Effect of Input Servitization On Carbon Emission Reduction: Evidence From China's Manufacturing Industry

Mingrui Hao
Hunan University
Yiding Tang (yd_tang@163.com)
Hunan University https://orcid.org/0000-0003-2084-9207
Shujin Zhu
Hunan University

Research Article

Keywords: manufacturing servitization, carbon emission reduction, input-output, industrial transformation

Posted Date: October 21st, 2021

DOI: https://doi.org/10.21203/rs.3.rs-880851/v1

Title page

Effect of input servitization on carbon emission reduction: evidence from china's manufacturing industry

Mingrui Hao[1], Yiding Tang[1,*], Shujin Zhu[1]

The affiliation and full address of all authors

***Corresponding author:** Yiding Tang

[1] School of Economics and Trade, Hunan University, Changsha, 410006, China.

E-mail: yd_tang@163.com

Mingrui Hao

[1] School of Economics and Trade, Hunan University, Changsha, 410006, China.

E-mail: haomingrui@hnu.edu.cn

Shujin Zhu

[1] School of Economics and Trade, Hunan University, Changsha, 410006, China.

E-mail: shujin_zhu@126.com

Effect of input servitization on carbon emission reduction: evidence from china's manufacturing industry

Abstract: As a new form of industry that integrates manufacturing and service, manufacturing servitization is not only conducive to high-quality economic development, but also has a positive effect on reducing carbon emissions. Using panel data of 30 provincial sub-sectors in China, this study systematically investigates the effect of manufacturing input servitization on carbon emission reduction. The results showed that input servitization can reduce carbon emissions. Concerning the regional heterogeneity, input servitization plays a relatively more important role in China's central region. Concerning the industrial heterogeneity, the carbon reduction effect of input servitization in pollution-intensive manufacturing sectors is greater than in non-pollution sectors. Furthermore, the mediating test demonstrates that input servitization reduces carbon emissions by improving technological innovation and optimizing the structure, while technological innovation is more effective in achieving carbon emission reduction. These conclusions show that improving the input servitization level of the manufacturing industry is feasible to coordinating the development of the manufacturing industry and the attaining the goals of China's carbon emission reduction.

Key words: manufacturing servitization; carbon emission reduction; input-output; industrial transformation

1. Introduction

The world economy is rapidly transforming from industry- to service-oriented. China is also gradually shifting from a crude development model that pursues scale and speed to a connotative development model that pursues structural optimization and environmental friendliness. Although there is a global trend toward servitization and decarbonization of the economy, many countries have not shaken off their high dependence on energy for GDP growth. For instance, China, the world's second largest economy, needs to consume large amounts of fossil energy to stimulate economic growth, in which large amounts of carbon dioxide are emitted into the environment. In the face of the increasingly serious energy situation and environmental problems, 178 nations signed the Paris Agreement in 2016, aiming to limit the increase in global average temperature to less than 2°C compared to the pre-industrial period.

China, as one of the members of the Paris Agreement, has pledged to reduce its carbon emission intensity by 60–65% by 2030 compared to 2005. The Chinese government has introduced many policies to promote energy conservation and carbon emission reduction. In the 13th Five-Year Plan, China set the goal of reducing energy consumption and carbon emissions, and in the 14th Five-Year Plan, China proposed to continuously improve environmental quality and accelerate the green transformation of its economic development. However, the actual effect of these policies on carbon emission reduction has not been satisfactory. According to the Statistical Review of World Energy 2021 published by BP, China is still the world's largest carbon emitter in 2020, contributing 30.9% of global emissions. With a high energy consumption and low efficiency development model, it is a daunting task to achieve the “double carbon” goals of carbon peak by 2030 and carbon neutrality by 2060. Therefore, overcoming the dilemma of economic growth and environmental quality improvement and finding new paths for green transformation have become urgent issues for China.

As a new form of industry that integrates manufacturing and service, manufacturing servitization is an important development model for upgrading the manufacturing industry. In the context of a global service-based economy, Vandermerwe and Rada (1988) first used the term "business servitization" in 1988, which means that enterprises no longer solely supply products, but offer the market a combined bundle or package of products and services. To meet the increasing demand of consumers and the globalization of markets, many manufacturing companies are shifting from pure manufacturing to integration of products and services (Matthyssens and Vandenbempt, 1998). Reiskin et al. (1999) further expanded the concept of manufacturing servitization by arguing that all participants in the value chain can achieve a higher value through manufacturing servitization.

Currently, most research on manufacturing servitization has focused on its economic effects. Manufacturing servitization has been found to have significant advantages in upgrading China's value chain (Liu et al., 2016) and increasing the domestic value added in exports (Xu et al., 2017). Manufacturing servitization is also seen as a sustainable business strategy at the global level (Mont, 2002). Manufacturing in Europe is shifting from production to service orientation, and servitization helps European manufacturing firms maintain and expand their competitive advantages (Lay et al., 2010). A study analyzing data from global listed companies also shows that the larger the company, the higher the possibilities of the company to increase its level of manufacturing servitization (Neely, 2008).

In recent years, scholars have found that factors such as energy structure, industrial sector (Dong et al., 2018), capital stock (Sung et al., 2018), FDI (Yang et al., 2021), urbanization (Khan and Su, 2021) and GVC (Zhu et al., 2021) influence carbon emissions. Scholars have also considered if manufacturing servitization, as an important factor closely related to the above, has environmental effects. From the perspective of input servitization, service factors are cleaner and consume lower energy than energy factors such as coal and natural gas. Therefore, by reducing the proportion of physical inputs in the production process, the energy consumption is reduced, generating a wide environmental benefit (Rothenberg, 2007). In addition, improvements in technological innovation and resource efficiency, which are derived from servitization transformation (Doni et al., 2019; Zhu et al., 2020), are also considered to have positive environmental effects to some extent.

Our contribution to the literature is as follows. First, we investigate the influence of input servitization on carbon emission reduction, covering the shortage in the current research on the environmental effects of manufacturing servitization, and provide a new perspective for advancing green development. Second, we consider the effects of technological innovation and structural optimization on carbon emission reduction due to input servitization and explore the direction and magnitude of the mediating mechanism. Third, we match the data of China's provincial industries with the WIOD database and construct three-dimensional dynamic panel data from 2003 to 2011, which provides a more reliable identification basis for the empirical study.

The remainder of the article is organized as follows: In Section 2, we analyze the status of the input servitization of manufacturing industries and carbon emissions in China. In Section 3, we present the theoretical framework and propose the hypotheses. In Section 4, we design an econometric model and describe the data source. In Section 5, we report and discuss the empirical results and conduct some tests. In Section 6, we present the conclusions and policy suggestions.

