The impact of technological innovation from domestic innovation, import and FDI channels on carbon dioxide emissions of China's textile industry

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ABSTRACT – REZUMAT

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Technological innovation is the key to reducing carbon dioxide (CO_2) emissions. In order to analyse the role of technological innovation from domestic innovation, import and FDI channels in the CO_2 emissions reduction of China's textile industry (CTI), this study uses OLS models to study the impact of domestic innovation, import technology spill over and FDI technology spillover on CO_2 emissions and CO_2 emission intensity of CTI respectively. The research results show that domestic innovation has significantly reduced CTI's CO_2 emissions and CO_2 emission intensity, while import technology spillover has increased them. FDI technology spillover has increased CO_2 emission intensity, but its impact on CO_2 emissions isn't significant. Therefore, China should take domestic R&D investment as the key measure to reduce CTI's CO_2 emissions in the future and continue to improve the level of independent innovation. China should also attract more low-carbon and green international investment and avoid becoming the "pollution heaven" for high-emission capital. The level of technology embedded in the imported textile products should be improved further. The use of various technological innovation strategies not only reduces CTI's CO_2 emissions but also makes positive contributions to China's goal of "carbon peaking and carbon neutralization".

Keywords: China's textile industry, carbon dioxide emissions, technological innovation, domestic innovation, import, FDI

Impactul inovației tehnologice din canalele interne de inovare, import și FDI asupra emisiilor de dioxid de carbon ale industriei textile din China

Inovația tehnologică este cheia reducerii emisiilor de dioxid de carbon (CO_2). Pentru a analiza rolul inovației tehnologice din canalele de inovație internă, import și investiția străină directă (FDI) în reducerea emisiilor de CO_2 ale industriei textile din China (CTI), acest studiu utilizează modele OLS pentru a determina impactul inovației interne, răspândirea tehnologiei de import și a tehnologiei FDI asupra emisiilor de CO_2 și respectiv, intensitatea emisiilor de CO_2 ale CTI. Rezultatele cercetării arată că inovația internă a redus semnificativ emisiile de CO_2 ale CTI și intensitatea emisiilor de CO_2, în timp ce răspândirea tehnologiei de import le-a crescut. Răspândirea tehnologiei FDI a crescut intensitatea emisiilor de CO_2, dar impactul acesteia asupra emisiilor de CO_2 nu este semnificativ. Prin urmare, China ar trebui să adopte investițiile interne în cercetare și dezvoltare ca măsură cheie pentru a reduce emisiile de CO_2 ale CTI în viitor și să continue să îmbunătățească nivelul de inovare independentă. China ar trebui, de asemenea, să atragă mai multe investiții internaționale cu emisii scăzute de carbon și ecologice și să evite să devină „raiul poluării" pentru capitalul cu emisii ridicate. Nivelul de tehnologie încorporat în produsele textile importate ar trebui îmbunătățit în continuare. Utilizarea diferitelor strategii de inovare tehnologică nu numai că reduce emisiile de CO_2 ale CTI, dar aduce și contribuții pozitive la obiectivul Chinei de „reducere a emisiilor de carbon și de neutralizare a carbonului".

Cuvinte-cheie: industria textilă din China, emisii de dioxid de carbon, inovație tehnologică, inovație internă, import, FDI

INTRODUCTION

Global climate warming is a common problem faced by human beings. Reducing carbon dioxide (CO_2) emissions has become a key measure for all nations to combat climate warming. Xi Jinping, the president of China, announced at UN General Assembly in September 2020 that China "strives to peak carbon emissions by 2030 and achieve carbon neutrality by 2060". At the Climate Ambition Summit in December 2020, Xi further promised that "by 2030, China's CO_2 emissions per unit of GDP will drop by more than 65%, compared with 2005 and the proportion of non-fossil energy consumption will reach 25% of primary energy consumption". These promises set clear time and quantity targets for China's CO_2 emissions and reducing CO_2 emissions has become an urgent task for Chinese governments at all levels.

The textile industry is one of the traditional pillar industries of China's economy and has made remarkable contributions to promoting economic growth and social development. The textile industry is also one of the important sources of China's CO_2 emissions. In 2019, the CO_2 emissions of China's textile industry (CTI) exceeded 22 million tons and it was still a large

one. Therefore, reducing CTI's CO_2 emissions is of great significance for China to achieve the goal of "carbon peaking and carbon neutralization" and transfer to a green and low-carbon development model.

