Study on the effect of manufacturing services in promoting carbon emission reduction in a low carbon economy

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Abstract: The concept of low-carbon green development has become a global consensus, and the servitization of manufacturing is a feasible path to achieving green development in manufacturing. This paper takes manufacturing enterprises in 27 provinces and cities in China from 2006 to 2019 as samples, and empirically analyzes the effects of manufacturing servitization to promote carbon emission reduction in a low-carbon economy, which shows that: manufacturing servitization can reduce carbon emissions, and informatization, urbanization and energy structure optimization promote carbon emission reduction; in the less developed and backward central and western regions of the economy, manufacturing servitization promotes carbon emission reduction The effect is obvious. In the future, China should give full play to the digital economy's new advantages, optimize the manufacturing industry's energy use structure, and take the lead in promoting the servitization of the manufacturing industry in less economically developed regions.

1 Introduction

Carbon peaking and carbon neutrality have become important targets for global development, and the concept of low-carbon green development has become a global consensus. The report proposes to "accelerate the green transformation of development methods ..... The development of green and low-carbon industries". Servitization of the manufacturing industry is a feasible path to balance economic and environmental benefits and achieve green development of the manufacturing industry. Therefore, it is of certain theoretical and practical significance to study the effect of servitization of the manufacturing industry in promoting carbon emission reduction in a low-carbon economy.

Early foreign scholars argued that the servitization of manufacturing reduces resource consumption and environmental pollution by improving enterprise productivity and resource use efficiency (Fishbein, 2000[1]; Rothenberg, 2007[2]). Domestic academics argue that the servitization of manufacturing can reduce carbon emissions (Rao, 2013[3]; Wang et al., 2018[4]); Reduce energy intensity through technological innovation, factor structure optimization, and scale expansion through the servitization of manufacturing (Zhu et al., 2020[5]); reduce carbon intensity, the stronger the carbon reduction effect of a low-tech, advanced economy, knowledge-intensive manufacturing servitization (Wang et al., 2022[6]). But what is the effect of the servitization of manufacturing on carbon reduction in China? Further research is needed on how it differs from region to region.

Therefore, this paper empirically analyzes the direct and heterogeneous effects of the servitization of manufacturing industries to promote carbon emission reduction in a low-carbon economy and proposes suggestions for the servitization of manufacturing industries to promote carbon emission reduction in China.

2 Methods and data

2.1. Sample selection

The data in this paper are mainly obtained from the China Statistical Yearbook, Wind database, and CEADs, in which the sample data used for measuring the servitization level of the manufacturing industry are listed manufacturing enterprises in 27 provinces, cities, and autonomous regions of China, excluding Taiwan, Hong Kong, Guizhou, Qinghai, Ningxia, and Tibet, Macao with a total of 2,235 enterprises. Therefore, this paper uses these 27 provinces and cities from 2006 - 2019 as the sample to empirically test the theoretical hypotheses in the previous section.

2.2. Model specification

2.2.1. direct effects model

To analyze whether and in what direction the servitization of manufacturing has had an impact on national carbon emissions reductions, the model was set up as follows:

$$Ce_{it} = \alpha_0 + \alpha_1 Smi_{it} + \alpha_2 \lambda_{it} + \delta_i + v_t + \mu_{it} \quad (1)$$

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Where, i denotes province, t denotes year, Ce_{it} denotes China's carbon emissions, Smi_{it} denotes the level of servitization of manufacturing, and λ are other control variables that affect carbon emissions in China.

2.2.2. Heterogeneity effect model

In order to analyze whether there is heterogeneity in the impact of manufacturing services on national carbon emission reduction, the model is set as follows:

$$Ce_{at} = \alpha_2 + \alpha_3 Smi_{at} + \alpha_4 \lambda_{ai} + \delta_a + v_t + \mu_{at} \quad (2)$$

Among them, Ce_{at}, Smi_{at} and λ_{at} medium a = 1, 2, 3, respectively, represent the carbon emissions, manufacturing service level, and control variables of different types of regions.

2.3. Variable measurement

The explained variable of this paper is carbon emissions, which are measured by the carbon emissions calculated by CEADs.

The core explanatory variable of this paper is the manufacturing industry service index. Some studies have used micro-enterprise data to measure the manufacturing industry service mainly for the enterprise screening method and questionnaire survey method, and selected business scope, service business revenue, number of employees, etc. from the sample as the measurement indicators to represent the manufacturing industry service level (Neely, 2008[7]; Mart í n-Pea et al., 2019[8]). Among them, the questionnaire survey method has strong data subjectivity and narrow research scope, which has a negative impact on the scientificity of the conclusions. Therefore, this paper adopts the artificial enterprise screening method to measure the level of manufacturing service.

