} + \upsilon_t + \upsilon_k + \varepsilon_{ijtk} \tag{2}$$

In Equations (1) and (2), i, j, t and k represent enterprise, industry, year, and region, respectively. The dependent variable, $Polei$ represents the pollution emission intensity of the enterprise. Due to the widespread recognition and application of using sulfur dioxide as a representative pollutant in this field of research, sulfur dioxide emission intensity is used as a representative of pollution in this paper. The core independent variable, $Servitization$ represents the degree of manufacturing enterprises servitization, while $Servitization^2$ represents the square term of the servitization degree, and it is used to verify the nonlinear relationship between the service development degree and pollution reduction of manufacturing enterprises. $\overline{X}$ represents a set of control variables, υ_k and υ_t represent regional fixed effects and time fixed effects, respectively, and ε represents the error term.

3.2 Mechanism Validation

This article employs the following equations to conduct mechanism verification analysis:

$$Polei_{itk} = \rho_0 + \rho_1 Servitization_{ijtk} + \rho_2 MGVC_{jt} + \rho_3 Servitization_{ijtk} \times MGVC_{jt} + \mu \overline{X} + \upsilon_t + \upsilon_k + \varepsilon_{itk} \tag{3}$$

The nonlinear measurement model is as follows:

$$Polei_{itk} = \rho_0 + \rho_1 Servitization_{ijtk} + \rho_2 Servitization_{ijtk}^2 + \rho_3 MGVC_{jt} + \rho_4 Servitization_{ijtk} \times MGVC_{jt} + \rho_5 Servitization_{ijtk}^2 \times MGVC_{jt} + \mu \overline{X} + \upsilon_t + \upsilon_k + \varepsilon_{itk} \tag{4}$$

where $MGVC$ represents three relational multinational corporate GVC activity degree indicators. The value added created using three relational value chains as a proportion of the total value added created in its industry that year is expressed in this specification. Specifically, it includes the "domestic-foreign" type of GVC activity degree ($dom-for\_type$), that is, the proportion of value added contributed by domestic enterprises constitutes upstream value providers and multinational corporations represent downstream producers of goods in the GVC activities; the "foreign-domestic" type of GVC activity degree ($for-dom\_type$), that is, the proportion of value added contributed by multinational corporations represents upstream value providers and domestic enterprises represent downstream producers of goods in the GVC activities; and the "foreign-foreign" type of GVC activity degree ($for-for\_type$), that is, the proportion of value added contributed by multinational corporations represents upstream value providers and multinational corporations represent downstream producers of goods in the GVC activities. The specific identification steps are elaborated in detail in the appendix. $servitization \times struc\_GVC$ and $Servitization^2 \times Struc\_GVC$ are cross terms between the manufacturing industry's degree of servitization and various relational value chain activity degrees in the industry. Other items have the same meaning as the baseline regression.

3.3 Variable Description

3.3.1 Enterprise Pollution Emission Intensity

The pollution emission intensity is represented by the natural logarithm of the ratio of total sulfur dioxide emissions to total industrial output value, plus one. There are two main reasons for this choice. First, sulfur dioxide (SO_2) is one of the major pollutants in the air. Excessive sulfur dioxide emissions can cause acid rain, causing significant damage to the natural environment and harmful effects on human health. "Desulfurization" and "sulfur fixation" are also essential steps in the pollution reduction process for enterprises. Second, in the China Industrial Enterprise Pollution Emission Database, sulfur dioxide emission data are relatively comprehensive with almost no data gaps, ensuring that the empirical analysis results provide a realistic state. Therefore, this paper selects sulfur dioxide emission intensity as the main measurement indicator. At the same time, in the robustness test, the enterprise wastewater and smoke and dust emission intensity are selected as alternative dependent variables.

We obtained the emission characteristics of Chinese manufacturing enterprises from the enterprise pollution emission database spanning the period 2000 to 2013. In this article, we use the indicator of pollution emission intensity to measure the degree of corporate pollution. The calculation method is described as follows (5):

$$Polei_{ijtk} = Pole_{ijtk} / Opvalue_{ijtk} \tag{5}$$

In Equation (5), i, j, t, and k represent the enterprise, industry, year, and region, respectively. *polei* represents the emission intensity of sulfur dioxide from enterprises, which in this article refers to the intensity of pollution emissions from enterprises. *Pole* represents the total amount of sulfur dioxide emitted by enterprises, which in this article refers to the total amount of pollution emissions from enterprises. *Opvalue* represents the total industrial output value of enterprises. The pollution emission intensity of enterprises is the proportion of pollution emissions to the total industrial output value, indicating the degree of pollution emissions per unit output[6].

Figure 1 shows the changes in total pollution emissions and pollution emission intensity of Chinese enterprises from 2000 to 2013. Overall, the total pollution emissions from Chinese manufacturing enterprises exhibit an "up-down-up" N-shaped trend, while the pollution emission intensity of Chinese manufacturing enterprises shows a continuous downward trend.

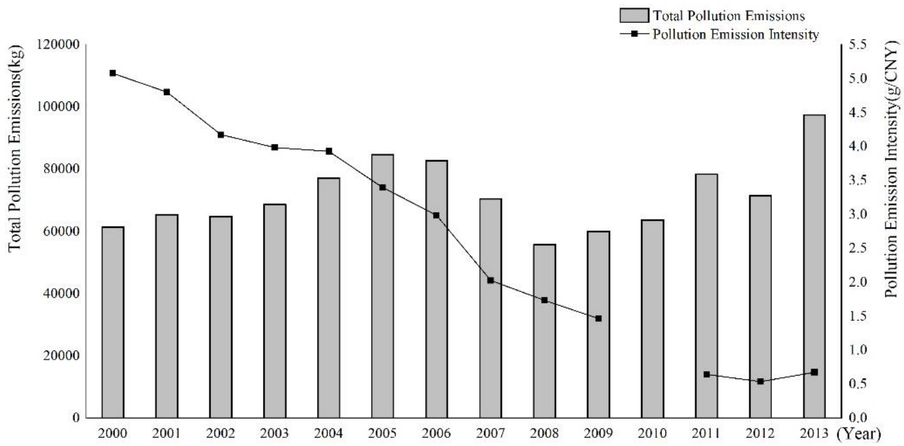

Figure 1: Pollution emission degree of manufacturing enterprises

3.3.2 Servitization Degree

Drawing on the methodology of Gao and Yuan (2020) for measuring the degree of industry servitization, this study measured the degree of manufacturing enterprise servitization based on China's interregional input–output tables, the Chinese industrial enterprise database, and the Chinese customs trade database. Furthermore, we distinguished the heterogeneity in the degree of manufacturing servitization inputs from different countries and industries, as detailed in the previous section. Traditionally, the degree of servitization of manufacturing industries has been measured using input–output analysis, characterizing an industry's direct or complete consumption coefficient for various services industries (Park, 1994; Zhao and Chen, 2021). Some studies have started to measure the degree of servitization of manufacturing industries from the perspective of value added, using the amount

[6] Due to missing and inaccurate data for the year 2010 in the enterprise pollution emission database, the quality of the data is poor and it is not possible to accurately calculate the pollution emission intensity of manufacturing enterprises for the year 2010. Therefore, some indicators for the year 2010 are missing in subsequent studies.

of service industry value added used in manufacturing production or exports to characterize the degree of servitization (Gao and Yuan, 2020). Regarding the degree of manufacturing enterprises servitization, the current research mainly selects relatively simple indicators for measurement, such as the proportion of servitization revenue in manufacturing enterprises, the structure of servitization personnel (Fang et al., 2008), and the proportion of operating service income to total enterprise income (Crozet and Milet, 2017). In fact, the method characterizing manufacturing servitization from a value-added perspective provides a foundation for expanding relevant index measurements at the enterprise level.

Gao and Yuan (2020) measured the degree of manufacturing servitization based on national interregional input–output tables, the Chinese industrial enterprise database, and the customs trade database, but unfortunately, the article did not distinguish the heterogeneity in the degree of manufacturing servitization from imports of products from different countries and industries. In the following sections, we introduce the measurement methodology for the degree of manufacturing input servitization at the enterprise level.

