

The High-Quality Development of China's Publication Printing Industry From an Environmental Perspective

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ABSTRACT

In this article, the authors measure the change in the green total factor productivity of the publication printing industry in 31 provinces in China between 2013 and 2019. An additive Luenberger-Hicks-Moorsteen total factor productivity indicator and an aggregate directional distance function measure are used to decompose a green total factor productivity into technical efficiency change, scale efficiency, and technological progress change. The results show that the average annual growth rate of China's publication printing industry's green total factor productivity during the sample period was -2.75%, indicating that the business situation of China's publication printing industry is not optimistic under the premise of reducing carbon emissions in recent years. Among the main driving factors of green total factor change, scale efficiency change and technical efficiency change significantly reduce the level of green total factor productivity in China's publication printing industry.

KEYWORDS

Green Total Factor Productivity, High Quality Development, Publication Printing Industry, Regional Differences

1. INTRODUCTION

The printing industry is a huge system with a long history and contains several segmented industries. Among these segmented industries, the publication printing industry has a large responsibility to spread excellent culture at home and abroad, plays an indispensable role in promoting a country's traditional culture, and enhances a country's soft power. Although emerging information technology has made phenomenal progress in recent years and has had a huge impact on publications, such as newspapers and periodicals, the impact of electronic publications has not shaken the status of the traditional publishing industry. According to an analysis by Guosheng Securities, the proportion of American e-book sales decreased from 24% to 14% between 2014 and 2018, and the proportion of British e-book sales decreased from 13% to 11%. In China, e-books and paper books shared a similar ratio of sales growth, and both of them had a stable market share (Guosheng Securities, 2019). This illustrates that book publications are not significantly impacted by emerging information technology. Since the Twelfth Five-year Plan, China's publication printing industry has maintained a stable development trend, but there are still many problems in this industry, such as imbalanced industrial structure, irrational allocation of production resources, and low efficiency of enterprise operation. The

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report of the Nineteenth National Congress of the Communist Party of China made a major judgment that China's economy has shifted from a stage of rapid growth to a stage of high-quality development and put forward urgent requirements for improving total factor productivity (TFP) (The Xinhua News Agency, 2017). As an important segment of the printing industry, production technology updates and production efficiency improvement of the publication printing industry are of great significance to promoting the quality and efficiency of China's printing industry and can help China move from a large printing country to a powerful printing country.

It is worth noting that while the publication printing industry produces knowledge and cultural content, it also consumes a large number of natural resources, such as wood, and causes serious environmental pollution. This is not in line with the current shift of China's economy from a stage of rapid growth to a stage of high-quality development, the urgent requirement to increase TFP and the goal of accelerating the promotion of green and low-carbon development. In 2021, to proactively follow the global trend of green and low-carbon development, "Carbon Peak" was first included in the Chinese government's work report; that is, China's carbon dioxide emissions will no longer increase before 2030 and will gradually decrease after reaching the peak. In this context, it is necessary to pay attention to and study how to improve the TFP level of China's publication printing industry under the premise of reducing energy consumption and protecting the environment.

This paper is organized as follows. The second section is the literature review. The third section is research method, which sets the production technology and the aggregate directional distance function (DDF) and introduces the Luenberger-Hicks-Moorsteen (LHM) TFP and its decomposition. The fourth section introduces the data and variable descriptions. The fifth section is the analysis of the empirical results. The last section is the research conclusions and policy recommendations.