2. Status analysis of China's manufacturing servitization and carbon emissions

Before theoretically deriving and empirically testing the effect of input servitization on carbon emission reduction, this study qualitatively describes and analyzes the status of manufacturing's carbon emissions and input servitization in China during 2000-2014, showing the dynamic evolution and correlation between them.

2.1 Trends in carbon emissions of China's manufacturing industry

In previous literature, scholars have used indicators such as carbon intensity or carbon emission index to measure carbon emissions. To more intuitively show the incremental trend of carbon emissions from all manufacturing sectors in China during 2000–2014, this study uses total carbon emissions as an observation indicator, with data being obtained from the CEADs database[1]. Meanwhile, to better distinguish the regional differences in manufacturing industries' carbon emissions, this study divides the 30 provinces into four regions—eastern, central, western, and northeastern—based on the latest regional classification by the National Bureau of Statistics of China[2].

As shown in Figure 1, the total manufacturing industry's carbon emissions in China generally showed an accelerated growth trend from 2000 to 2010. There was a brief slowdown in 2005, but the wave of infrastructure development caused by the financial crisis in 2008 once again increased the total carbon emissions. The year 2011 witnessed an important inflection point in China's manufacturing carbon emissions, and the overall increase in amplitude leveled off, and the emissions stagnated at a similar level from 2011 to 2014.

---

[1] The CEADs database, supported by several institutions including the National Natural Resources Foundation of China, the Chinese Academy of Sciences, and the Newton Foundation, is jointly compiled by leading Chinese and foreign scholars. It provides an inventory of carbon emissions in China by province and industry. The data unit used in this article is metric tons (Mt).

[2] According to the standards of the National Bureau of Statistics of China, the eastern region includes 10 provinces: Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan; the central region includes 6 provinces: Shanxi, Anhui, Jiangxi, Henan, Hubei and Hunan; the western region includes 11 provinces: Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang; and the northeast region includes 3 provinces: Liaoning, Jilin and Heilongjiang. The data of Tibet, Hong Kong, Macao, and Taiwan are missing, so they are excluded from the analysis.

Examining China’s manufacturing carbon emissions data by region reveals that the four regions show roughly the same trend as the national level. The eastern region of China has the highest carbon emissions among the four regions, which is significantly higher than the other three regions, and there is a certain degree of decreasing growth rate in the eastern region from 2005 to 2009.

Before 2007, the overall manufacturing industries’ carbon emissions in the central and western regions did not differ significantly and showed a steady increase; in 2008 and the following years, the manufacturing industries’ carbon emissions in the western region became higher than those of the central region, and the gap between the two continued to widen. The central region showed an inflection point in 2011, while the western region slowed down its carbon emission growth rate in 2012. The manufacturing industry’s carbon emissions in the northeastern region, which has always been at the bottom of the list due to the small number of provinces, showed a fluctuating upward trend from 2000 to 2010, and the growth rate dropped from 2011.

To investigate the carbon emission status quo of different industries, this study selected five cross-sections of 2000, 2004, 2008, 2011, and 2014 to analyze the carbon emissions of 18 manufacturing industries [ISIC Rev.4 is the International Standard Industrial Classification. c5 is manufacture of food products, beverages and tobacco products, c6 is manufacture of textiles, wearing apparel and leather products, c7 is manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials, c8 is manufacture of paper and paper products, c9 is printing and reproduction of recorded media, c10 is manufacture of coke and refined petroleum products, c11 is manufacture of chemicals and chemical products, c12 is the manufacture of basic pharmaceutical products and pharmaceutical preparations, c13 is manufacture of rubber and plastic products, c14 is manufacture of other non-metallic mineral products, c15 is manufacture of basic metals, c16 is manufacture of fabricated metal products, except machinery and equipment, c17 is manufacture of computer, electronic and optical products, c18 is manufacture of electrical equipment, c19 is manufacture of machinery and equipment n.e.c., c20 is manufacture of motor vehicles, trailers and semi-trailers, c21 is manufacture of other transport equipment, c22 is manufacture of furniture; other manufacturing.]. As illustrated in Figure 2, there exists huge industrial heterogeneity of manufacturing carbon emission in China: c10 manufacture of coke and refined petroleum products, c11 manufacture of chemicals and chemical products, c14 manufacture of other non-metallic mineral products and c15 manufacture of basic metals emit a great amount of carbon emissions; c5 manufacture of food products, beverages and tobacco products, c6 manufacture of textiles, wearing apparel, and leather products, c8 manufacture of paper and paper products, c13 manufacture of rubber and plastic products, and c19 manufacture of machinery and equipment n.e.c. also has a considerable amount of carbon emissions; c7 manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials, c9 printing and reproduction of recorded media, c12 manufacture of basic pharmaceutical products and pharmaceutical preparations, c16 manufacture of fabricated metal products, except machinery and equipment, c17 manufacture of computer, electronic and optical products, c18 manufacture of electrical equipment, c20 manufacture of motor vehicles, trailers, and semi-trailers, c21 manufacture of other transport equipment, and c22 manufacture of furniture; other manufacturing emit a small amount of carbon dioxide.

Over time, the carbon emissions of most manufacturing industries showed an overall increasing trend during 2000–2014 and peaked in 2011, and the scale of carbon emissions shrank in 2014. Only c9 printing and reproduction of recorded media, c13 manufacture of rubber and plastic products, c14 manufacture of other non-metallic mineral products, and c15 manufacture of basic metals continue to have higher carbon emissions in 2014 than in 2011; however, the growth rate of carbon emissions in these industries has also decreased since 2011.

2.2 A realistic observation of the input servitization level of China's manufacturing industry

In the previous literature, researchers have measured the level of input servitization by the complete consumption coefficient, service elements' share in manufacturing exports, or the proportion of service revenues of micro firms. To better measure the input servitization level, we need to consider the direct consumption of service inputs and the indirect input relationships among different manufacturing sectors. Therefore, this study selects the complete consumption coefficient as the index of the input servitization level. The calculation formula of the index is as given below:

$$Servitization_{hi} = a_{hi} + \sum_{k=1}^{n} a_{hk}a_{ki} + \sum_{s=1}^{n}\sum_{k=1}^{n} a_{hs}a_{sk}a_{ki} + L \quad (1)$$

where $Servitization_{hi}$ represents the input servitization level of manufacturing sector i, a_{hi} is the direct consumption coefficient of manufacturing sector i to sector h, $\sum_{k=1}^{n} a_{hk}a_{ki}$ and $\sum_{s=1}^{n}\sum_{k=1}^{n} a_{hs}a_{sk}a_{ki}$ denote the first and second rounds of indirect consumption, respectively. Data are taken from the 2016 version of the World Input-Output Tables of the WIOD database.