The key to reducing CO_2 emissions is technological innovation, which reduces energy consumption and CO_2 emissions by improving energy efficiency, producing more low-carbon products and optimizing industrial structure. In an open economy, the sources of technological innovation include not only domestic innovation activity but also technology spillovers from import and foreign direct investment (FDI) [1]. In the reduction of CTI's CO_2 emissions, what role do these three channels of technological innovations play? What's the difference between them? Therefore, it has great empirical significance to study the impact of technological innovation of these three channels on CTI's CO_2 emissions for answering these questions. And it will provide a beneficial reference to guide CTI to rationally make use of their CO_2 emissions reduction effects.

The research on the impact of technological innovation on CO_2 emissions began with the study of the relationship between exogenous technological innovation and environmental problems. Then academia studied it under the framework of the endogenous growth model and the commonly used research methods include the STIRPAT model, EKC model, CGE model and LDMI method et al. Regarding the relationship between technological innovation and CO_2 emissions, most scholars believe that it has a positive impact on reducing CO_2 emissions. Lu [2] found that breakthrough low-carbon technological innovation had a reduced effect on CO_2 emissions by using China's Provincial Spatial Panel data. Daniel [3] confirmed that environmental innovation did contribute to CO_2 emissions reduction in the EU-27 countries between 1992 and 2014. Meanwhile, some scholars believe that the CO_2 emissions reduction effect of technological innovation is inconclusive and it may even increase CO_2 emissions. The rebound effect explicitly reveals that technological innovation promotes the decrease of product cost and price, then increases external demand and will lead to an increase in CO_2 emissions, instead of a decrease [4]. The research of Li [5] proved that technological innovation had a rebound effect on China's CO_2 emissions, about 9% – 75%. Chen [6] found that the impact of China's general domestic technological progress on CO_2 emissions was complex. In Central and West China, it reduced CO_2 emissions, whereas in East China it slightly increased emissions.

On the impact of technological innovation from domestic innovation, import and FDI channels on CO_2 emissions, Chinese scholars have achieved some research findings. Bi [7] confirmed that the horizontal spillover effect, forward linkage spillover effect and backward linkage spillover effect of FDI all reduced the CO_2 emission intensity of China's industry.

Guo [8] found that import technology spillover reduced China's CO_2 emissions. When it increased by 1%, the CO_2 emissions would decrease by 0.513%. But Alfred [9] held the opposite opinion based on the research on Turkey. Ma [10] studied the impact of technological innovation from domestic innovation activity, direct technology introduction and indirect technology introduction (FDI and import) channels on China's CO_2 emission intensity for the first time. The results showed that domestic innovation activity, FDI and import reduced CO_2 emission intensity, while export increased that and the effect of direct technology introduction was not significant.

Regarding the research on the impact of technological innovation from different channels on the CO_2 emissions of the textile industry, the literature is rare. Only Ignas [11] studied the impact of international trade on the CO_2 emissions of the EU clothing industry, excluding the textile industry. As to the research on CTI's CO_2 emissions, existing literature focuses on the measurement of CO_2 emissions and their relationship with economic development. Lu [12] and Gong [13] proved the weak decoupling relationship between GDP and CO_2 emissions of textile and garment industry in China and Xinjiang respectively. There are some shortcomings in these researches, such as poor data timeliness and rough distinguishment between the textile industry and garment industry. Furthermore, previous research has not paid sufficient attention to the impact of technological innovation on CTI's carbon emissions and there is also a lack of research from the channels of domestic innovation, import and FDI.

Under the overall requirements of innovative development and green development, it is of great practical urgency and value to explore the impact of technological innovation from domestic innovation, import and FDI channels on CTI's CO_2 emissions. Meanwhile, academia has not yet done research in this field. Given this fact, this study first calculates and analyses CTI's CO_2 emissions and CO_2 emission intensity from 2003 to 2019. Then it constructs OLS models to investigate the impact of domestic innovation, import technology spillover and FDI technology spillover on CTI's CO_2 emissions and CO_2 emission intensity respectively. Analysing the different impacts of the three channels of technological innovation, can not only provide evidence suggesting policy recommendations targeting CTI's CO_2 emissions reduction but also address the research gap in this field.