2. LITERATURE REVIEW

An investigation of existing research found that the current academic discussion on the publishing industry or publication printing industry mainly focuses on the problems and challenges faced by the traditional publishing industry in the new media era and the development of e-books. For example, John (1997) found that the new challenge of the publication printing industry is balancing the excitement for opportunities of the new technologies. Maxim and Maxim (2012) examined the impact of e-books and e-commerce on the development of the book industry in the US and European markets based on qualitative methods and the analysis of second-hand data. Borgstrom (2013) described the factors that are important to creating publications in both digital and physical formats. Lin et al. (2013) reviewed Taiwan's current e-book market from the perspective of e-book supply chain members and pointed out that government regulations, content quality, e-book prices, and reading devices are the most challenging factors for Taiwan's e-book publishing industry. Huang & Hao (2014) examined digital publishing policies and regulations in China. Souza Rodrigues et al. (2014) conducted in-depth interviews with senior executives of publishing companies to explore how the Brazilian publishing industry transforms its business model in the face of the impact of new technologies.

Ainul (2017) explored the factors that impede the uptake of lean principles in the printing industry. Siler (2017) proposed the potential trajectories and results of the costs and benefits of academic publishing. Fu et al. (2018) used online surveys to examine the current situation and attitudes of academic publishers on academic e-book publishing in mainland China and pointed out that China's academic e-book industry is still in an early stage of development and that the market size is still small. Moreira et al. (2018) discussed how to reduce the use and cost of toxic raw materials during the offset printing process and proposed specific measures to improve the productivity of the printing industry. Yun (2019) examined China's digital publishing industry and pointed out that the interaction of government, markets, and emerging technologies had a significant impact on the digital transformation of China's publishing industry. Li (2016) and Fan (2021) proposed a path to promote its transformation and upgrade based on an analysis of the development status of the paper publishing

industry, that is, breaking barriers in the alliance, promoting digital development, integrating and optimizing the publishing industry chain, establishing publishing websites, and providing security guarantees for the digitization process.

The research above-mentioned is mainly based on macrolevel discussion. Although it can provide references for the development status and trends of the publishing industry for this study, it also lacks empirical analysis based on objective data and cannot provide methodological reference for this article. Compared with the above studies, research on the TFP of the publishing industry is still lacking, and there is no literature that uses the data envelopment analysis (DEA) model to measure the TFP of the publishing industry and the publication printing industry.

DEA was proposed by Charnes and Cooper (1978) and is an important field of interdisciplinary research on operations research, management science and mathematical economics. It has certain advantages in dealing with multiple indicator inputs and multiple indicator outputs, and it has been widely used to measure the performance and the TFP of various industries and sectors, such as industry, agriculture, health care and finance. For example, Mudit & Jyoti (2002) used DEA for performance analysis of different coal mining regions. Beck et al. (2005) identified best-practice cases of efficient e-commerce performance in Denmark and the United States by using the DEA model. Li et al. (2015) analyzed the TFP of 11 Chinese coastal cities' marine economies during the period of the 11th Five-year Plan. Sueyoshi & Wang (2018) conducted environmental assessment and performance measurement on the U.S. petroleum industry by using the DEA model. Phung et al. (2020) studied the operating performance of 26 Taiwanese banks. Shen and Valdmantis (2020) evaluated the operational efficiency and TFP of public hospitals in China. Michali et al. (2021) evaluated the environmental efficiency of railways in 22 European countries and incorporated noise pollution into railway efficiency measurement research by using the DEA model. Giri et al. (2021) measured the operating efficiency levels of 20 steel production companies in India. Balezentis et al. (2021) estimated the green economic growth performance of the agricultural sector in some European countries. However, there is still a lack of research that uses the DEA model to evaluate the performance of the publishing industry or publication printing industry in one or more countries. This is the most important topic that this research aims to investigate.

Yet, there are few studies focused on the factors which are related to the printing industry. Hargrave (2013) found that disruptive technologies are considered as an important factor in printing industry. Pattabhiramaiah, Sriram and Sridhar (2017) examined the newspaper's optimal pricing equations, and revealed the role of subsidy and demand in the prices of printing paper. Bai et al. (2020) discussed the relationship between global innovation network characteristics and the R&D efficiency and the income of the main business of the 3D printing industry. Therefore, it is of great importance to analyze the traditional printing industry.