First, we define the degree of manufacturing input servitization as the proportion of service industry value added in exported manufacturing goods. Let the service industry value added used by enterprise i in its exported goods be denoted as SV_i. In theory, this value added can come from two sources: imported foreign service industry value added ($IMSV_i$) and domestic service industry value added (DSV_i). The former can be further divided into service industry value-added imported through general trade ($IMSV_i^O$) and service industry value-added imported through processing trade ($IMSV_i^P$). Therefore, the degree of manufacturing servitization for an enterprise (FMS_i) can be expressed as follows:

$$FMS_i = \frac{SV_i}{Export_i} = \frac{IMSV_i^O + IMSV_i^P + DSV_i}{Export_i} \tag{6}$$

In Equation (6), FMS_i represents the servitization degree of manufacturing enterprise i, while $Export_i$ represents its total exports. The reason for distinguishing between different trade modes when importing service industry value added is mainly because processing trade is usually an operational activity where an enterprise imports all parts, components, packaging materials, etc., processes or assembles them into finished products, and then re-exports them. This means that all foreign value-added imported under processing trade, including imported service industry value-added, will all be used for exports. Conversely, service industry value-added in products imported through general trade may not necessarily be fully exported, and the size of service industry value-added exports depends on how much intermediate goods are used for exporting by the enterprise. DSV_i depends on how much domestic service industry value added is used in the enterprise's export products. Both the imported foreign service industry value added and the domestic service industry value added mentioned above depend on the service industry value added rate at the product industry level.

Further refinement of the three components in Equation (6) can be expressed in following equation:

$$IMSV_i^P = \boldsymbol{\delta}^{\mathrm{T}} \times \mathbf{IMP^P} = (\delta_i^1 \quad \delta_i^2 \cdots \delta_i^{nk})^{\mathrm{T}} \times (imp_i^{1P} \quad imp_i^{2P} \cdots imp_i^{nkP}) \tag{7}$$

$$IMSV_i^O = \left[\frac{Export_i}{Sale_i}\right] * \left[\boldsymbol{\sigma}^{\mathrm{T}} \times \mathbf{IMP^O}\right] = \left[\frac{Export_i}{Sale_i}\right] * \left[(\sigma_i^1 \quad \sigma_i^2 \cdots \sigma_i^{nk})^{\mathrm{T}} \times (imp_i^{1O} \quad imp_i^{2O} \cdots imp_i^{nkO})\right] \tag{8}$$

$$DSV_i = DR_i * \left[\boldsymbol{\tau}^{\mathrm{T}} \times \mathbf{EXP}\right] = DR_i * \left[(\tau_i^1 \quad \tau_i^2 \cdots \tau_i^k)^{\mathrm{T}} \times (\exp_i^1 \quad \exp_i^2 \cdots \exp_i^k)\right] \tag{9}$$

In Equations (7)-(9), n represents the range of countries from which the enterprise imports, and k represents the industry in which the enterprise imports or the domestic industry in which the enterprise exports. Therefore, nk represents all countries and industries in the world. Parameters $\boldsymbol{\delta}$ and $\boldsymbol{\sigma}$ are vectors representing the import value-added rate of the service industry and general trade, respectively, both at the industry level, with dimensions of $[1' \ nk]$. Parameter $\boldsymbol{\tau}$ is a vector representing the increase in the value-added rate of the service industry in each domestic industry's export, with dimensions of $[1' \ k]$ at the industry level. In Equation (8), $Sale_i$ represents the total sales of enterprise i, and DR_i represents the share of domestic value added used in its exports, namely, Domestic Value Added in Export (DVAR). In Equation (7), $\mathbf{IMP^P}$ refers to the scale of imports of enterprise i from all countries and industries in the world using the processing trade form as a vector, where each element imp_i^{nkP} represents the scale of imports by enterprise i from country n and industry k using the processing trade form. Similarly, in Equation (8), $\mathbf{IMP^O}$ refers to the scale of imports of enterprise i from all countries and industries in the world using the general trade form, where each element imp_i^{nkO} represents the scale of imports by enterprise i from country n and industry k using the general trade form. $\mathbf{EXP}$ in Equation (8) refers to the export scale of enterprise i in each domestic industry, where each element $\exp_i^k$ represents the export of enterprise i in industry k. The basic logic of Equations (7)-(9) is that the increase in value added of the service industry in manufacturing enterprises' imports and exports is equal to the weighted average of the manufacturing service degree of each product level according to the import and export product structure of the enterprise.

The following describes how to calculate the value-added ratio of the service industry in exports at the industry level for various countries around the world, namely, δ_i^{nk}, σ_i^{nk}, and τ_i^k. This article uses Wang et al.'s (2017) method to measure from the perspective of value-added decomposition, focusing on the value-added ratio of the service industry in exports in various industries. An example is given of two countries and two industries, assuming the existence of two countries, the home country (h country) and foreign country (g country), each with a manufacturing industry (m industry) and a service industry (s industry). According to the classical input–output model, the following input–output relationship equation exists:

$$\mathbf{X} = \mathbf{AX} + \mathbf{Y} = (\mathbf{I}\text{-}\mathbf{A})^{-1}\mathbf{Y} = \mathbf{BY} \tag{10}$$

In Equation (5), $\mathbf{A}$ represents the intermediate input matrix, $\mathbf{B}$ represents the Leontief inverse matrix, and $\mathbf{Y}$ represents the final demand column vector. At this point, the value-added vector can be represented as the value added induced by final demand, namely, $\mathbf{VBY}$. This article rewrites $\mathbf{VBY}$ in matrix form as follows:

$$\mathbf{VBY} = \begin{bmatrix} v_h^m & 0 & 0 & 0 \\ 0 & v_h^s & 0 & 0 \\ 0 & 0 & v_g^m & 0 \\ 0 & 0 & 0 & v_g^s \end{bmatrix} \times \begin{bmatrix} b_{hh}^{mm} & b_{hh}^{ms} & b_{hg}^{mm} & b_{hg}^{ms} \\ b_{hh}^{sm} & b_{hh}^{ss} & b_{hg}^{sm} & b_{hg}^{ss} \\ b_{gh}^{mm} & b_{gh}^{ms} & b_{gg}^{mm} & b_{gg}^{ms} \\ b_{gh}^{sm} & b_{gh}^{ss} & b_{gg}^{sm} & b_{gg}^{ss} \end{bmatrix} \times \begin{bmatrix} y_h^m \\ y_h^s \\ y_g^m \\ y_g^s \end{bmatrix} \tag{11}$$

Based on Equation (6), this article only discusses the value added of the service industry in the manufacturing industry exports of the home country as an example. The y_h^m in Equation (6) is adjusted to the export e_h^m of industry m in the home country (h country), and other countries' and industries' exports that are not considered are adjusted to 0, resulting in the following Equation (12):

$$\mathbf{VBE}_h^m = \begin{bmatrix} v_h^m & 0 & 0 & 0 \\ 0 & v_h^s & 0 & 0 \\ 0 & 0 & v_g^m & 0 \\ 0 & 0 & 0 & v_g^s \end{bmatrix} \times \begin{bmatrix} b_{hh}^{mm} & b_{hh}^{ms} & b_{hg}^{mm} & b_{hg}^{ms} \\ b_{hh}^{sm} & b_{hh}^{ss} & b_{hg}^{sm} & b_{hg}^{ss} \\ b_{gh}^{mm} & b_{gh}^{ms} & b_{gg}^{mm} & b_{gg}^{ms} \\ b_{gh}^{sm} & b_{gh}^{ss} & b_{gg}^{sm} & b_{gg}^{ss} \end{bmatrix} \times \begin{bmatrix} e_h^m \\ 0 \\ 0 \\ 0 \end{bmatrix} \tag{12}$$

Equation (12) produces a column vector containing four factors:

$$\mathbf{VBE}_h^m = [v_h^m b_{hh}^{mm} e_h^m \quad v_h^s b_{hh}^{sm} e_h^m \quad v_g^m b_{gh}^{mm} e_h^m \quad v_g^s b_{gh}^{sm} e_h^m]^T \tag{13}$$

In Equation (13), the first to fourth parts represent the value added of the home country's manufacturing industry caused by exports in the home country's manufacturing industry, the value added of the home country's service industry caused by exports in the home country's manufacturing industry, the value added of the foreign manufacturing industry caused by exports in the home country's manufacturing industry, and the value added of the foreign service industry caused by exports in the home country's manufacturing industry, respectively. $v_h^s b_{hh}^{sm} e_h^m$

represents the desired value added of the home country's service industry at the manufacturing industry level in exports in this article. Therefore, the value-added ratio of the home country's service industry in manufacturing industry exports is represented by $SVAR_h^m = v_h^s b_{hh}^{sm} e_h^m / e_h^m$. The elements in vectors $\boldsymbol{\delta}^{\mathrm{T}}$, $\boldsymbol{\sigma}^{\mathrm{T}}$ and $\boldsymbol{\tau}^{\mathrm{T}}$ in Equations (7)-(9) are derived from the $SVAR_h^m$ measurements conducted across various industries and countries[7].