Figure 3 reflects the general trend of the manufacturing input servitization level in China from 2000 to 2014. In a horizontal comparison, the overall level of China's manufacturing input servitization measured by the complete consumption coefficient is within the range of 40%–50%, which is lagging compared with the 70% level maintained in developed countries, and the overall level of China's manufacturing input servitization measured by direct consumption coefficient is around 10%–12%. The above data show that there is still potential for development in the servitization transformation of China's manufacturing industries. In the longitudinal comparison, the input servitization level of China's manufacturing industry shows a trend of fluctuating growth. From 2000 to 2004, the manufacturing servitization level revealed a remarkable decline; from 2005 to 2014, it displayed a fluctuating upward trend.

Simultaneously, manufacturing servitization appears to have large industry heterogeneity, as shown in Figure 4. Manufacturing industries such as c17, c18, c19, and c20 have a higher servitization level, most of which use capital or technology as the main production input; industries such as c5, c10, and c22, inputting labor elements in chief, generally have a lower manufacturing servitization level, differing from the industries with the highest servitization level by about 20%. Pollution-intensive industries such as c10, c14, and c15 are in the middle and lower tiers of all manufacturing industries, and the input servitization level of non-pollution manufacturing industries is also uneven and varies significantly.

3 Mechanism Analysis and Research Hypotheses

Before the empirical analysis, this study proposes two mechanisms of how input servitization in the manufacturing industry reduces carbon emissions.

3.1 Technological innovation effect

At present, China has entered the era of a service-oriented economy, with the proportion of the service industry in GDP expanding every year; in addition, the manufacturing input servitization level has been increasing. China's technological innovation at this stage has become an important carrier of the intelligent, green, and sustainable industries. Numerous studies have shown that technological innovation is the main contributor to energy efficiency improvement.

This study finds that manufacturing input servitization can reduce carbon emissions through the technological innovation effect. In the production process of traditional manufacturing industries, production and supporting services are completed by one enterprise. This mode lacks specialization, because manufacturing enterprises must balance the simultaneous development of production and service. However, service inputs such as communication technology and information management can improve the production efficiency and access to information of manufacturers; services such as finance, insurance, and law can reduce the financing cost and avoid various risks that may exist in business; warehousing, logistics, and transportation can facilitate enterprises to reduce transportation costs and extend business areas. Therefore, if external services are introduced into the manufacturers, they can focus on the core production process, strengthen their technology, thus improving energy efficiency.

Simultaneously, we note that the change in enterprises' viewpoint on servitization and the intervention of new technologies can extend the life cycle of products, reduce the defective rate, decrease energy consumption per unit of output, and eventually reduce carbon emissions. In addition, by embedding service elements, such as intellectual capital, into the production chain, manufacturing enterprises can lead service elements to expand their technological innovation advantages and generate less carbon emissions under the same energy input. The spread of Internet information technology also allows manufacturing companies to portray their customers and produce customized products or directly provide services, such as product leasing. This will improve manufacturers' inventory, avoid waste, and reduce CO_2 emissions.

According to many scholars' studies, technological innovation has spillover properties. Therefore, the linkage between manufacturing enterprises will lead to the flow of service elements from one sector to another, which improves the manufacturing level of the inflow enterprises. This will expand the coverage of technology benefits, helping the entire manufacturing industry to achieve capacity breakthroughs, bringing a triple virtuous cycle of technological innovation, profit increase, and emission reduction.

3.2 Structural optimization effect

Manufacturing input servitization must be led by the company’s decision makers, who advocate the introduction of advanced concepts, knowledge and technology, thus promoting the reorganization of the company’s production and operation. Among manufacturing firms, this will achieve a renewal of the internal organizational structure and resource allocation of the enterprise. As the service elements have demonstrated more potential for green development, along with the reduction of physical, especially energy, input proportion in the total input, the overall input servitization level of the industry, has improved and the energy consumption has been reduced, which has led to a reduction in total carbon emissions with higher technology.

This transformation and upgrading of services will lead to the concentration of service factors, and the substitution of service factors for energy factors will reduce the dependence of enterprises on energy, reduce energy consumption, and further optimize the input structure. This is a “disruptive” innovation, and this kind of production, which integrates physical and service elements, will have the effect of “1+1>2”, promoting the paradigm shift from pure physical production to a new mode with servitization input and output.

The analysis reveals that the optimization of industrial structure is based on technological innovation, but its emphasis is more on the optimization of the internal structure of the enterprise, in terms of production process, personnel structure, and so on. The technological innovation effect emphasizes reducing carbon emissions through technology, while the structural optimization effect emphasizes the improved allocation of resources and improves energy efficiency. Structural optimization will also continue to produce a virtuous circle, further introducing more service elements to improve the servitization level and ultimately synergize with technological innovation on the carbon reduction effect.

After analyzing the mechanisms by which manufacturing input servitization affects carbon emission reduction, we believe that it will have a suppressive effect on carbon emissions from two perspectives: technological innovation and structural optimization. Therefore, based on the slow growth rate of total carbon emissions in China in recent years and the overall incremental level of manufacturing's input servitization, this study proposes the following two hypotheses:

Hypothesis 1: *Controlling for other conditions, input servitization of the manufacturing industry will have a significant carbon reduction effect.*

Hypothesis 2: *Technological innovation and structural optimization resulting from manufacturing input servitization will have a dampening effect on carbon emissions, and the emission reduction intensity of the former is higher than that of the latter.*

4. Econometric model and preliminary analysis

4.1 Econometric model and data source

The following basic econometric formula is set up to investigate the impact of manufacturing input servitization on carbon emission reduction.

$$Carbon_{pit} = \alpha_0 + \alpha_1 Servitization_{it} + \gamma Control_{pit} + \mu_p + \mu_i + \mu_t + \mu_{pi} + \varepsilon_{pit} \tag{2}$$

where $Carbon_{pit}$ is the carbon emission of p province's i industry in t year, $Servitization_{it}$ denotes the input servitization level of manufacturing industry i in t year; $Control_{pit}$ represents the control variables, containing five variables that are closely related to the study; μ_p, μ_i and μ_t are the fixed effects of province, industry, and year, respectively; to better fix the industry and province, the interaction term of province and industry μ_{pi} is included in this article; ε_{pit} is the random error.