METHODOLOGY AND DATA SOURCES

Estimation model

Referring to the research method of Ma [10], this study takes CO_2 emissions and CO_2 emission intensity of CTI as dependent variables and domestic innovation, import technology spillover and FDI technology spillover as independent variables, then constructs regression equations to investigate the impact

of domestic innovation, import technology spillover and FDI technology spillover on CTI's CO_2 emissions (Model 1) and CO_2 emission intensity (Model 2) respectively. Thus, the impact of technological innovation from different channels on the CO_2 emissions of CTI can be comprehensively analysed. The equations are as follows:

$$\ln(CM_t) = C + \ln(R\&D_t) + \ln(FDI_t) + \ln(IMP_t) + \varepsilon \quad (1)$$

$$\ln(CMI_t) = C + \ln(R\&D_t) + \ln(FDI_t) + \ln(IMP_t) + \varepsilon \quad (2)$$

CM and CMI represent CTI's CO_2 emissions and CO_2 emissions intensity in year t. $R\&D$ represents CTI's domestic innovation in year t. FDI and IMP represent FDI technology spillover and import technology spillover of CTI in year t. C represents the constant and ε represents the residual.

Variables explanation and data sources

CO_2 emissions: Since there is no direct statistical data on CO_2 emissions in China, most scholars usually use the energy consumption of a specific industry to calculate CO_2 emissions indirectly. Referring to the method provided by IPCC [14], this study calculates CTI's CO_2 emissions by adding up the CO_2 emissions of the nine main energy CTI consumes, including raw coal, coke, coke oven gas, crude oil, gasoline, kerosene, diesel oil, fuel oil and natural gas. The equation is as follows:

$$CM = \sum E_i \times \rho_i \times \mu_i \quad (3)$$

where CM represents CTI's CO_2 emissions, E_i represents the consumption of energy i, $i = 1, 2, …, 9$, ρ_i and μ_i represent the coal equivalent coefficient and carbon emission coefficient of energy i.

CO_2 emission intensity refers to the amount of CO_2 emitted per 10,000 CNY of GDP. It's measured by the ratio of CTI's CO_2 emissions to its total output to calculate CO_2 emission intensity.

Domestic innovation: It's measured by the domestic R&D capital stock of CTI and calculated by the perpetual inventory method.

Import technology spillover: Import is a major channel of technology spillover. Referring to the LP model proposed by Lichtenberg [15], which is used to measure the foreign R&D capital stock spilt from international trade channels, this study uses the following formula to calculate import technology spillover:

$$S_t^{imp} = \sum_{j \neq k} \frac{S_{jt}^{rd}}{Y_{jt}} M_{jkt} \quad (4)$$

S_t^{imp} represents import technology spillover of CTI in year t. S_{jt}^{rd} represents the domestic R&D capital stock of country j in year t. Y_{jt} represents the GDP of country j in year t. M_{jkt} represents the total value of textile industry products imported by country k from country j in year t. The bilateral trade between China and OECD countries accounts for a large proportion of China's foreign trade and the world's R&D investment is mainly concentrated in OECD countries, mostly in the United States, Japan, Germany, France,

Italy, Britain, Canada, South Korea and other countries. Therefore, this study chooses these eight countries as the source countries for spilling R&D capital to China and then measures import technology spillover of CTI.

FDI technology spillover: FDI is another major channel of technology spillover. Similarly, referring to the LP model, the calculation formula for FDI technology spillover of CTI is as follows:

$$S_t^{fdi} = \sum_{j \neq k} \frac{S_{jt}^{rd}}{K_{jt}} FDI_{jkt} \quad (5)$$

S_t^{fdi} represents FDI technology spillover of CTI in year t. S_{jt}^{rd} represents the domestic R&D capital stock of country j in year t. K_{jt} represents the total fixed capital formation of country j in year t. FDI_{jkt} represents the textile industry FDI of country k from country j in year t.

The above data are obtained from China Statistical Yearbook, China Statistical Yearbook on Science and Technology, China Energy Statistical Yearbook and the UN Comtrade Database. The time series is 2003–2019.

CO_2 EMISSIONS OF CHINA'S TEXTILE INDUSTRY

CO_2 emissions and CO_2 emission Intensity

The CO_2 emissions of CTI declined from 28.81 million tons in 2003 to 22.72 million tons in 2019 (table 1), more than 20%. Its share in the industry had also been declining from 2.56% to 0.88%, lower

<div style="text-align:right">Table 1</div>

THE CO_2 EMISSIONS AND CO_2 EMISSION INTENSITY OF CTI			
Year	CO_2 emissions (million tons)	Share in industry (%)	CO_2 emission intensity (kg/10,000 CNY)
2003	28.81	2.56	384
2004	33.38	2.48	333
2005	31.64	2.02	256
2006	32.89	1.93	220
2007	34.54	1.90	190
2008	31.58	1.55	152
2009	29.58	1.42	132
2010	27.76	1.30	99
2011	23.71	1.04	73
2012	19.31	0.83	60
2013	34.03	0.90	94
2014	25.34	0.89	66
2015	23.44	0.87	59
2016	24.97	0.97	61
2017	25.03	1.00	69
2018	22.60	0.89	81
2019	22.72	0.88	92

than the share of CTI's total output (2.31%). This reveals that CTI has made remarkable achievements in reducing CO_2 emissions. In addition to eliminating the backward production capacity with high energy consumption and CO_2 emissions, a large part of the reduction is attributed to technological innovation activities, such as technological transformation and upgrading.