This article selects relevant data on the publication printing industry of 31 provinces, cities, and districts in China from 2013 to 2019 and adopts the additive LHM-TFP indicator and aggregate DDF to measure the change and regional difference in China's publication printing industry. The main contributions of this article manifest in two aspects. (1) The DEA model is introduced into the TFP evaluation of the publication printing industry, which expands the empirical research field of the model and relatively fills the gap of using industrial data on the publishing and publication industries to comprehensively measure their development. Moreover, existing studies rarely discuss the environmental pollution of the publication printing industry and rarely include it as an attribute of an energy- and resource-intensive industry. This article also enriches related research. (2) Based on the aggregate DDF and the additive LHM-TFP indicator, this paper takes all of China as a unified direction and measures the contribution of each region and province to the green TFP of the publication printing industry in China. This method ensures that the performance of publication printing industries in various regions and provinces are comparable, and the improvement suggestions derived under this premise are highly pertinent and feasible.

3. METHODOLOGY

3.1 Production Technology and Aggregate Directional Distance Functions

To measure the green TFP of China's publication printing industry, it is necessary to use the relevant input and output data of 31 provinces in China to construct the frontier of production feasibility. In general, the production set is used to represent the production technology (T), assuming that there are N nonpolluting inputs (x^p) and M polluting inputs (x^q) used to produce J expected outputs (y), M polluting inputs (x^q) are used to produce R undesired outputs (z), and the input and output data of all evaluated units are used to construct a production set. According to the definitions of Hackman (2008) and Shen and Valdmanis (2020), the production set needs to meet basic economic assumptions; for example, the production set should be a closed set, the production possibility frontier is convex, the variable returns to scale (VRS), and the output and input variables have free disposability. Referring to Yuan et al. (2021), the by-production technology (T_{BP}) in this article is expressed as Equation (1):

$$T_{BP} = T_1 \cap T_2 = \left\{ (x^p, x^q, y^j, z^r) \in R_+^{N+M+J+R} : (x^p, x^q) \text{ can produce } y^j; x^q \text{ can produce } z^r \right\}$$

$$T_1 = \left\{ (x^p, x^q, y^j) \in R_+^{N+M+J} \mid f(x^p, x^q, y^j) \leq 0 \right\}$$

$$T_2 = \left\{ (x^q, y^j) \in R_+^{M+R} \mid g(x^q) \leq z^r \right\} \quad (1)$$

where $f(\cdot)$ and $g(\cdot)$ are continuously differentiable functions. Based on the assumptions regarding free disposability in T_1 and costly disposability in T_2 , pollution-generating inputs and undesirable outputs are related by joint disposability (Ray et al., 2018).

After setting the production technology, the input and output data are used to construct a production set, in which benchmark provinces with low input and high desirable output constitute the frontier of production feasibility. At this time, distance functions need to be introduced to measure the development gap between each province and the benchmark province. The distance function is often used to measure the gap between the evaluated unit and the benchmark (i.e., the best performer) on the frontier of production feasibility, including the Shephard distance function and the directional distance function. Among them, the value of the directional distance function can be expressed as the gap between the evaluated unit and the production frontier, that is, the inefficiency value of the evaluated unit (Chambers et al., 1996). The directional distance function, D, used in this paper can be expressed by Formula (2):

$$D(x, y, z; g_x, g_y, g_z) = \max \left\{ \partial, \delta, \beta \in R_+ : (x - \partial g_x, y + \delta g_y, z - \beta g_z) \in T \right\} \quad (2)$$

where ∂ and δ represent the inefficiency value of input and output variables, respectively, which can be understood as the potential reduction space of input and the potential growth space of output.