The data source and processing of two core variables, carbon emission $Carbon_{pit}$ and input servitization level of manufacturing industry $Servitization_{it}$, are described in Section 2 of this article. Meanwhile, the following core control variables are selected in this study: capital productivity kp, energy price $price$, urbanization rate $urban$, share of secondary industry is and foreign direct investment fdi; in addition, an additional control variable is selected, that is, industry size $size$. To reduce heteroskedasticity, the foreign direct investment fdi and industry size $size$ are taken as logarithms.

Capital productivity kp reflects the productivity of the manufacturing industry. Because manufacturing industries are mostly capital-intensive, we control for the effect of capital productivity on carbon emissions; the ratio of gross production to total assets for each manufacturing industry is used as a measure. The energy price $price$ is generally used to reflect the frequency of energy usage, which has a significant impact on the level of carbon emissions, measured by the ratio of the national purchasing price index of raw materials (PPIRM), which represents the cost of industrial energy use, to the product price index (PPI). The demand and structure of energy consumption and carbon emissions are influenced by urbanization. Thus, urbanization rate $urban$ is chosen as the control variable in this study, which is measured by the proportion of urban population in the total population. Some scholars believe that the secondary industry is the main driver of CO_2 emission growth. Thus, this study introduces the share of secondary industry is as a control variable to control the impact of industry structure on CO_2 emissions. Foreign direct investment is considered to have a significant spillover effect on energy intensity and promotes carbon emission reduction. Therefore, this study also includes foreign direct investment fdi as one of the control variables, which is measured by the actual amount of foreign investment used in each province in China. Industrial agglomeration will stimulate energy consumption to some extent and expand the industrial scale of the manufacturing industry, which will have a negative impact on the reduction of carbon emissions. Therefore, this study introduces an additional variable industry-scale $size$ in the robustness test to control the scale expansion effect, which is expressed as the logarithm of gross industrial production.

Limited by the availability of data, this study selected 18 manufacturing data from 30 provinces in China for nine years from 2003 to 2011 to constitute the research sample. Carbon emission data are obtained from the CEADs database, which is supported by institutions, including the Chinese National Natural Science Foundation, the Chinese Academy of Sciences, and the Newton Foundation, and is jointly compiled by renowned Chinese and foreign scholars, providing an inventory of carbon emissions by province and industry in China. The raw data of input servitization were obtained from the 2016 version input-output table of the WIOD database, and the data related to the control variables were obtained from the China Statistical Yearbook. In addition, the WIOD database adopts the international classification standard ISIC Rev. 4, which is slightly different from China's industry classification; therefore, this study successively compares China's and international industry classification standards, and finally collates 18 manufacturing industries.

4.2 Preliminary analysis

Considering the prerequisites for econometric models, we begin with some preliminary analyses, including a statistical description and a correlation test for the main variables. Table 1 presents the overall situation of the sample.

Table 2 presents the Pearson correlation coefficients. The independent variable input servitization has a significant negative correlation with the dependent variable carbon emission, with a correlation coefficient of -0.091, suggesting that multicollinearity was not an issue. This tentatively confirms the conjecture that the input servitization of the manufacturing industry reduces the carbon emissions. Capital productivity, energy price, secondary industry share, and foreign direct investment are significantly correlated with carbon emission at 1% level. The above correlation analysis reveals that input servitization may have a negative effect on carbon emissions.

5. Empirical results and analysis

5.1 Basic estimation results

Table 3 reports the results of the basic empirical regressions. Column (1) shows the results of the OLS regression considering only the independent and dependent variables, and the coefficient of input servitization $Servitization$ is -15.557, which is significant at 1% level. This indicates that every 1% increase in the input servitization level over the sample period contributes to a decrease of about 0.15 units in carbon emissions. Column (2) shows the results of the model after controlling for province, industry, and year fixed effects, when the regression coefficients of $Servitization$ increase, with no change in symbol or significance. Column (3) considers two control variables related to industry, and column (4) controls for a variety of variables at the industrial and regional levels, and the regression sign and significance are as expected. The results in column (4) show that, controlling for other variables, every 1% increase of manufacturing input servitization level in China will reduce carbon emissions by about 0.51 units, which tentatively indicates that manufacturing input servitization reduces carbon emissions. Consequently, ***Hypothesis 1*** is supported. Therefore, we believe that the service transformation of manufacturing industry will contribute to the reduction of carbon emissions in China to a greater extent and play a more active role in protecting ecology and achieving green development.

5.2 Endogeneity test and robustness test

Based on previous studies, we argue that endogeneity may exist due to reverse causality. Therefore, in column (1) of Table 4, we select a one-period lag of the independent variable, complete consumption coefficient, as the instrumental variable, and perform two-stage least squares estimation. The results are significant at 1% level, indicating that the regression results remain robust after accounting for the potential endogeneity problem.

To test the reliability of this study, in column (2), we use the direct consumption coefficient to replace the complete consumption coefficient as a measure of input servitization. The coefficient of this result is -82.003, revealing that the more a manufacturing sector directly consumes the products or services from the service sectors, the more the carbon emissions of this manufacturing sector will decrease, and each 1% increase in its servitization level will reduce the carbon emissions by 0.82 units. A possible reason for this phenomenon is that the complete consumption coefficient considers the increasing input servitization level due to linkage with other sectors. If the manufacturing sector increases the input servitization level, it will consume less energy and have a stronger emission reduction effect. In column (3), we include $size$ as an extra control variable, whose coefficient is similar to that of the basic regression with fixed effects, significant at 1% level, indicating that the results of the basic regression are robust and reliable.

5.3 Regional heterogeneity test

According to the previous literature, the servitization transformation of manufacturing enterprises has certain regional characteristics. Therefore, in this study, 30 provinces are classified into four regions, namely, eastern, central, western, and northeastern, to examine the regional heterogeneity of input servitization's carbon emission reduction effects. Table 5 shows that the coefficients and significance of $Servitization$ are consistent with the basic estimation results, indicating that the carbon reduction effect of input servitization does not change substantially depending on the region. However, by observing the coefficients, we find that the carbon reduction effect of manufacturing industry's input servitization is most significant in the central region, followed by the northeastern and western regions, and weakest in the eastern region.