The CO_2 emission intensity of CTI showed a sharp decline and a slight rise during 2003–2019 (table 1). It first dropped from 384kg/10,000 CNY in 2003 to 59 in 2015. Then it slowly increased to 92 in 2019 and there was still more than 3/4 decline compared with 2003. CTI's CO_2 emission intensity has always been lower than the industry average and is currently only 37.99% of it. This shows that the CO_2 emissions caused by per unit output of CTI are relatively low, compared to the industry. However, the slow increase of CO_2 emission intensity since 2016 reminds us that CTI must always put more emphasis on curbing CO_2 emissions and not relaxing.

CO_2 emissions structure

The CO_2 emissions structure of CTI has shifted from being dominated by raw coal and supplemented by fuel oil and diesel oil to mainly natural gas with raw coal as a supplement (table 2). In 2003, the main source of CO_2 emissions was raw coal, followed by fuel oil, diesel, gasoline and natural gas. The total CO_2 emissions of these five energies accounted for 99.35% of CTI and that of raw coal accounted for about 78.34%. From 2004 to 2015, the share of raw coal had been always higher than 80%, even reaching the maximum of 87.59% in 2015. It indicates that

CTI relies heavily on raw coal and reducing the use of raw coal is the key to cutting down CTI's CO_2 emissions. In 2016, as the use of natural gas (especially liquefied natural gas) increased significantly, the CO_2 emissions share of raw coal fell below 80% for the first time, to 66.95%. Then it dropped to 22.38% in 2019, while the CO_2 emissions from natural gas increased sharply to 69.68%. As a result, CTI's CO_2 emissions have made a great structural adjustment from raw coal-based to natural gas-based with raw coal as a supplement. It also proves that optimizing energy structure is beneficial to CO_2 emissions reduction. The CO_2 emissions share of coke oven gas increased from 0.33% in 2003 to 4.86%, while fuel oil dropped from 8.17% to 0.69%. And gasoline and diesel both dropped to about 1%.

EMPIRICAL RESULTS AND DISCUSSIONS

Robustness check and co-integration test

This study first does a robustness check for each variable and the results show that they all pass the robustness check at a 10% significance level. The results of the co-integration test show that there is a co-integration relationship among the variables. Due to space limitations, the results of the robustness check and co-integration test are not presented here.

Empirical results

This study uses OLS models to analyse the impact of technological innovation from the channels of domestic innovation, import technology spillover and FDI technology spillover on CTI's CO_2 emissions (Model 1) and CO_2 emission intensity (Model 2) respectively. The estimation results are shown in table 3.

Table 2

				THE CO_2 EMISSIONS STRUCTURE OF CTI					
Year	Raw coal	Coke	Coke oven gas	Crude oil	Gasoline	Kerosene	Diesel oil	Fuel oil	Natural gas
2003	78.34%	0.31%	0.33%	0.00%	3.92%	0.57%	5.79%	8.17%	2.56%
2004	80.33%	0.19%	0.17%	0.03%	2.74%	0.27%	7.60%	7.85%	0.83%
2005	84.65%	0.26%	0.11%	0.03%	2.28%	0.29%	5.70%	5.72%	0.97%
2006	84.81%	0.28%	0.09%	0.02%	2.49%	0.25%	5.58%	5.50%	0.98%
2007	85.38%	0.29%	0.10%	0.02%	2.49%	0.22%	5.62%	4.91%	0.97%
2008	81.82%	0.46%	0.12%	0.03%	3.06%	0.19%	7.27%	5.11%	1.93%
2009	82.99%	0.39%	0.43%	0.03%	3.82%	0.06%	6.69%	3.67%	1.92%
2010	81.32%	0.51%	0.65%	0.00%	4.18%	0.08%	7.19%	3.66%	2.41%
2011	82.78%	0.46%	0.61%	0.00%	3.85%	0.06%	6.50%	2.80%	2.94%
2012	84.20%	0.44%	1.04%	0.00%	3.76%	0.03%	4.65%	2.06%	3.81%
2013	83.92%	0.23%	0.00%	1.95%	0.02%	2.30%	0.99%	8.09%	2.51%
2014	86.96%	0.23%	0.71%	0.00%	2.42%	0.01%	2.76%	1.42%	5.50%
2015	87.59%	0.23%	1.12%	0.00%	2.55%	0.03%	0.34%	0.08%	8.05%
2016	66.95%	0.16%	1.40%	0.00%	2.07%	0.01%	2.28%	1.06%	26.06%
2017	46.17%	0.15%	3.03%	0.00%	2.25%	0.01%	3.77%	1.14%	43.48%
2018	33.47%	0.25%	4.00%	0.01%	1.33%	0.00%	1.42%	0.97%	58.54%
2019	22.38%	0.15%	4.86%	0.00%	1.06%	0.01%	1.17%	0.69%	69.68%