Referring to existing research, this paper selects the following control variables that may have an impact on carbon emissions. The descriptive statistical results of the main variables are shown in Table 1. To enhance the robustness of the results, the four indicator variables of total carbon emissions, manufacturing profitability, degree of networking, and degree of openness were logarithmically treated.

Table 1. Descriptive statistics of variable

Variable	(1)	(2)	(3)	(4)	(5)	(6)
		Obs	Mean	Std.Dev.	Min	Max
ce	Total carbon emissions	378	5.54	0.70	2.95	6.84
Smi	Ratio of manufacturing enterprises carrying out service-oriented business to total manufacturing enterprises	378	0.8051	0.1316	0.3600	1.0000
pgdp	GDP per capita	378	5.88	2.11	2.24	13.47
czd	Proportion of fiscal expenditure in GDP	378	0.21	0.07	0.08	0.46
R&D	R&D investment intensity	378	1.59	1.10	0.20	6.31
mc	Value added of manufacturing industry	378	7.14	1.05	3.42	9.27
loi	Total number of Internet users	378	1.89	0.17	1.26	2.20
open	Proportion of total foreign direct investment imports and exports in GDP	378	1.68	1.71	-3.70	4.78
urb	Proportion of urban population in total population	378	0.56	0.14	0.30	0.94
coalstr	Proportion of coal consumption and total energy consumption	378	65.89	27.86	1.77	175.78
re	Proportion of installed renewable energy power generation	378	27.68	20.76	0.00	84.31

Table 2. Stationary test of main variables (HT test)

Variable	ce	Smi	pgdp	czd	R&D	mc	loi	open	urb	coalstr	re
Z Value	2.3699	1.3065	6.9951	7.6185	7.3756	1.6357	6.6863	7.3760	7.1658	7.1332	2.9463
P Value	0.0089	0.0957	0.0000	0.0000	0.0000	0.0510	0.0000	0.0000	0.0000	0.0000	0.0016

The HT test is shown in Table 2 and the variables are smooth and capable of direct model estimation. The Hausman test p-value was 0, and a fixed effects model was selected. To further determine heteroskedasticity and autocorrelation, the White test P-value was 0.8917 and there was no heteroskedasticity. The autocorrelation test P-value was 0, and there was within-group autocorrelation. To solve the problem of within-group autocorrelation, the PCSE model was selected as the reference model.

3 Results and discussion

3.1. Impact effect analysis

The results of the benchmark regression between manufacturing servitization and carbon emissions are shown in Table 3. The PCSE model was chosen because the goodness of fit was similar to the FE value, but the PCSE model optimized the intra-group autocorrelation

problem. The estimated results show that the impact coefficient of manufacturing servitization on carbon emissions is -1.2046, indicating that manufacturing servitization can reduce carbon emissions. *The Made in China 2025* also points out that "the servitization of the manufacturing industry can help promote energy saving and emission reduction in the manufacturing industry and achieve green development". In addition, information technology, urbanization, and energy structure have a negative effect on carbon emissions; trade openness has a significant positive effect on carbon emissions.

3.2 Heterogeneity influence effect analysis

The results of the heterogeneity test are shown in Table 4, which indicates that there is heterogeneity in the impact of manufacturing servitization on carbon emissions influenced

Table 3. Direct effect regression results.

Variable	(1) OLS	(2) OLS	(3) FE	(4) FE	(5) PCSE
	Dependent variable = Service oriented manufacturing industry				
Smi	-1.2359*** (0.2180)	-1.3934*** (0.2149)	-1.5823*** (0.2170)	-1.4706*** (0.2215)	-1.2046 **(0.6693)
pgdp		0.0826*** (0.0306)		0.0627* (0.0374)	0.0742*** (0.0292)
czd		0.7883 (0.5964)		1.4251 (0.9321)	0.8177*** (0.3454)
R&D		-0.0495 (0.0513)		0.0228 (0.0692)	-0.0561 (0.0410)
mc		0.0782 (0.0533)		0.0760 (0.0566)	0.0715 (0.0445)
Loi		-0.5539* (0.3562)		-0.8182** (0.4081)	-0.4593** (0.3539)
urb		-1.6428*** (0.4878)		-0.6077 (0.7590)	-1.5877*** (0.3665)
open		0.0055*** (0.0022)		0.0060** (0.0030)	0.0063*** (0.0018)
coalstr		-0.0019 (0.0016)		-0.0007 (0.0020)	-0.0018* (0.0011)
re		0.0047** (0.0023)		0.0037 (0.0029)	0.0044** (0.0022)
Constant	6.5065*** (0.1733)	7.3807*** (0.5841)	6.7763*** (0.1722)	7.3078*** (0.5841)	7.0974*** (0.6693)
Observation	378	378	378	378	378
R^2	0.0763	0.1392	0.1277	0.1553	0.1516