The possible reasons are that the central region already has a foundation for servitization transformation, and the marginal effect of its service input is the strongest. Every time the manufacturing enterprises in the central region improve their input servitization level, they will achieve carbon emission reduction to a greater extent. The western and northeastern regions have weaker economic infrastructure, and their carbon emission reduction effect is not as obvious as that of the central region. The eastern region has been well developed, and its people and government focus on environmental protection; thus, the current manufacturing servitization level is high and the carbon emission amount is relatively small, and the marginal effect of manufacturing servitization is smaller than that of the other three regions. Thus, the effect of manufacturing input servitization on carbon emission reduction is closely related to the local economic base and degree of development.

5.4 Industrial heterogeneity test

To explore the carbon emission reduction effect of different industries, this article refers to the classification of pollution-intensive manufacturing industries by Lu (2009), and classifies c8, c9, c10, c11, c14, and c15 as pollution-intensive manufacturing industries and other industries as non-pollution industries.

The regression results show that the coefficients of pollution-intensive and non-pollution industries are both negative, indicating that input servitization can significantly reduce the carbon emissions of both types of manufacturing industries. Comparing the coefficient values, we find that the coefficient of input servitization in pollution-intensive industries is -140.866, while that of non-pollution industries is -12.435. This indicates that servitization brings a stronger carbon emission reduction effect on heavily polluting manufacturing industries and a weaker effect on lightly polluting manufacturers. A possible reason is that pollution-intensive manufacturing can more easily replace the energy inputs in production, while non-pollution manufacturing contains many labor-intensive industries, which make it more difficult to replace labor inputs in the production process. Therefore, for China, which is in a period of economic transformation and upgrading, achieving a higher level of input servitization in the pollution-intensive manufacturing sectors will have a more rapid carbon reduction effect.

5.5 Mediating effect test

In the preceding mechanism analysis, this study highlights two possible ways in which input servitization affects carbon emission reduction in manufacturing industries: the technological innovation effect and the structural optimization effect, both of which will negatively affect carbon emissions. The following mediating effect formulas are constructed to analyze the transmission mechanism of the carbon emission reduction effect of input servitization:

$$Carbon_{pit} = \alpha + \beta_1 Servitization_{it} + \gamma Control_{pit} + \mu_p + \mu_i + \mu_t + \mu_{pi} + \varepsilon_{pit} \quad (3)$$

$$M_{pit} = \varphi + \beta_2 Servitization_{it} + \gamma Control_{pit} + \mu_p + \mu_i + \mu_t + \mu_{pi} + \varepsilon_{pit} \quad (4)$$

$$Carbon_{pit} = \delta + \beta_3 Servitization_{it} + \beta_4 M_{pit} + \gamma Control_{pit} + \mu_p + \mu_i + \mu_t + \mu_{pi} + \varepsilon_{pit} \quad (5)$$

where M_{pit} is the mediating variable, that is, technological innovation and structural optimization. The measures and meanings of the two mediating variables are as follows:

(1) Technological innovation. Unlike the number of patent inventions and R&D costs, total factor productivity tfp is widely used as a measure of technological innovation. The measure of this variable draws on the approach of Xu and Wang (2016), which uses the following estimating equation to calculate the approximate figure of total factor productivity tfp:

$$tfp = \ln\left(\frac{y}{l}\right) - s * \ln\left(\frac{k}{l}\right) \quad (6)$$

where y is the industrial value added of the manufacturing industry, which is substituted by the gross industrial output due to missing data, k is the total assets of the industry, l is the average annual number of employees, and s represents the contribution of capital in the production, which is set to 1/3.

(2) Structural optimization. Capital and labor are the most important production factors in the manufacturing production process, and industries with high levels of input servitization mostly adopt intellectual capital and information technology as capital inputs. Therefore, in the process of production and operation, the intensity of capital input affects the input servitization level of the manufacturing industry. Eventually, the relevant manufacturing industries will incorporate more capital elements and reduce the demand for ordinary labor. Referring to Zhu et al. (2020), the capital-labor ratio is used to measure the degree of structural optimization. In this study, we calculated the year-on-year growth rate of tfp and $klratio$ to measure their effects on carbon emission reduction.

Table 7 reports the results of the mediating effects. Column (1) of Table 7 corresponds to equation (3) and is consistent with the results in column (4) of Table 3. Columns (2) and (3) of Table 7 demonstrate the tfp_gr results of equation (4) and (5). In column (2), the coefficient of $Servitization$ is 0.423, which is significant at 1% level, indicating that manufacturing input servitization can drive technological innovation. In column (3), the coefficient of $Servitization$ and tfp_gr are both negative, revealing that technological innovation has a mediating effect on the carbon emission reduction of manufacturing input servitization. Servitization reduces the waste of energy and improves energy efficiency through technological innovation, while the spillover effect of technology results in the servitization of one certain manufacturing industry covering more industries and pushes the transformation of manufacturing industries to servitization.

Columns (4) and (5) of Table 7 show the $klratio\_gr$ results of equations (4) and (5) when used as a mediating variable. In column (4), the coefficient of $Servitization$ is 0.229, significant at 1% level, indicating that input servitization can optimize the structure. In column (5), the coefficients of $Servitization$ and $klratio\_gr$ are both negative, indicating that structural optimization is a mediating channel for the carbon emission reduction effect of manufacturing input servitization. After the integration of manufacturing and service elements, the inclusion of intellectual capital, financial services, transportation, and information management in service products is conducive to the innovation of production patterns and personnel structure, which improves the resource allocation efficiency and thus reduces carbon emissions. The mediating effects of technological innovation and structural optimization are calculated to be -3.0401 and -2.4585, respectively, and the shares of the mediating effects in the total effect are 5.94% and 4.81%[3], respectively. Comparing

[3] Mediating effect $=\beta_2 \times \beta_4$. The weight of mediating effect in total effect $= \beta_2 \times \beta_4/\beta_1$. Comparing the coefficients' signs of $\beta_2 \times \beta_4$ and β_3, if they are consistent, it implies that there is a partial mediating effect, and we need to report the weight of the mediating effect: $\beta_2 \times \beta_4/\beta_1$.

the magnitude of the mediating effects' coefficients, we find that the coefficients in columns (3) and (5) of Table 7 are higher than those in column (1). Thus, ***Hypothesis 2*** is supported, that is, technological innovation and structural optimization resulting from manufacturing input servitization will have a dampening effect on carbon emissions, and the emission reduction intensity of the former is higher than that of the latter.