Certainly, in Equation (9), it is necessary to measure the DVAR of the enterprise, or DR_i. The measurement method for DR_i is relatively mature, and this article will not go into detail about it. Kee and Tang (2016) as well as Tang and Zhang (2018) methods were used to measure DR_i in this paper.

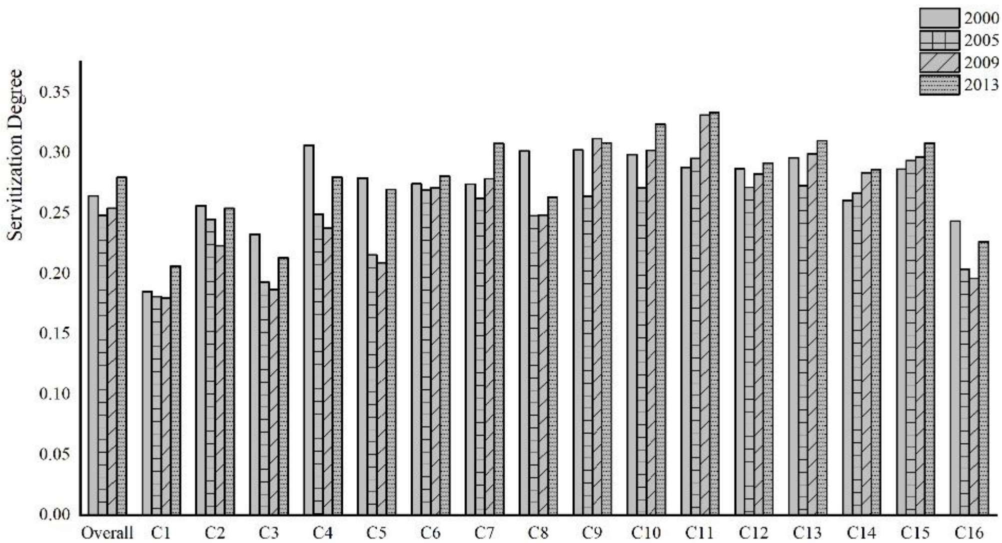

Figure 2: The overall degree of servitization for manufacturing enterprises[8]

[7] This article uses data from the WIOD database to calculate the value-added ratio of the domestic service sector in exports of 18 manufacturing industries in 43 countries (regions) (including rest of the world) from 2000 to 2015. In fact, the WIOD database can only calculate data from 2000 to 2014, and the data for 2015 in this article was calculated by matching the OECD-ICIO database with the WIOD database.

[8] This article classifies and organizes the industry codes of enterprises in the industrial enterprise database according to the ISIC Rev4.0 industry codes, forming 16 major industry categories, including: Food, beverages and tobacco (C1); Textiles, wearing apparel, leather and related products (C2); Wood and wood products (C3); Paper and paper products; printing and reproduction of recorded media (C4); Coke and refined petroleum products (C5); Chemicals and pharmaceutical products (C6); Rubber and plastics products (C7); Other nonmetallic mineral products (C8); Basic metals (C9); Fabricated metal products (C10); Computer, electronic and optical products (C11); Electrical equipment (C12); Machinery and equipment (C13); Motor vehicles, trailers and semitrailers (C14); Other transport equipment (C15); Other manufacturing and repair and installation of machinery and equipment (C16).

Based on the above method, we obtained specific data on the degree of servitization for manufacturing enterprises between 2000 and 2013. Figure 2 shows the overall servitization degree for manufacturing export enterprises in selected years, indicating an upward trend for China's manufacturing enterprises. Labor-intensive industries such as food, beverages, and tobacco (C1), wood and its products (C3), and other repair and installation services for machinery and equipment (C16) exhibit a relatively low degree of servitization. Conversely, capital-intensive or technology-intensive industries such as basic metal products (C9), metal products (C10), computers, electronic and optical equipment (C11), machinery (C13) and other transportation equipment (C15) have a relatively high degree of servitization.

3.3.3 Control Variables

The control variables selected in this article at the enterprise level include enterprise size ($Size$), which is obtained by taking the logarithm of the number of employees at the end of the year; enterprise age (Age), which is obtained by taking the logarithm of the difference between the data collection year and the year the enterprise was established; per capita capital stock (Cap), which is obtained by taking the logarithm of the ratio between capital stock and employment; profitability (Prf), which is obtained by calculating the ratio of profits to main business income; debt-to-asset ratio ($Alration$), which is obtained by calculating the proportion of total debt to total assets; and return on capital ($Return$), which is obtained by taking the logarithm of the ratio of total profit to actual capital. At the industry level, this article uses industry size ($Industrysize$) as a control variable and represents it by adding up and taking the logarithm of the industrial output value of enterprises at the industry level. At the regional level, the level of urbanization ($City$) is used as an instrumental variable.

3.4 Data Sources

The main data sources used in this paper are the China Industrial Enterprise Database, China Industrial Enterprise Pollutant Emission Database, China Customs Import and Export Database, OECD-AMNE Database and China Province Statistical Yearbook. The sample period is 2000 to 2013. Based on the information of enterprise name, region and industry, the databases are matched. Finally, panel data with 58,995 observations used in the empirical study of this paper are obtained from millions of original data records. Due to incomplete data and poor data quality in 2010, to ensure the reliability of the empirical analysis, the data from 2010 are excluded from the metric analysis. Moreover, since the AMNE database only released data from 2005, the sample period is changed to 2005 to 2013 in the mechanism test part of this paper. In addition, to eliminate the interference of extreme outliers, a 1% Winsorize treatment is performed on all continuous variables in this paper.

4. Results and Discussion

4.1 Benchmark regression results

Column (1) in Table 1 presents the OLS estimate results without considering fixed effects. The coefficient of servitization is -0.1638 and it is significant at the 1% level, indicating that servitization can have a restraining effect on pollution emissions in manufacturing enterprises. Column (2) shows the regression results after controlling for time and regional effects. The coefficient of manufacturing servitization is -0.4618, and it remains significant, suggesting that servitization has a negative linear impact on the pollution emission intensity of enterprises, confirming Hypothesis 1.