Parameter	Model 1 Coefficient	Model 2 Coefficient
C	3.679** [2.504]	−2.351*** [−0.819]
RD	−0.344* [−1.815]	−0.427** [−0.427]
IMP	0.370** [0.874]	2.635*** [0.828]
FDI	−0.182 [−0.973]	0.350** [0.957]
Adj-R2	0.680	0.870

Table 3

THE ESTIMATION RESULTS

Note: ***, **, * represent significance levels of 1%, 5% and 10%, respectively, *t* values are shown in parentheses.

Technological innovation from domestic innovation has significantly reduced CTI's CO_2 emissions, while the import technology spillover has increased it and the effect of the FDI technology spillover isn't significant. The impact coefficient of domestic innovation on CTI's CO_2 emissions is −0.344, which demonstrates that improving the technological innovation level by increasing domestic R&D investment will help mitigate CTI's CO_2 emissions. The reason is that textile enterprises attach more and more important to improving independent innovation capability. Through continuously increasing R&D investment, they're able to alleviate the pressure from environmental regulations and maintain their competitive edge in the market. The impact coefficient of import technology spillover is 0.370, which means importing foreign textile products has a negative environmental externality and it plays a role in increasing CTI's CO_2 emissions, instead of reducing them. The reason may be that level of technology embedded in the imported textile products is relatively low. The impact coefficient of the FDI channel is −0.182, not significant.

Technological innovation from domestic innovation also has reduced CTI's CO_2 emission intensity, while import technology spillover and FDI technology spillover have increased it. All the impact coefficients of these three channels have passed the significance test. The impact coefficient of domestic innovation is −0.427, which indicates that increasing domestic R&D investment helps reduce CTI's CO_2 emission intensity. That of import technology spillover is 2.635,

which also confirms the negative environmental externality of importing foreign textile products. The impact coefficient of FDI technology spillover is 0.35. It means that FDI also has negative environmental externalities and it increases CTI's CO_2 emission intensity. This proves the "Pollution Heaven Hypothesis" [16] to a certain extent, that is, FDI in CTI has the effect of transferring pollution. Therefore, it is necessary to raise the environmental protection standards for foreign capital to enter CTI.

CONCLUSIONS AND POLICY SUGGESTIONS

This study uses OLS models to investigate the impact of domestic innovation, import technology spillover and FDI technology spillover on CTI's CO_2 emissions and CO_2 emission intensity respectively, to analyze the differences in the effects of technological innovation through these three channels on CTI's CO_2 emissions. The research results are as follows: Technological innovation from domestic innovation has significantly reduced CTI's CO_2 emissions and CO_2 emission intensity, while import technology spillover has increased them. FDI technology spillover has increased CO_2 emission intensity, but its impact on CO_2 emissions isn't significant. This demonstrates that increasing domestic R&D investment to promote technological innovation levels does reduce CTI's CO_2 emissions. Importing foreign textile products has negative environmental externality and it aggravates environmental pollution by intensifying the carbon emissions. FDI in CTI has increased CO_2 emission intensity and has the effect of transferring pollution.

Therefore, China should take domestic R&D investment as the key measure to reduce CTI's CO_2 emissions in the future and continue to improve the level of independent innovation. China should also attract more low-carbon and green international investment and avoid becoming the "pollution heaven" for high-emission capital. At the same time, the level of technology embedded in the imported textile products should be improved further. Thus, CTI's CO_2 emissions can be further reduced and this can make positive contributions to China's goal of "carbon peaking and carbon neutralization" eventually.

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