6. Conclusion and policy implications

Currently, China is under dual pressure to promote economic growth and improve its ecological environment and is chastised by countries such as the United States for carbon emission issues. Therefore, although the Chinese government is implementing stricter energy conservation and emission reduction policies at all levels, simply restricting the energy usage of manufacturing companies will have a negative impact on the economy due to the present production pattern. Input servitization, however, creates a breakthrough for reducing the manufacturing industry and even national carbon emissions from a new perspective.

The following conclusions can be drawn from the empirical analysis: The input servitization of the manufacturing industry has a significant carbon emission reduction effect, and this conclusion still holds after the endogeneity and robustness tests. Concerning the region heterogeneity, input servitization plays a more important role in China's central region than in other regions; concerning the industry heterogeneity, the carbon reduction effect of input servitization in pollution-intensive manufacturing sectors is greater than in non-pollution sectors. Simultaneously, this study finds two main ways for manufacturing input servitization to influence carbon emission reduction, namely technological innovation and structural optimization, and the effect of technological innovation on carbon emission reduction is more obvious.

This study has several policy implications, based on the above findings. First, policymakers should recognize the importance of developing manufacturing servitization to China's economic transformation, operate proper policies to promote the deep integration of the manufacturing and service industry, and eliminate administrative barriers among provinces and industries. Second, the central, western, and northeastern regions should undertake the transfer of strategic new industries in the eastern region, accept the radiation and drive of developed regions, and adopt high-end servitization strategies. Third, each manufacturing enterprise should actively participate in the construction of the government's shared industrial chain. This process reduces the financing cost and improves energy efficiency by introducing advanced technologies and adjusting their organizational structure to adapt to global markets. In this way, manufacturing enterprises can achieve a win-win relationship with both corporate and social benefits.

Authors contribution All authors contributed the conception and design of this study. The empirical work and the manuscript's first draft were performed by Mingrui Hao; The methodology guidance and software supporting were provided by Yiding Tang; The conceptualization and funding supporting were provided by Shujin Zhu. All authors read and approved the final manuscript.

Funding This work was supported by the National Natural Science Foundation of China [7217030894]; Postgraduate Scientific Research Innovation Project of Hunan Province [20210002].

Availability of data and materials The data sets supporting the results of this article are included within the article and its additional files.

Declarations

Ethics Approval Not applicable

Consent to participate Not applicable

Consent for publish Not applicable

Competing Interests The authors declare no competing interests.

References

Dong, F., Yu, B., Hadachin, T., Dai, Y., Wang, Y., Zhang, S., & Long, R. (2018). Drivers of carbon emission intensity change in China. Resources, Conservation and Recycling, 129, 187-201. https://doi:10.1016/j.resconrec.2017.10.035

Doni, F., Corvino, A., & Martini, S. B. (2019). Servitization and sustainability actions. Evidence from European manufacturing companies. Journal of environmental management, 234, 367-378. https://doi:10.1016/j.jenvman.2019.01.004

Khan, K., & Su, C. W. (2021). Urbanization and carbon emissions: a panel threshold analysis. Environmental Science and Pollution Research, 28(20), 26073-26081. https://doi:10.1007/S11356-021-12443-6

Lay, G., Copani, G., Jäger, A., & Biege, S. (2010). The relevance of service in European manufacturing industries. Journal of Service Management. https://doi:10.1108/09564231011092908

Liu, B., Wei, Q., Lv Y., & Zhu K. F. (2016). Servitization of Manufacturing and Value Chain Upgrading. Economic Research Journal, 51(03),151-162. https://doi:CNKI:SUN:JJYJ.0.2016-03-023

Lu, Y. (2009). Do Environmental Regulations Influence the Competitiveness of Pollution-intensive products? Economic Research Journal, 44(04), 28-40. https://doi:CNKI:SUN:JJYJ.0.2009-04-005

Matthyssens, P., & Vandenbempt, K. (1998). Creating competitive advantage in industrial services. Journal of Business & Industrial Marketing. https://doi:10.1108/08858629810226654

Mont, O. (2002). Drivers and barriers for shifting towards more service-oriented businesses: Analysis of the PSS field and contributions from Sweden. The Journal of Sustainable Product Design, 2(3), 89-103. https://doi:10.1023/B:JSPD.0000031027.49545.2b

Neely, A. (2008). Exploring the financial consequences of the servitization of manufacturing. Operations management research, 1(2), 103-118. https://doi:10.1007/s12063-009-0015-5

Reiskin, E. D., White, A. L., Johnson, J. K., & Votta, T. J. (1999). Servicizing the chemical supply chain. Journal of Industrial Ecology, 3(2-3), 19-31. https://doi:10.1162/108819899569520

Rothenberg, S. (2007). Sustainability through servicizing. MIT Sloan management review, 48(2), 83-89.

Sung, B., Song, W. Y., & Park, S. D. (2018). How foreign direct investment affects CO_2 emission levels in the Chinese manufacturing industry: Evidence from panel data. Economic Systems, 42(2), 320-331. https://doi:10.1016/j.ecosys.2017.06.002

Vandermerwe, S., & Rada, J. (1988). Servitization of business: adding value by adding services. European management journal, 6(4), 314-324. https://doi:10.1016/0263-2373(88)90033-3

Xu, H. L., Cheng, L. H., & Sun, T. Y. (2017). The effect of the input servitization of manufacturing on upgrading export domestic value added of enterprises—Empirical evidence from Chinese micro-enterprise. China Industrial Economics, 76(10), 62-80. https://doi:10.19581/j.cnki.ciejournal.2017.10.005

Xu, H. L., & Wang, H. C. (2016). The Effect of Minimum Wage Standards on Firms' Export Quality. The Journal of World Economy, (07), 73-96. https://doi:CNKI:SUN:SJJJ.0.2016-07-005

Yang, X., Jia, Z., Yang, Z., & Yuan, X. (2021). The effects of technological factors on carbon emissions from various sectors in China—A spatial perspective. Journal of Cleaner Production, 301, 126949. https://doi.org/10.1016/j.jclepro.2021.126949

Zhu, S. J., Tang, Y. D., Qiao, X. Z., You, W. H., & Peng, C. (2021). Spatial Effects of Participation in Global Value Chains on CO2 Emissions: A Global Spillover Perspective. Emerging Markets Finance and Trade, 1-14. https://doi.org/10.1080/1540496X.2021.1911801

Zhu, S. J., Xie, Y., & Wu, D. S. (2020). A study on the energy-saving effect of manufacturing servitization and its intermediary mechanism. Finance and Trade Economics, (11), 126-140. https://doi:10.19795/j.cnki.cn11-1166/f.20201106.008.