Note: (1) All standard errors (shown in parentheses) are robust and adjusted for the presence of correlation between the error terms of firms located in the same city. (2) *** significant at 0.001 level; ** significant at 0.01 level; * significant at 0.05 level.

Table 4. Heterogeneity influence effect regression results.

Variable	(1) OLS (eastern region)	(2) PCSE (eastern region)	(3) OLS (central region)	(4) PCSE (central region)	(5) OLS (western region)	(6) PCSE (western region)
	Dependent variable = Service oriented manufacturing industry					
Smi	-.0691*** (0 .4165)	-3.0096*** (1.1614)	0.7390*** (0.2103)	0.7337 (0.5711)	1.8968*** (0.3707)	1.0591** (0.4941)
pgdp	0.0348 (0.0954)	0.0724* (0.0411)	0.0529** (0.0272)	0.0528*** (0.0257)	-0.0031 (0.0467)	0.0209 (0.0340)
czd	1.8558 (2.3842)	0.9261 (0.9041)	0.3234 (0.5797)	0.3265 (0.3411)	1.6665** (0.7244)	1.2858*** (0.3873)
R&D	-0.0285 (0.1688)	-0.1067* (0.0554)	0.0042 (0.0499)	0.0043 (0.0243)	0.2325** (0.1011)	0.2019*** (0.0526)
mc	0.0931 (0.1564)	0.0774 (0.0911)	-0.0211 (0.0571)	-0.0213 (0.0685)	0.0471 (0.0425)	0.0398 (0.0302)
Loi	-.5664 (1.0212)	-0.2210 (0.5419)	-0.1188 (0.3766)	-0.1170 (0.4610)	-0.5433 (0.3723)	-0.4774* (0.2720)
urb	0.3006 (1.7452)	-0.8707 (0.7694)	-1.6619*** (0.5909)	-1.6656*** (0.4937)	-1.7152*** (0.4549)	-1.8649*** (0.3190)

open	0.0061 (0.0067)	0.0056* (0.0031)	0.0055** (0.0024)	0.0056*** (0.0018)	0.0021 (0.0045)	0.0003 (0.0025)
coalstr	-0.0007 (0.0051)	-0.0026 (0.0018)	0.0008 (0.0017)	0.0008 (0.0012)	-0.0004 (0.0019)	-0.0008 (0.0015)
re	0.0094 (0.0061)	0.0088* (0.0045)	0.0011 (0.0023)	0.0011 (0.0017)	0.0017 (0.0026)	0.0010 (0.0017)
Constant	7.2211*** (1.3416)	7.5103*** (0.9279)	5.8593*** (0.5467)	5.8631 (0.6031)	4.5470*** (0.6608)	5.3450*** (0.6654)
Observation	126	126	112	112	84	84
R^2	0.3795	0.5311	0.3701	0.2652	0.3522	0.9893

by regional differences in environmental and economic factor endowments. In the economically developed eastern region, manufacturing servitization significantly reduces carbon emissions; in the less economically developed central region, manufacturing servitization may increase carbon emissions; in the economically backward western region, manufacturing servitization significantly increases carbon emissions. This is mainly due to the low level of manufacturing servitization in less economically developed regions, which cannot bring into play the innovative effect of industrial upgrading. At the same time, low levels of manufacturing servitization can increase industry sectors and further expand the sources of carbon emissions for the overall economy.

4 Robustness test

4.1. Endogenous

In this paper, the lag of one year is taken as the manufacturing servitization current instrument variable. The endogeneity test was conducted through Two Stage Least Square and Generalized Method of Moments. The test results are shown in columns (1) - (2) of Table 5. It can be seen from the regression results that the results of the two estimation methods are completely consistent. The regression results are highly consistent with Table 3 except that there are slight differences in the coefficient size and the significance of some coefficients, which do not affect the conclusion. To sum up, this paper can draw the conclusion that the conclusion of this paper is still robust even considering endogenous problems.