Referring to the analysis of Boussemart et al. (2015) and Shen et al. (2018), this article uses the aggregate DDF in which each evaluated unit is compared with all evaluated units. The advantage of this setting is that the green TFP of the publication printing industry in all regions and provinces can be compared, and the values can also be accumulated. Productivity changes have a clearer economic meaning and can provide decision-makers with relatively reasonable reference information and policy recommendations. This distance function can be expressed by Formula (3):

$$(g_x, g_y) = \left(\sum_{k=1}^k x_k, \sum_{k=1}^k y_k \right) \quad (3)$$

3.2 The Additive LHM Indicator and Its Decomposition

The LHM productivity indicator was first proposed by Briec and Kerstens (2004). It has the advantage of being additively complete, meaning it can accurately measure the change of input and output and then accurately reflect the intertemporal change rate of TFP. Based on the additive LHM-TFP indicator proposed by Boussemart et al. (2015) and Shen & Valdmanis (2020), this article innovatively uses the aggregate DDF to measure the green TFP of China's publication printing industry. The LHM indicator of the aggregate DDF can be expressed as Formula (4):

$$\begin{aligned} LHM^t &= \left[D^t \left(x_k^t, y_k^t, z_k^t; 0, g_y^t, g_z^t \right) - D^t \left(x_k^t, y_k^{t+1}, z_k^{t+1}; 0, g_y^{t+1}, g_z^{t+1} \right) \right] \\ &\quad - \left[D^t \left(x_k^{t+1}, y_k^t, z_k^t; g_x^t, 0, 0 \right) - D^t \left(x_k^t, y_k^t, z_k^t; g_x^t, 0, 0 \right) \right] \\ LHM^{t+1} &= \left[D^{t+1} \left(x_k^{t+1}, y_k^t, z_k^t; 0, g_y^t, g_z^t \right) - D^{t+1} \left(x_k^{t+1}, y_k^{t+1}, z_k^{t+1}; 0, g_y^{t+1}, g_z^{t+1} \right) \right] \\ &\quad - \left[D^{t+1} \left(x_k^{t+1}, y_k^{t+1}, z_k^{t+1}; g_x^{t+1}, 0, 0 \right) - D^{t+1} \left(x_k^t, y_k^{t+1}, z_k^{t+1}; g_x^t, 0, 0 \right) \right] \end{aligned} \quad (4)$$

Where LHM^t and LHM^{t+1} represent the changes in productivity in periods t and $t+1$, respectively, and their arithmetic average is the LHM-TFP indicator, which can be expressed as Formula (5):

$$TFP_{LHM}^{t,t+1} = \frac{1}{2} (LHM^t + LHM^{t+1}) \quad (5)$$

Furthermore, the LHM-TFP indicator can be decomposed into technical efficiency change (TEC), scale efficiency change (SEC), and technological progress (TP), expressed as Formula (6):

$$TFP_{LHM}^{t,t+1} = TEC^{t,t+1} + SEC^{t,t+1} + TP^{t,t+1} \quad (6)$$

$TEC^{t,t+1}$ is used to measure the level of rational use of resources. The larger the value is, the more reasonable the allocation and use of production factors such as capital and labor in production activities. $SEC^{t,t+1}$ is the distance between the production scale of the evaluated unit and the optimal production scale. The larger the value is, the more favorable the scale change is to promote the growth of TFP. $TP^{t,t+1}$ reflects the pull of the production frontier caused by technological innovation. The larger the value is, the greater the power provided by technological progress for economic growth. Referring to the decomposition of LHM indicators by Shen et al. (2019), the decomposition elements of LHM-TFP indicators can be expressed as Formula (7):

$$TEC^{t,t+1} = D^t \left(x_k^t, y_k^t, z_k^t; 0, g_y^t, g_z^t \right) - D^{t+1} \left(x_k^{t+1}, y_k^{t+1}, z_k^{t+1}; 0, g_y^{t+1}, g_z^{t+1} \right)$$