Figures

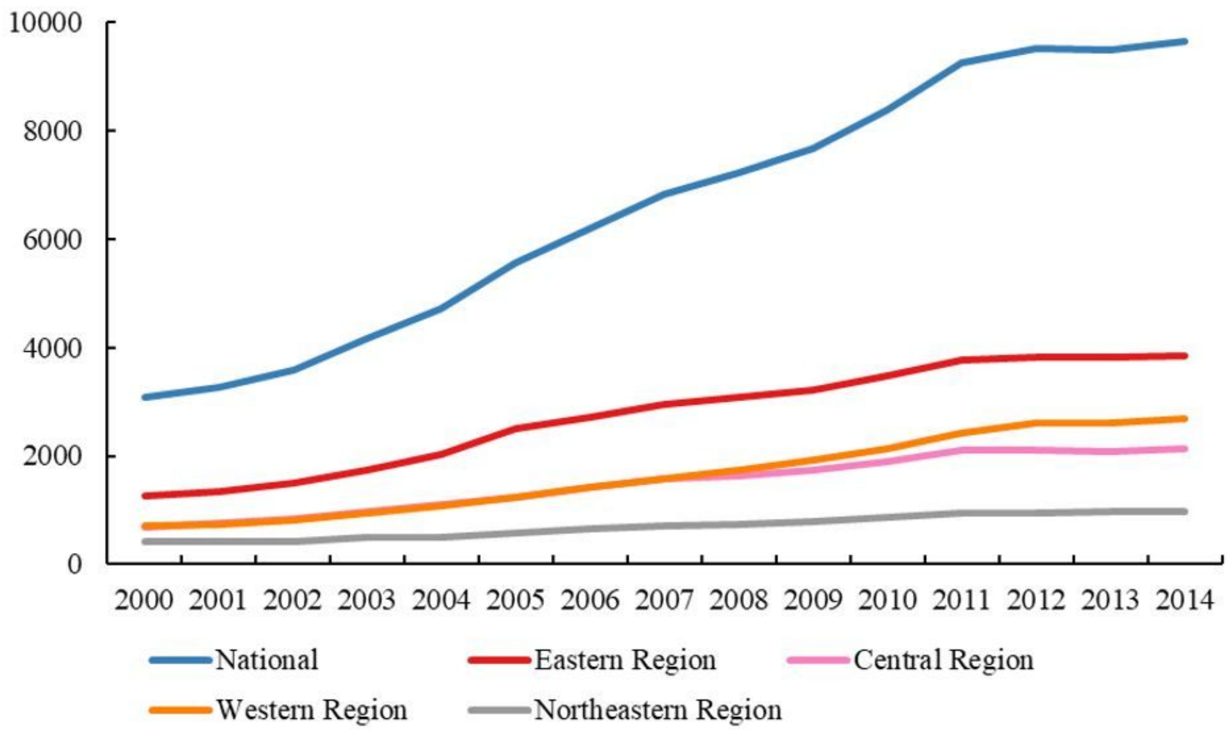

Figure 1

Carbon emissions of manufacturing industry by region in China from 2000 to 2014

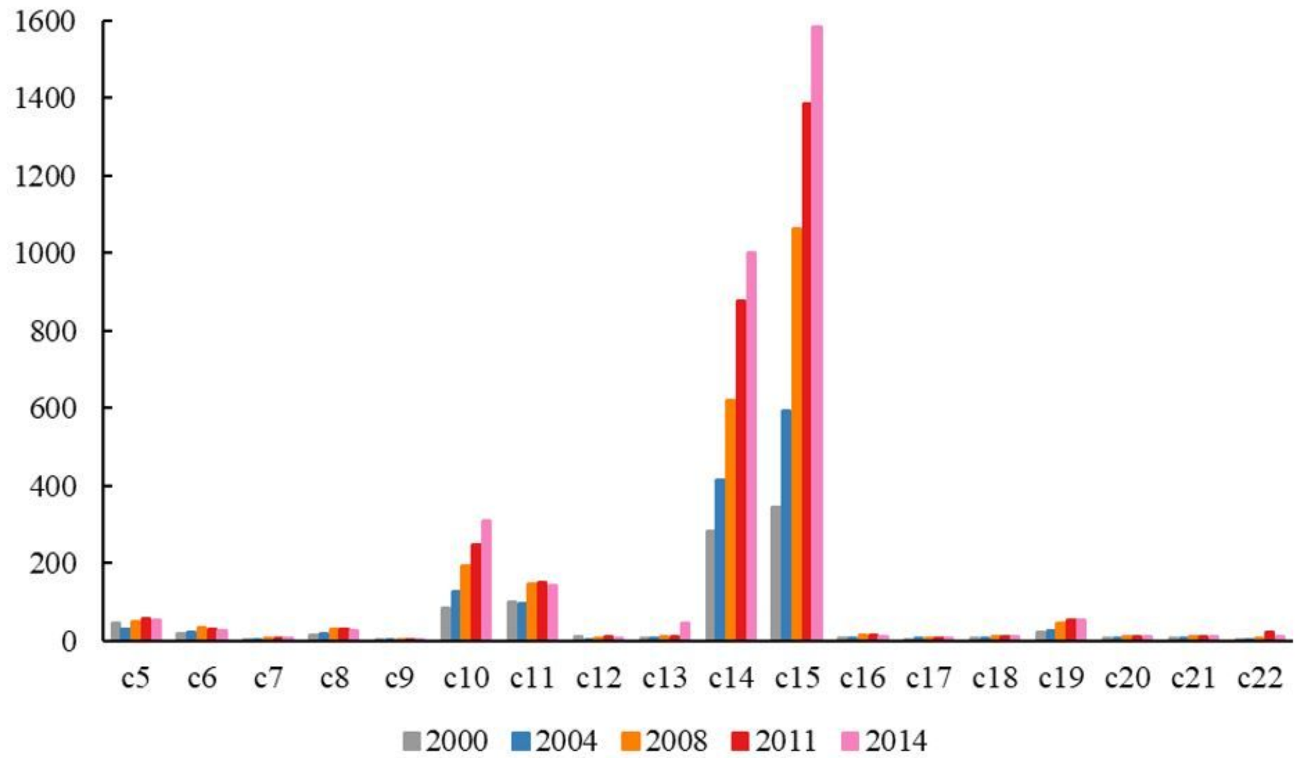

Figure 2

Carbon emissions of manufacturing industry in China from 2000 to 2014