Table 1: Results of benchmark regression

Variables	Linear regression		Nonlinear regression	
	(1)	(2)	(3)	(4)
Servitization	-0.1638***	-0.4618***	3.2556***	3.8639***
	(-3.04)	(-8.80)	(9.87)	(11.86)
Servitization^2			-9.2114***	-11.7039***
			(-10.53)	(-13.52)
Pol	-0.1194***	-0.1122***	-0.1194***	-0.1115***
	(-26.63)	(-25.58)	(-26.63)	(-25.41)
Cap	0.0544***	0.0396***	0.0560***	0.0412***
	(14.57)	(10.76)	(15.02)	(11.21)
Age	0.0479***	0.0361***	0.0485***	0.0366***
	(9.17)	(7.01)	(9.30)	(7.13)
Prf	-0.2387***	-0.2579***	-0.2324***	-0.2503***
	(-4.74)	(-5.19)	(-4.61)	(-5.03)
Size	-0.0171***	-0.0185***	-0.0169***	-0.0182***
	(-6.13)	(-6.61)	(-6.07)	(-6.52)
Industrysize	0.0129***	0.0745***	0.0097***	0.0747***
	(4.23)	(17.53)	(3.20)	(17.59)
City	-0.0089***	-0.0051***	-0.0088***	-0.0052***
	(-36.14)	(-2.58)	(-35.93)	(-2.65)
Alration	0.2357***	0.1808***	0.2366***	0.1812***
	(18.76)	(14.47)	(18.84)	(14.51)
Return	0.0227***	0.0223***	0.0231***	0.0222***
	(2.93)	(2.90)	(2.98)	(2.90)
Constants	0.8316***	-0.1731	0.5904***	-0.5403***
	(12.76)	(-1.00)	(8.42)	(-3.07)
Year FE	No	Yes	Yes	Yes
Regional FE	No	Yes	Yes	Yes
N	58995	58995	58995	58995
adj. R^2	0.0678	0.1128	0.0693	0.1153

*** $p<0.01$. ** $p<0.05$. * $p<0.1$.

According to the estimation results in Columns (3) and (4), the coefficients of servitization and servitization squared are significantly positive and negative, respectively, demonstrating the existence of a nonlinear relationship between the pollution reduction effect of servitization and servitization, exhibiting an "inverted U" trend. This may be due to the weak industrial foundation and strong investment dependence in the early stage of China's entry into the WTO. Although economic globalization has promoted the development of servitization of manufacturing in China, the lack of attention to environmental issues made it difficult for enterprises to achieve high-quality servitization. Additionally, insufficient input scale of service factors during the initial stage of manufacturing enterprise development or low efficiency of service factor input during the production expansion period and low quality of service factor input during the production phase can all lead to servitization having a reverse impact on pollution reduction. However, with the deepening of servitization and the improvement of the quality and scale of servitization of manufacturing inputs, positive spillover effects of manufacturing enterprise servitization have gradually emerged, such as improving production capacity utilization and energy efficiency, innovation in production processes and paradigms, enhancing value-added and RandD capabilities, reducing production costs, and enhancing international competitiveness, thereby resulting in significant positive promotion effects on pollution reduction, thus confirming Hypothesis 2.

4.2 Endogeneity

There may be endogeneity issues in the baseline regression: companies may undergo a service transformation in response to consumer environmental concerns, providing themselves with an environmentally friendly development path through the cleanliness of service elements. Thus, there may be endogeneity issues resulting from the reverse causality between corporate servitization and pollution emission intensity. This paper uses the two-stage least squares (2SLS) method to address potential endogeneity issues in the econometric model. The two instrumental variables selected are the servitization levels of the manufacturing industry in India and the United States, measured using the complete exhaustion coefficient method. The reasons for selecting these two are as follows: first, India and China, as the two largest developing countries in the world, have been compared in numerous studies in terms of population size, regional characteristics, economic conditions, development paths, etc. At the same time, China's reform and opening-up can have a significant impact on India, but India's service sector development is unlikely to affect China's corporate pollution emissions, making it a reasonable choice as an instrumental variable. Second, due to the close trade ties between the United States and China and the relative domestic manufacturing learning from the more advanced development models of the United States, the correlation between the servitization of the manufacturing industries of the two countries is relatively high. Moreover, the servitization of U.S. domestic manufacturing industry is unlikely to affect the pollution emissions of domestic enterprises, so the servitization level of the U.S. manufacturing industry is selected as the second instrumental variable. In addition, in nonlinear regression, due to the presence of two explanatory variables, servitization itself and its quadratic term, the above two instrumental variables are taken as the quadratic term of the corporate servitization level to solve the endogeneity problem in the nonlinear regression. Columns (1) and (2) of Table 2 show the regression results after addressing endogeneity in linear and nonlinear estimation, respectively. After overcoming the endogeneity problem, the direction and significance of the coefficients of the core explanatory variables in Columns (1) and (2) have not changed, confirming the robustness of the baseline regression results.

Table 2: Endogenous processing

Variables	Linear regression		Nonlinear regression	
	India	USA	India	USA
	(1)	(2)	(3)	(4)
Servitization	-4.9161***	-4.6750***	55.8663***	13.9503***
	(-26.25)	(-10.71)	(21.28)	(3.59)
Servitization^2			-154.9872***	-40.6210***
			(-23.04)	(-4.37)
Pol	-0.1124***	-0.1123***	-0.1029***	-0.1098***
	(-24.69)	(-24.78)	(-20.08)	(-24.40)
Cap	0.0581***	0.0571***	0.0648***	0.0476***
	(14.85)	(13.62)	(14.79)	(12.33)
Age	0.0428***	0.0424***	0.0453***	0.0390***
	(8.02)	(7.96)	(7.83)	(7.56)
Prf	-0.2359***	-0.2371***	-0.1515***	-0.2283***
	(-4.61)	(-4.63)	(-2.67)	(-4.52)
Size	0.0065**	0.0052	-0.0095***	-0.0141***
	(2.06)	(1.32)	(-2.67)	(-3.79)
Industrysize	0.0591***	0.0599***	0.0728***	0.0729***
	(13.29)	(12.88)	(14.14)	(16.19)
City	-0.0069***	-0.0068***	-0.0071***	-0.0057***
	(-3.39)	(-3.36)	(-3.09)	(-2.89)
Alration	0.1866***	0.1863***	0.1869***	0.1829***
	(14.26)	(14.32)	(12.58)	(14.49)
Return	0.0311***	0.0306***	0.0233**	0.0232***
	(3.84)	(3.79)	(2.51)	(2.96)
Constants	1.0232***	0.9585***	-4.7806***	-1.2864***
	(5.46)	(4.55)	(-14.69)	(-2.86)
Year FE	Yes	Yes	Yes	Yes
Regional FE	Yes	Yes	Yes	Yes
N	58995	58995	58995	58995
Kleibergen–Paap rk LM statistic	3736.24 [0.0000]	825.10 [0.0000]	1167.57 [0.0000]	584.56 [0.0000]
Kleibergen–Paap rk Wald F statistic	5475.80 {16.38}	946.43 {16.38}	731.300 {16.38}	233.52 {16.38}

The values in brackets [] indicate the p-value, and the values in brackets {} indicate the critical value at the 10% level of the Stock-Yogo test. Standard errors in parentheses.
*** p<0.01. ** p<0.05. * p<0.1.

4.3 Robustness Test

4.3.1 Change Core Dependent Variable

Manufacturing enterprises' pollution emissions encompass various forms, including gas, liquid, and solid. The benchmark regression in the article uses the emission intensity of sulfur dioxide, a gaseous pollutant, to characterize the pollution emission intensity of manufacturing enterprises. This approach is unable to reflect the pollution emissions in liquid and solid forms by manufacturing enterprises. To ensure the robustness of the empirical results, a robustness test is conducted using the method of replacing the explained variable. By calculating and conducting the regression analysis, the core explained variable is replaced with the discharge intensity of wastewater and particulate matter, and these are also sourced from the Chinese industrial enterprise pollution database. Columns (1) and (3) of Table 3 show the estimated results after replacing the core explained variable with the discharge intensity of wastewater, while Columns (2) and (4) show the estimated results after replacing the core explained variable with the discharge intensity of particulate matter. The coefficient of the servitization degree of manufacturing enterprises ($Servitization$) and its quadratic term ($Servitization^2$) in the benchmark regression remain unchanged in terms of the sign direction. Therefore, it can be concluded that manufacturing enterprise servitization has similar effects on the various forms of pollution emissions by enterprises, thus verifying the robustness of the model.