$$\begin{aligned}
 SEC^{t,t+1} &= \frac{1}{2} \left[\begin{aligned} &D^t(x_k^{t+1}, y_k^{t+1}, z_k^{t+1}; 0, g_y^{t+1}, g_z^{t+1}) - D^t(x_k^t, y_k^t, z_k^t; 0, g_y^t, g_z^t) \\ &- \left[D^t(x_k^{t+1}, y_k^t, z_k^t; g_x^{t+1}, 0, 0) - D^t(x_k^t, y_k^t, z_k^t, g_x^t, 0, 0) \right] \\ &+ \left[D^{t+1}(x_k^{t+1}, y_k^t, z_k^t; 0, g_y^t, g_z^t) - D^{t+1}(x_k^t, y_k^t, z_k^t, 0, g_y^t, g_z^t) \right] \\ &- \left[D^{t+1}(x_k^{t+1}, y_k^{t+1}, z_k^{t+1}; g_x^{t+1}, 0, 0) - D^{t+1}(x_k^t, y_k^{t+1}, z_k^{t+1}; g_x^t, 0, 0) \right] \end{aligned} \right] \\
 TP^{t,t+1} &= \frac{1}{2} \left(\begin{aligned} &\left[D^{t+1}(x_k^t, y_k^t, z_k^t; 0, g_y^t, g_z^t) - D^t(x_k^t, y_k^t, z_k^t; 0, g_y^t, g_z^t) \right] \\ &+ \left[D^{t+1}(x_k^{t+1}, y_k^{t+1}, z_k^{t+1}; 0, g_y^{t+1}, g_z^{t+1}) - D^t(x_k^{t+1}, y_k^{t+1}, z_k^{t+1}; 0, g_y^{t+1}, g_z^{t+1}) \right] \end{aligned} \right) \quad (7)
 \end{aligned}$$

3.3 Nonparametric Model

The estimation of the distance function can use parametric or nonparametric measurement methods. Because the nonparametric method does not require the preliminary setting of the production function form, it is more flexible and convenient. This article adopts the nonparametric measurement method following Balezentis et al. (2021). The decomposition of the additive LHM-TFP indicators requires the calculation of the aggregate DDF of 10 different intertemporal combinations. Taking calculation $D^t(x_k^{t+1}, y_k^{t+1}, z_k^{t+1}; 0, g_y^{t+1}, g_z^{t+1})$ as an example, the linear programming based on the DEA method can be expressed as Formula (8):

$$\begin{aligned}
 D^t(x_k^{t+1}, y_k^{t+1}, z_k^{t+1}; 0, g_y^{t+1}, g_z^{t+1}) &= \max_{\phi, \lambda, \gamma} \phi \\
 st. \sum_{k=1}^k \lambda_k y_k^{j,t+1} &\geq y_k^{j,t+1} + \delta \sum_{k=1}^k y_k^{j,t+1} \quad j = 1, 2, \dots, J \\
 \sum_{k=1}^k \gamma_k z_k^{r,t+1} &\leq z_k^{r,t+1} + \delta \sum_{k=1}^k z_k^{r,t+1} \quad r = 1, 2, \dots, R \\
 \sum_{k=1}^k \lambda_k x_k^{p+q,t+1} &\leq x_k^{p+q,t+1} \quad p = 1, 2, \dots, P; q = 1, 2, \dots, Q \\
 \sum_{k=1}^k \lambda_k x_k^{q,t+1} &= \sum_{k=1}^k \gamma_k x_k^{q,t+1} \quad q = 1, 2, \dots, Q \\
 \sum_{k=1}^k \lambda_k &= 1, \lambda_k \geq 0, k = 1, 2, \dots, K \\
 \sum_{k=1}^k \gamma_k &= 1, \gamma_k \geq 0, k = 1, 2, \dots, K \quad (8)
 \end{aligned}$$

where ϕ is the inefficiency value, which represents the space where the expected output can be increased and the space where the undesired output can be reduced. When $\phi = 0$, the evaluation unit has the highest efficiency on the frontier of production feasibility. λ and γ are the coefficient variables of reference sets T_1 and T_2 , respectively, and the value is the benchmark of the evaluated unit. $\sum_{k=1}^k \lambda_k = 1$ and $\sum_{k=1}^k \gamma_k = 1$ are the constraints for variable returns to scale.