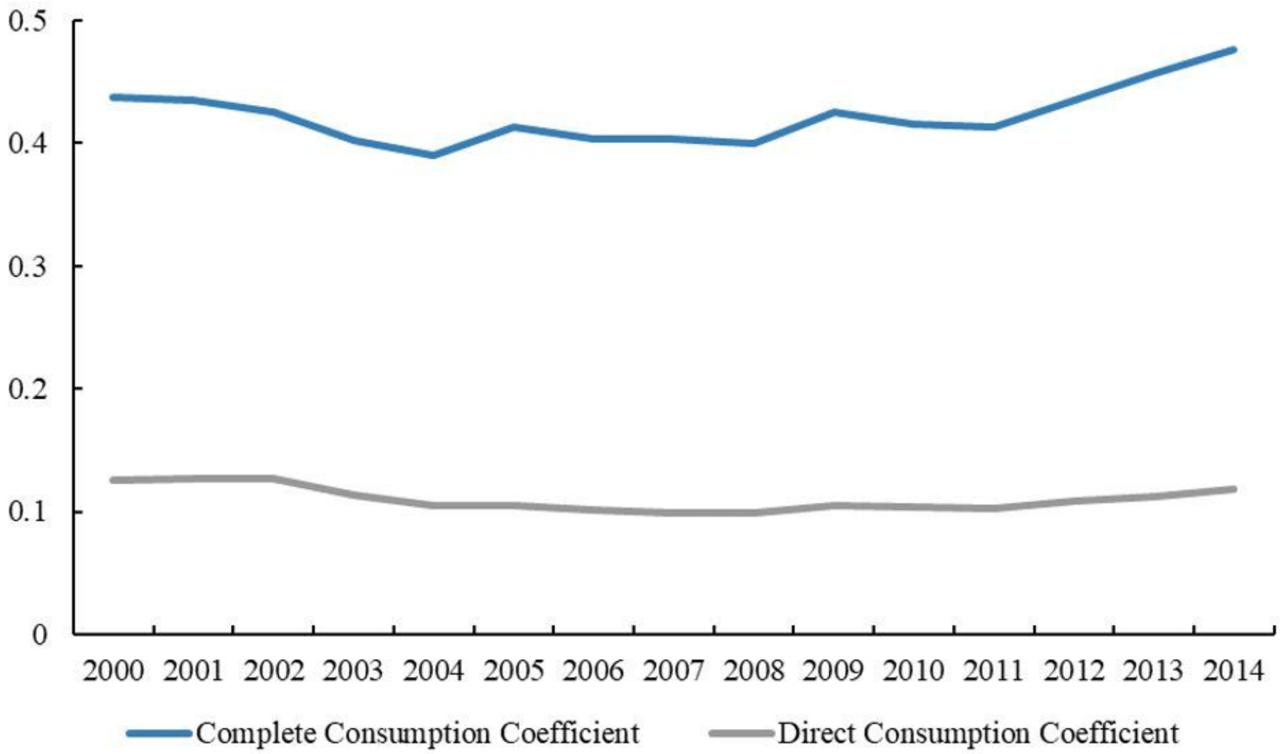

Figure 3

Overall level of China’s manufacturing input servitization from 2000 to 2014

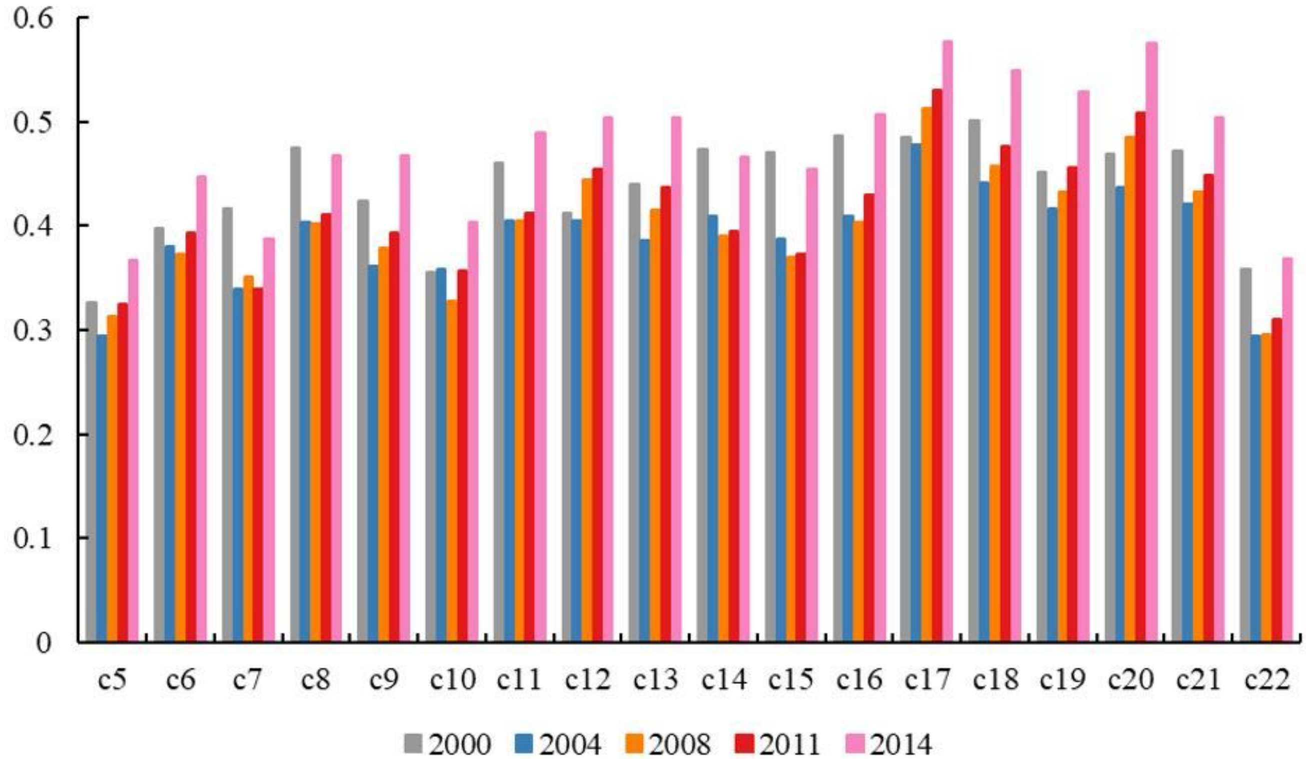

Figure 4

Manufacturing input servitization level in China from 2000 to 2014