Table 3: Change core dependent variable

Variables	Linear regression		Nonlinear regression	
	Wastewater	Dust	Wastewater	Dust
	(1)	(2)	(3)	(4)
Servitization	-3.6765***	-0.0590**	11.1261***	1.3953***
	(-22.34)	(-2.54)	(11.38)	(9.96)
Servitization^2			-39.9739***	-3.9400***
			(-15.36)	(-10.56)
Pol	-0.8061***	-0.0386***	-0.8031***	-0.0384***
	(-71.86)	(-19.32)	(-71.67)	(-19.22)
Cap	0.3180***	0.0067***	0.3232***	0.0073***
	(34.19)	(4.01)	(34.76)	(4.34)
Age	0.1291***	0.0114***	0.1309***	0.0117***
	(11.02)	(4.87)	(11.20)	(4.96)
Prf	-0.9873***	-0.1038***	-0.9617***	-0.1012***
	(-9.50)	(-4.63)	(-9.23)	(-4.52)
Size	-0.1191***	-0.0114***	-0.1179***	-0.0113***
	(-15.94)	(-8.96)	(-15.82)	(-8.87)
Industrysize	0.5744***	0.0138***	0.5747***	0.0137***
	(42.71)	(6.93)	(42.69)	(6.93)
City	-0.0218***	0.0003	-0.0220***	0.0002
	(-4.50)	(0.30)	(-4.56)	(0.25)
Alration	0.5449***	0.0625***	0.5486***	0.0626***
	(15.69)	(11.30)	(15.82)	(11.34)
Return	0.1204***	0.0045	0.1200***	0.0045
	(5.01)	(1.25)	(5.00)	(1.24)
Constants	-6.5930***	0.0667	-7.8699***	-0.0550
	(-14.25)	(0.82)	(-16.76)	(-0.66)
Year FE	Yes	Yes	Yes	Yes
Regional FE	Yes	Yes	Yes	Yes
N	53180	55621	53180	55621
adj. R^2	0.2226	0.1329	0.2261	0.1343

*** $p<0.01$. ** $p<0.05$. * $p<0.1$.

4.3.2 Add Control Variables

Improving the business environment will be more conducive to green economic growth. The improvement of such an environment is bound to be achieved through enterprises as market entities. There is a certain correlation between the regional business environment and the degree of pollution discharged by enterprises. To ensure the robustness of the conclusion of this paper, the business environment (Env) is added as a control variable to the regression equation. Drawing on the method of Yao and Wei (2007), this paper includes general budget expenditures of local finance, regional GDP, main business taxes and surcharges of industrial enterprises above a designated size, total profits of industrial enterprises above a designated size, government intervention and corporate tax burden as evaluation indicators for the business environment. Accordingly, the business environment index for 31 provinces, municipalities, and autonomous regions in China from 2000 to 2013 was obtained. Columns (1) and (2) in Table 4 show the regression results with the business environment added as a control variable. The coefficient for enterprise servitization is -0.4629 and it is still significant at the 1% level, thus verifying the robustness of the benchmark regression results. Meanwhile, the coefficient for the business environment is -0.0262 and it is significant at the 10% level. The direction of the coefficient in the nonlinear regression is consistent with that of the benchmark regression, further confirming the robustness of the nonlinear benchmark regression.

Table 4: Add control variables

Variables	Linear regression	Nonlinear regression
	(1)	(2)
Servitization	-0.4629***	3.8625***
	(-8.82)	(11.85)
Servitization^2		-11.7035***
		(-13.52)
Env	-0.0262*	-0.0261*
	(-1.75)	(-1.74)
Pol	-0.1121***	-0.1114***
	(-25.55)	(-25.38)
Cap	0.0395***	0.0411***
	(10.75)	(11.20)
Age	0.0359***	0.0365***
	(6.98)	(7.11)
Prf	-0.2572***	-0.2495***
	(-5.17)	(-5.02)
Size	-0.0185***	-0.0183***
	(-6.63)	(-6.54)
Industrysize	0.0746***	0.0747***
	(17.54)	(17.60)
City	-0.0036*	-0.0037*
	(-1.73)	(-1.79)
Alration	0.1809***	0.1812***
	(14.47)	(14.51)
Return	0.0226***	0.0225***
	(2.94)	(2.94)
Constants	-0.2946	-0.6617***
	(-1.61)	(-3.57)
Year FE	Yes	Yes
Regional FE	Yes	Yes
N	58995	58995
adj. R^2	0.1128	0.1153

*** p<0.01. ** p<0.05. * p<0.1.

4.3.3 Distinguishing Time Periods

With the global financial crisis in 2008, financial difficulties forced multinational corporations to scale back their operations. The breadth and depth of international economic cooperation suffered a severe blow, and factor investment and commodity trade were significantly affected. Therefore, the sample period was divided into two subperiods: 2000-2007 and 2008-2013 (excluding 2010) for re-estimation. The results are shown in Columns (1) and (3) as well as (2) and (4) of Table 5, representing the estimation results before and after 2008, respectively. Columns (1) and (2) show that regardless of whether it was before or after the financial crisis, the coefficient of manufacturing enterprise servitization remained significantly negative, with larger estimates after 2008 at -0.2844 and -0.5719, respectively, both significant at the 1% level. This indicates that the linear regression conclusion remains robust when considering the event of the financial crisis, and the overall effect of manufacturing enterprise servitization on pollution reduction and control is stronger after the outbreak of the financial crisis. Columns (3) and (4) show that the sign of the coefficient in the nonlinear regression remains unchanged after the sample is reduced, with greater numerical values after 2008. This can prove that the nonlinear relationship between manufacturing enterprise servitization and pollution reduction and control remains robust after experiencing the global economic crisis, with a more pronounced "inverted U-shaped" trend change after the financial crisis.

Table 5: Distinguishing time periods

Variables	Linear regression		Nonlinear regression	
	Before 2008	After 2008	Before 2008	After 2008
	(1)	(2)	(3)	(4)
Servitization	-0.2844***	-0.5719***	3.7940***	4.1416***
	(-3.04)	(-10.32)	(6.39)	(11.51)
Servitization^2			-10.7161***	-13.0867***
			(-7.01)	(-13.68)
Pol	-0.1390***	-0.0905***	-0.1380***	-0.0899***
	(-18.67)	(-17.28)	(-18.53)	(-17.17)
Cap	0.0409***	0.0373***	0.0422***	0.0393***
	(6.59)	(8.50)	(6.80)	(8.94)
Age	0.0424***	0.0123**	0.0431***	0.0123**
	(5.60)	(1.98)	(5.70)	(1.99)
Prf	-0.1950***	-0.2610***	-0.1854**	-0.2539***
	(-2.66)	(-3.82)	(-2.53)	(-3.72)
Size	-0.0157***	-0.0257***	-0.0162***	-0.0244***
	(-3.44)	(-8.10)	(-3.53)	(-7.71)
Industrysize	0.1127***	0.0366***	0.1111***	0.0389***
	(15.67)	(7.87)	(15.50)	(8.37)
City	0.0056	-0.0040	0.0052	-0.0036
	(1.48)	(-1.31)	(1.38)	(-1.18)
Alration	0.1844***	0.1686***	0.1858***	0.1690***
	(8.13)	(12.05)	(8.19)	(12.10)
Return	0.0095	0.0185**	0.0082	0.0189**
	(0.64)	(2.04)	(0.56)	(2.09)
Constants	-1.7079***	0.1571	-2.0136***	-0.3450
	(-5.22)	(0.52)	(-6.07)	(-1.13)
Year FE	Yes	Yes	Yes	Yes
Regional FE	Yes	Yes	Yes	Yes
N	27151	31844	27151	31844
adj. R^2	0.1240	0.0860	0.1254	0.0909

*** p<0.01. ** p<0.05. * p<0.1.

4.4 Heterogeneity Analysis

4.4.1 Analysis of Regional Heterogeneity

The development of manufacturing enterprises is influenced by the pollution reduction policies and economic development degree of their respective regions. Columns (1), (2), and (3) of Table 6 group the sample enterprises based on their location in the eastern, central, or western regions of China for estimation. The results show that investment in servitization by manufacturing enterprises in the eastern and western regions has a significant negative impact on their pollution emissions intensity. The strongest pollution reduction effect is observed in the western region, while there is also a negative impact in the central region, but it is not significant. This is perhaps because the overall economic development degree is higher in the eastern region, with larger enterprise sizes, leading to a more significant pollution reduction effect from servitization behavior (Zong and Gu, 2022). In contrast, the environmental regulation in the central region is relatively relaxed, and the overall degree of servitization development by enterprises is limited, resulting in a limited positive effect, explaining the insignificant pollution reduction effect. In the western region, enterprises have a stronger "latecomer advantage" due to their lagging economic development degree. Therefore, servitization can bring higher marginal benefits, resulting in a more significant pollution reduction effect. Columns (4), (5), and (6) show that the servitization behavior of enterprises in the eastern, central, and western regions all exhibit an "inverted U-shaped" trend in pollution emissions intensity. The steepness of this inverted U-shaped trend is the most pronounced in the western region, followed by the central region and the eastern region based on coefficient analysis.