4.2. Replace core explanatory variable

In order to further verify the robustness of the regression results, this paper uses the method of replacing the key variable indicators to replace the core explanatory variables. We use the carbon emission intensity index to re measure the carbon emission level (Ce_{it}). The calculation method of carbon emission intensity is as follows:

Table 5. Robustness test regression results.

Variable	(1) 2SLS	(2) GMM	(3) OLS	(4) FE
	Smi	Smi	Smi	Smi
Smi	-0.4754** (0.2293)	-0.4754** (0.2293)		
L.ce				
ei			-0.4406* (0.2260)	-0.4417* (0.2542)
pgdp	0.0826*** (0.0314)	0.0826*** (0.0314)	-0.0447** (0.0186)	-0.0351 (0.0370)
czd	0.6699 (0.6054)	0.6699 (0.6054)	-0.4326 (0.6567)	-0.7862 (0.7198)
R&D	-0.0300** (0.0492)	-0.0300 (0.0492)	-0.2326*** (0.0289)	-0.2215*** (0.0621)
mc	0.0952* (0.0551)	0.0952* (0.0551)	0.0124 (0.0402)	0.0124 (0.0642)
Loi	-0.8191*** (0.3379)	-0.8191** (0.3379)	-2.9003*** (0.3296)	-2.9003*** (0.4276)
urb	-1.3742*** (0.5581)	-1.3742*** (0.5581)	1.9737*** (0.5001)	1.9737*** (0.5834)
open	0.0054*** (0.0023)	0.0054** (0.0023)	-0.0074*** (0.0017)	-0.0074** *(0.0027)
coalstr	-0.0006 (0.0017)	-0.0006 (0.0017)	0.0280*** (0.0017)	0.0280*** (0.0020)
re	0.0057** (0.0025)	00.0057** (0.0025)	-0.0048 (0.0031)	-0.0048*** (0.0028)

Constant	6.8310*** (0.5189)	6.8310*** (0.5189)	5.8656*** (0.3895)	5.8656*** (0.6446)
DWH P-Value	0.5648			
Kleibergen-Paap rk LM P-Value	0.0000			
Cragg-Donald Wald F	3.0733			
K-P Wald rk F	1220.247			
Stock-Yogo 10%	16.38			
Observation	351	351	378	378
R^2	0.0816	0.0816	0.6845	0.6845

Note: (1) All standard errors (shown in parentheses) are robust and adjusted for the presence of correlation between the error terms of firms located in the same city. (2) *** significant at 0.001 level; ** significant at 0.01 level; * significant at 0.05 level.

$$\mathrm{Cei}_{\mathrm{it}} = [co2_{it} / gdp_{it}] \quad (3)$$

Where $Co2_{it}$ is the total carbon emissions in i region t period, gdp_{it} is the carbon emissions intensity in i region t period, Ce_{it} is the carbon emissions intensity in period i region t period, the larger the index value, the higher the carbon emissions in the region, and vice versa. The estimation results of the robustness test are shown in columns (3) - (4) in Table 5. The estimation results show that the test results are generally consistent with the findings in Table 3, except for some differences in the magnitude and significance of the estimated coefficients, and therefore the conclusions of the paper are robust.

5 Conclusion and suggestion

This paper empirically analyses the effects of manufacturing servitization on carbon emission reduction under a low-carbon economy and draws the research conclusions: (1) the impact coefficient of manufacturing servitization on carbon emissions is -1.4706, indicating that manufacturing servitization can reduce carbon emissions. At the same time, informatization, urbanization, and energy structure all have a negative effect on carbon emissions. Trade openness has a significant positive effect on carbon emissions. (2) There is heterogeneity in the impact of the manufacturing service industry on carbon emissions. In the economically developed eastern region, the coefficient of the impact of the manufacturing service industry is positive, indicating that the manufacturing service industry reduces and suppresses carbon emissions; in the economically less developed and backward central and western regions, the coefficient of the impact of manufacturing service industry on carbon emissions is positive, and the more economically underdeveloped the region, the more obvious is the promotion effect of manufacturing service industry on carbon emissions.

Therefore, this paper puts forward the following suggestions: (1) give full play to the new advantages of the digital economy and use digital technology to empower the development of the servitization of manufacturing; (2) encourage manufacturing enterprises to improve the level of servitization, optimize the structure of energy use in manufacturing, vigorously develop clean energy technology and promote the development of manufacturing towards green; (3) take full advantage of regional differences and take the lead in promoting the servitization of manufacturing in the less economically developed and backward central and western regions to play an emphatic leading and demonstration effect.

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