Table 6: Analysis of regional heterogeneity

Variables	Linear regression			Nonlinear regression		
	East	Central	West	East	Central	West
	(1)	(2)	(3)	(4)	(5)	(6)
Servitization	-0.4857***	-0.3273	-0.7094**	3.5570***	4.0789***	7.4790***
	(-9.60)	(-1.41)	(-2.22)	(11.28)	(2.98)	(3.35)
Servitization ^{2}				-10.8760***	-12.2065***	-23.0359***
				(-12.99)	(-3.21)	(-3.80)
Pol	-0.0882***	-0.2052***	-0.2334***	-0.0872***	-0.2058***	-0.2389***
	(-20.50)	(-11.76)	(-8.31)	(-20.24)	(-11.79)	(-8.46)
Cap	0.0284***	0.0896***	0.0765***	0.0297***	0.0922***	0.0835***
	(7.84)	(6.11)	(3.42)	(8.18)	(6.27)	(3.71)
Age	0.0301***	0.0420**	0.0273	0.0304***	0.0437**	0.0298
	(5.80)	(2.21)	(1.17)	(5.88)	(2.30)	(1.29)
Prf	-0.1769***	-0.6918***	-0.3595	-0.1689***	-0.6909***	-0.3497
	(-3.64)	(-3.41)	(-1.35)	(-3.47)	(-3.41)	(-1.32)
Size	-0.0259***	-0.0081	0.0127	-0.0256***	-0.0081	0.0114
	(-9.84)	(-0.71)	(0.74)	(-9.74)	(-0.71)	(0.66)
Industrysize	0.0503***	0.1684***	0.2891***	0.0510***	0.1666***	0.2785***
	(12.25)	(8.76)	(10.05)	(12.44)	(8.68)	(9.71)
City	-0.0046**	-0.0142*	0.0255	-0.0047**	-0.0149*	0.0262
	(-2.45)	(-1.79)	(1.50)	(-2.49)	(-1.88)	(1.53)
Alration	0.1661***	0.1042**	0.4119***	0.1665***	0.1061**	0.4165***
	(13.55)	(2.08)	(4.48)	(13.59)	(2.12)	(4.54)
Return	0.0072	0.1039***	0.0156	0.0063	0.1082***	0.0211
	(0.95)	(3.37)	(0.34)	(0.84)	(3.51)	(0.47)
Constants	0.2299	-1.2174**	-5.3171***	-0.1327	-1.5229***	-5.7684***
	(1.38)	(-2.18)	(-6.49)	(-0.78)	(-2.68)	(-6.95)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Regional FE	Yes	Yes	Yes	Yes	Yes	Yes
N	49486	6298	3211	49486	6298	3211
adj. R^2	0.0841	0.1336	0.1433	0.0870	0.1348	0.1474

*** p<0.01. ** p<0.05. * p<0.1.

4.4.2 Analysis of Industry Heterogeneity

Following the research methodology of Busse (2004), paper and printing (C4), chemicals and pharmaceuticals (C6), other nonmetallic mineral products (C8), and metal products (C10) are classified as pollution-intensive industries, while other industries are classified as nonpolluting-intensive enterprises. Through classification analysis, the pollution reduction effect of servitization on enterprises in different pollution-intensive industries was measured. The linear regression results for pollution-intensive and nonpolluting-intensive enterprises are shown in Columns (1) and (2) of Table 7, respectively. Both coefficients are significantly negative, with the coefficient for nonpolluting-intensive enterprises (-0.5502) being greater than that for pollution-intensive enterprises (-0.5186). This indicates that servitization can bring relatively stronger pollution reduction effects to nonpolluting-intensive enterprises. Columns (3) and (4) show the nonlinear estimation results for both types of enterprises. The sign of the independent variable coefficient remains unchanged, indicating that the trend of servitization's pollution reduction effect for both pollution-intensive and nonpolluting-intensive enterprises follows an "inverted U-shaped" trend. However, the coefficient for pollution-intensive enterprises is relatively larger, and the inverted U-shaped trend is more pronounced.

Table 7: Analysis of industry heterogeneity

Variables	Linear regression		Nonlinear regression	
	Pollution intensive	Non pollution intensive	Pollution intensive	Non pollution intensive
	(1)	(2)	(3)	(4)
Servitization	-0.5186***	-0.5502***	4.6389***	3.8882***
	(-3.89)	(-11.14)	(5.69)	(12.46)
Servitization^2			-14.1515***	-11.9474***
			(-6.39)	(-14.46)
Pol	-0.1955***	-0.0848***	-0.1971***	-0.0831***
	(-18.47)	(-19.44)	(-18.63)	(-19.03)
Cap	0.0567***	0.0233***	0.0603***	0.0243***
	(6.80)	(6.31)	(7.21)	(6.59)
Age	0.0611***	0.0183***	0.0623***	0.0188***
	(5.32)	(3.60)	(5.43)	(3.71)
Prf	-0.3734***	-0.2525***	-0.3712***	-0.2416***
	(-3.63)	(-4.81)	(-3.61)	(-4.60)
Size	0.0380***	-0.0232***	0.0379***	-0.0230***
	(5.05)	(-8.70)	(5.04)	(-8.66)
Industrysize	0.1430***	0.0612***	0.1386***	0.0621***
	(12.12)	(14.84)	(11.76)	(15.10)
City	-0.0194***	0.0052**	-0.0190***	0.0050**
	(-4.79)	(2.56)	(-4.69)	2.45)
Alration	0.3028***	0.1180***	0.3033***	0.1181***
	(10.42)	(9.60)	(10.44)	(9.62)
Return	0.0143	0.0150*	0.0167	0.0143*
	(0.83)	(1.93)	(0.97)	(1.84)
Constants	-0.2765	-0.7555***	-0.6445	-1.1486***
	(-0.70)	(-4.32)	(-1.61)	(-6.42)
Year FE	Yes	Yes	Yes	Yes
Regional FE	Yes	Yes	Yes	Yes
N	17489	41506	17489	41506
adj. R^2	0.1888	0.0912	0.1906	0.0953

*** p<0.01. ** p<0.05. * p<0.1.

4.4.3 Analysis of Ownership Heterogeneity

Due to differences in ownership, enterprises have varying degrees of pressure to reduce pollution, financial constraints, development models, and technological degrees. Therefore, the sample enterprises were grouped based on their registration type and comprehensive control situation into state-owned, private, and foreign-funded enterprises for estimation. The linear estimation results are shown in Columns (1), (2), and (3) of Table 8, with significant negative coefficients for servitization, indicating that the pollution reduction effect of servitization exists across all three types of enterprises. State-owned enterprises exhibit the most pronounced effect, followed by foreign-funded enterprises, while private enterprises show the weakest pollution reduction effect. This may be due to the relatively stronger policy orientation, economic benchmarking, and social public welfare of state-owned enterprises, resulting in a greater demand for pollution reduction, and given that state-owned enterprises are generally larger in size, they exhibit significant scale effects, leading to stronger pollution reduction effects from servitization upgrades. Foreign-funded enterprises have advanced technology and management concepts, a higher servitization degree, and weaker green marginal benefits from further investment in servitization compared to state-owned enterprises. Private enterprises face market competition and financial constraints, resulting in the weakest pollution reduction effect from servitization. Columns (4), (5), and (6) reveal that the nonlinear pollution reduction effect of manufacturing enterprise servitization is only significant in foreign-funded and private enterprises, with state-owned enterprises having a coefficient conforming to the inverted U-shaped trend but not significant.

Table 8: Analysis of ownership heterogeneity

Variables	Linear regression			Nonlinear regression		
	State-owned	Foreign	Private	State-owned	Foreign	Private
	(1)	(2)	(3)	(4)	(5)	(6)
Servitization	-0.8281***	-0.4582***	-0.2208***	1.0707	2.7869***	5.7092***
	(-3.23)	(-7.84)	(-2.63)	(0.61)	(7.23)	(10.68)
Servitization²				-4.9929	-8.5414***	-16.7964***
				(-1.11)	(-8.63)	(-11.12)
Pol	-0.1588***	-0.0881***	-0.1547***	-0.1598***	-0.0869***	-0.1544***
	(-9.00)	(-17.46)	(-18.67)	(-9.06)	(-17.24)	(-18.65)
Cap	0.1053***	0.0338***	0.0663***	0.1062***	0.0344***	0.0680***
	(6.29)	(7.76)	(9.40)	(6.35)	(7.91)	(9.66)
Age	0.0528***	0.0027	0.0056	0.0532***	0.0025	0.0089
	(3.59)	(0.37)	(0.71)	(3.62)	(0.34)	(1.14)
Prf	-0.7829***	-0.0708	-0.6316***	-0.7826***	-0.0644	-0.6077***
	(-3.96)	(-1.44)	(-5.35)	(-3.96)	(-1.31)	(-5.16)
Size	0.0593***	-0.0318***	-0.0375***	0.0590***	-0.0313***	-0.0385***
	(5.43)	(-10.37)	(-7.64)	(5.41)	(-10.23)	(-7.83)
Industrysize	0.1633***	0.0482***	0.0644***	0.1610***	0.0493***	0.0648***
	(8.12)	(9.82)	(9.35)	(7.96)	(10.04)	(9.44)
City	0.0052	-0.0067***	-0.0054	0.0052	-0.0068***	-0.0060
	(0.91)	(-3.21)	(-1.34)	(0.90)	(-3.23)	(-1.48)
Alration	0.1171**	0.1505***	0.1543***	0.1184**	0.1508***	0.1565***
	(1.97)	(10.39)	(7.06)	(1.99)	(10.41)	(7.17)
Return	0.0947**	0.0139	0.0629***	0.0971**	0.0132	0.0622***
	(2.31)	(1.45)	(4.65)	(2.37)	(1.38)	(4.61)
Constants	-3.1157***	0.3644*	0.4924	-3.2288***	0.0541	0.0368
	(-5.07)	(1.92)	(1.45)	(-5.15)	(0.28)	(0.11)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Regional FE	Yes	Yes	Yes	Yes	Yes	Yes
N	6466	27801	24728	6466	27801	24728
adj. R^2	0.1626	0.0807	0.1241	0.1628	0.0830	0.1282

*** p<0.01. ** p<0.05. * p<0.1.

4.5 Mechanism Verification

The empirical results are shown in Table 9, where Columns (1), (2), and (3) verify the linear moderating effects of "domestic-foreign" GVC, "foreign-domestic" GVC, and "foreign-foreign" GVC activity degree on servitization's pollution reduction effect in manufacturing enterprises. The results show that the cross-term between "domestic-foreign" and "foreign-domestic" GVC activities and servitization degree is significantly negative at the 1% and 5% levels. Furthermore, the coefficient for the "domestic-foreign" GVC cross-term (-14.2982) is far greater than that for the "foreign-domestic" GVC cross-term (-4.2349), while the cross-term coefficient for "foreign-foreign" GVC and servitization degree is positive but not significant. These findings suggest that the multinational activities of multinational corporations with domestic and foreign production linkage relationships have a significant positive moderating effect on the pollution reduction effect of servitization in manufacturing enterprises. Columns (4), (5), and (6) test the nonlinear moderating effects and reveal that the first and second cross-term coefficients of "domestic-foreign" and "foreign-domestic" GVC activities are significantly positive and negative, respectively. This indicates that both types of GVC activity can significantly strengthen the nonlinear effect of servitization on pollution reduction, leading to a clear inverted U-shaped trend. This is perhaps because both types of GVC activities involve economic activities that link local enterprises with multinational corporations, reflecting the significant technology spillover effects of multinational corporations. Therefore, Hypothesis 3 of this study is confirmed.

Table 9: Mechanism verification

Variables	Linear regression			Nonlinear regression		
	D-F type	F-D type	F-F type	D-F type	F-D type	F-F type
	(1)	(2)	(3)	(4)	(5)	(6)
Servitization× dom-for_type	-14.2982***			31.3100***		
	(-8.90)			(3.03)		
Servitization× for-dom_type				-105.0138***		
				(-4.00)		
Servitization× for-for_type		-4.2349**			31.5059**	
		(-1.96)			(2.31)	
$Servitization^2$ × dom-for type					-84.3200**	
					(-2.33)	
$Servitization^2$ × for-dom type			1.5092			-31.2311***
			(1.50)			(-4.29)
$Servitization^2$ × for-for type						91.2736***
						(4.84)
Control Variable	Yes	Yes	Yes	Yes	Yes	Yes
Regional FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	45506	45506	45506	45506	45506	45506
adj. R^2	0.0955	0.0925	0.1109	0.0997	0.0980	0.1127

*** p<0.01. ** p<0.05. * p<0.1.

5. Conclusions and Policy Implications

Manufacturing servitization is an important pillar that supports China's high-quality development. It is a critical aspect of manufacturing that enhances the competitiveness of enterprises and promotes the green, service-oriented, and intelligent development of manufacturing industries. This study utilizes various databases, including the Chinese Industrial Enterprise Database, the Chinese Industrial Enterprise Pollution Emission Database, the Chinese Customs Import and Export Database, the OECD-AMNE Database, and the Provincial Statistical Yearbook of China, to measure the input of manufacturing service elements at the microlevel of enterprises to describe manufacturing servitization. The study examines the impact of manufacturing servitization on pollution reduction and explores the relevant mechanisms based on upstream and downstream relationships within the multinational production linkages of multinational corporations (GVC activities).

The research results indicate the following: (1) Overall, manufacturing servitization reduces the intensity of enterprise pollution emissions, and this effect is widespread across all types of ownership, pollution-intensive and nonpolluting-intensive enterprises, as well as eastern and western enterprises; (2) however, there is also a nonlinear "inverted U-shaped" effect of manufacturing servitization on pollution reduction, meaning that in the early stages of servitization, an increase in manufacturing service elements may lead to an increase in enterprise emissions. Only after the degree of servitization reaches a certain threshold will a significant pollution reduction effect be observed. This characteristic is particularly evident in foreign-funded and private enterprises. (3) Strengthening the domestic production linkage relationships between multinational corporations and local enterprises has a moderating effect on the pollution reduction effects of manufacturing servitization. The stronger the linkage degree is, the more significant the pollution reduction effect of manufacturing servitization.

In summary, the following insights can be drawn. First, it is necessary to continue deepening the degree of manufacturing servitization between advanced manufacturing and modern service industries, fully understand the importance of accelerating the transformation toward manufacturing servitization for China's high-quality economic development, and develop targeted development paths and roadmaps for different types of manufacturing enterprises. Policies should be implemented to promote diffusion and spillover effects, help manufacturing enterprises achieve environmentally friendly development, improve production capacity utilization efficiency and energy distribution efficiency, reduce production costs, and increase research innovation capability and international competitiveness. Second, leveraging China's objective advantages as one of the three core hubs of the global production network is important to explore the technology, brand, green and innovation spillover effects brought by the multinational flow of high-quality service elements carried by multinational corporations. Attention should be given to the significant driving role that the linkage relationship between multinational corporations and local enterprises plays in promoting the green development of manufacturing through manufacturing servitization. China should cultivate multinational corporations with international competitiveness and enhance the contribution of Chinese multinational corporations to GVC activities in trading partner countries. Third, it is essential to provide reasonable guidance for enterprises at different stages of development in terms of transformation and upgrading, strengthen policy support and technology path guidance, and minimize the negative impacts caused by low efficiency, small scale, and poor quality of service element inputs during the initial stage of transformation. At the same time, barriers in regional factor markets should be broken down, the business environment improved, and fair industrial competition policies formulated to weaken market segmentation between regions. This will optimize the layout of service element inputs and allow them to become a green engine driving the high-quality development of regional economies. Finally, state-owned enterprises should play a benchmarking role in green development and pollution reduction, as this will enhance environmental awareness among private enterprises and boost the overall pollution reduction effect of manufacturing enterprise servitization in China.

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Appendix A

Heterogeneity analysis of pollution emissions

Figure 3 shows the total amount and intensity of pollution emissions from enterprises in heterogeneous industries with varying pollution densities. We divided industries into pollution-intensive and nonpollution-intensive categories based on the classification method proposed by Busse (2004)[9]. The results indicate that both the total amount and intensity of pollution emissions from pollution-intensive industries have consistently been higher than those from nonpollution-intensive industries. However, in terms of pollution emission intensity, pollution-intensive industries saw a significant decrease from 2000-2013 and have now approached a degree similar to that of nonpollution-intensive industries in 2011-2013. This may be attributed to China's strict environmental regulations in polluting industries.

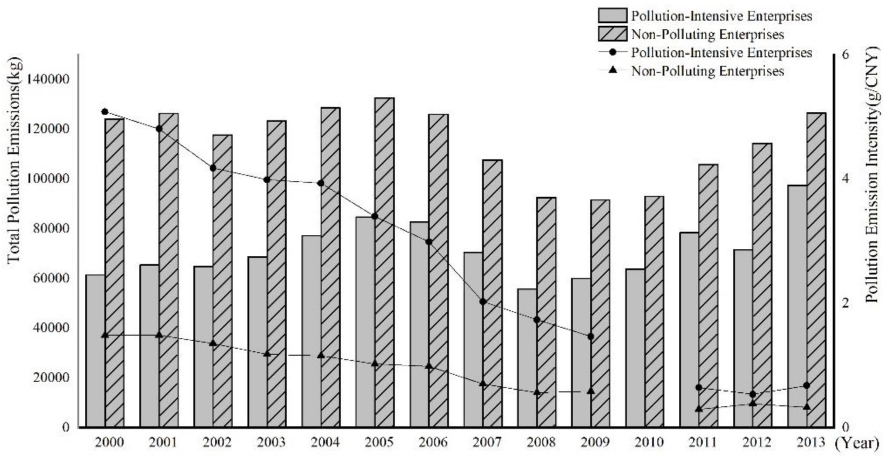

Figure 3: Pollution emission degree of heterogeneous enterprises

Figure 4 illustrates the changes in total pollution emissions and pollution emission intensity among enterprises with different ownership structures. State-owned enterprises had the highest degree of pollution emissions, considerably greater than those of foreign-funded and private enterprises. Although the pollution emission intensity was high, there was a clear downward trend. In terms of foreign-funded enterprises, both the total amount and intensity of pollution emissions were the lowest, and this may be closely related to their advanced production technology and green business philosophy. Regarding private enterprises, the overall degree of pollution emissions was not high, but the pollution emission intensity was relatively high, indicating that private enterprises have a higher cost of pollution control (Huang et al., 2023).

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9 Busse (2004) classified paper and printing (C4), chemicals and pharmaceuticals (C6), other nonmetallic mineral products (C8), and metal products (C10) as pollution-intensive industries, while all other industries were categorized as nonpollution-intensive.

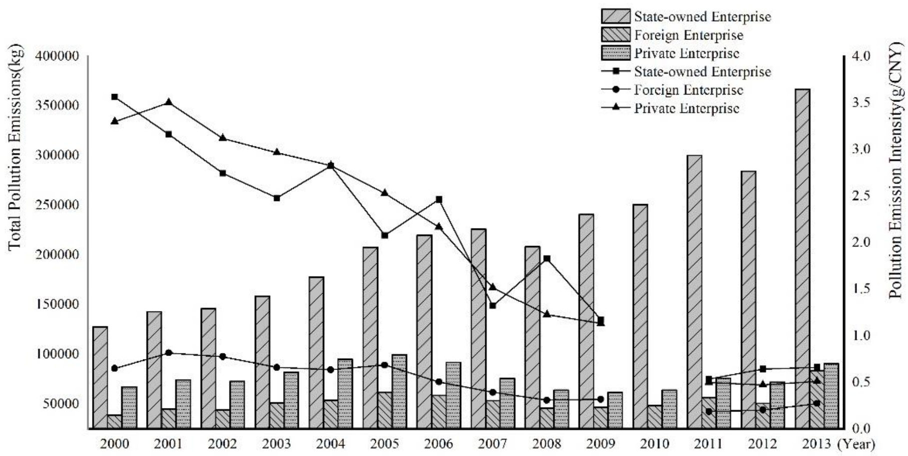

Figure 4: Pollution emission degree of enterprises with different ownership structures

Appendix B

Differentiating and measuring the GVC

As a crucial organizer and participant in the global value chain, multinational corporations serve as an important vehicle for global investment and trade and play an extremely significant role in the servitization process of domestic manufacturing enterprises. However, existing global value chain accounting frameworks based on trade and production decomposition perspectives (Koopman et al., 2014; Wang et al., 2017) overlook the global value chain activities of foreign branches (i.e., foreign-invested enterprises) of multinational corporations in host countries (Wang et al., 2021). Fortunately, the new global value chain accounting framework proposed by Wang et al. (2021) fills this gap by identifying and measuring the activities of multinational corporations. This paper applies this latest accounting framework and the latest OECD-ANME database to measure the GVC activities of multinational corporations with different types of enterprise relationships using MATLAB software based on upstream and downstream enterprise relationships.

According to the new accounting framework proposed by Wang et al. (2021), we can obtain the forward production decomposition accounting framework (14) that distinguishes between domestic-owned enterprises (D) and foreign-owned enterprises (F) with different GVC activities (for a detailed decomposition process, please refer to the original reference):

$$\hat{V}BY = \hat{V}_D L Y_D^L + \hat{V}_D L Y_D^E + \hat{V}_D L A_D^E BY$$

$$+\hat{V}_D L Y_F + \hat{V}_D L A^E B \hat{Y}_F + \hat{V}_F L Y_D + \hat{V}_F L A^E B \hat{Y}_D + \hat{V}_F L Y_F + \hat{V}_F L A^E B \hat{Y}_F \qquad (14)$$

According to the breakdown of (12) as described by Wang et al. (2021), we can see that the first three items represent value added created by pure domestic value chains ($\hat{V}_D L Y_D^L$), traditional final goods trade value chains ($\hat{V}_D L Y_D^E$), and trade-related GVCs

($\hat{V}_D LA_D^E BY$), respectively, and these are unrelated to the GVC activities of multinational corporations. The latter six items all relate to the GVC activities of multinational corporations. Based on the different roles played by multinational corporations in value chain activities, these six items can be further classified into three relationship-based value chains. The fourth ($\hat{V}_D LY_F$) and fifth ($\hat{V}_D LA^E B\hat{Y}_F$) items have domestic-owned enterprises as upstream value-added providers and foreign-owned enterprises as downstream product manufacturers, forming a "D-F" type GVC. The sixth ($\hat{V}_F LY_D$) and seventh ($\hat{V}_F LA^E B\hat{Y}_D$) items have foreign-owned enterprises as upstream value-added providers and domestic-owned enterprises as downstream product manufacturers, forming an "F-D" type GVC. The eighth ($\hat{V}_F LY_F$) and ninth ($\hat{V}_F LA^E B\hat{Y}_F$) items have both upstream value-added providers and downstream production being foreign-owned enterprises, forming an "F-F" type GVC. Therefore, this paper examines the effect of servitization pollution reduction mechanisms based on the GVC activity chains of the above three types of relationship-based multinational corporations.