4. DATA DESCRIPTION

This article uses industry data and carbon dioxide emission data of the publication printing industry of 31 provinces in China mainland from 2013 to 2019 and divides China into three regions: eastern, central, and western. The data used in this study come from the “Statistical Yearbook of Chinese Culture and Related Industries (2014-2020)”, “China Statistical Yearbook”, and the Wind database, and calculated by the author. All output values are adjusted to comparable prices based on the 2013 constant price. Note that Hong Kong, Macao, and Taiwan in China are not included due the data availability.

This paper selects three input variables, one expected output variable, and one undesired output variable. The input variables include the capital stock, paper consumption, and number of employees. Capital stock refers to the assets owned or controlled by the publication printing industry that can be measured in currency and can bring economic benefits. This indicator represents the capital investment and economic strength of the publication printing industry. Because paper is the most important raw material in the publication printing process, the amount of paper used is the most important cost component of the publication printing industry. The number of employees is the labor input.

Output variables include one expected and one undesired output variable, which are main business income and carbon dioxide emissions, respectively. The main business income reflects the basic income brought by the regular main business of the publication printing industry and reflects the profitability of the industry. Unexpected output refers to the carbon dioxide emissions generated during the printing of publications, which are produced in relation to the amount of paper used in publications and mainly reflect the environmental pollution caused by the paper publishing industry.

Table 1. Average annual growth rate of input and output (% , 2013-2019)

Region	Capital stock	Labor	Paper consumption	Main business income	CO ₂
Eastern region	4.741	-1.852	-6.425	2.284	0.406
Central region	1.918	-5.686	-7.271	-2.334	-24.929
Western region	2.851	-7.997	-4.416	-6.304	0.084
Total	3.876	-3.666	-6.406	0.354	-12.430

Note: The average annual growth rate is a random trend, calculated by Ordinary Least Squares (OLS).

Table 1 presents the changes in the average annual growth rate of the input, expected output, and undesired output variables of the publication printing industry in the three regions of China and the whole country from 2013 to 2019. From a national perspective, all input and output variables of the publication printing industry showed negative growth, except for the capital-level input and output variables. The capital stock (3.876%) and main business income (0.354%) both showed positive growth, and the average annual growth rate of capital stock was relatively large. The negative growth of carbon emissions (-12.430%) was the most significant, followed by paper consumption (-6.406%) and the number of employees (-3.666%).

In terms of input variables at the regional level, the eastern region (4.741%) had the highest growth rate of capital stock, followed by the western region (2.851%) and the central region (1.918%). The number of employees and the amount of paper consumption of the publication printing industry in the three regions showed negative growth. The number of employees in the western region (-7.997%) showed significant negative growth. Although the number of employees in the eastern region also showed a decreasing trend, the rate (-1.852%) was relatively moderate compared with that in the

central and western regions. Paper consumption in the central region (-7.271%) and the eastern region (-6.425%) showed relatively obvious negative growth.

In terms of output variables at the regional level, the main business income of the publication printing industry in the central and western regions showed negative growth, with the negative growth in the western region (-6.304%) being the most significant. The eastern region (0.406%) and the western region (0.084%) showed slight positive growth in carbon emissions, whereas the central region (-24.93%) showed very significant negative growth. However, the annual decline in CO₂ emissions in the central region may due to the slump in their industries.

5. EMPIRICAL ANALYSIS RESULTS

5.1 Change in Green TFP in the Publication Printing Industry and Its Driving Factors

Regarding China's publication printing industry as a whole (Table 2), the green TFP showed a year-to-year decline from 2013 to 2019, with an average annual growth rate of -2.75%. Compared with the TFP of China's publication printing industry (-5.76%) calculated by Chen (2010) without considering carbon dioxide emissions, the decline in green TFP of China's publication printing industry is relatively slow, which shows that although the operating situation of China's publication printing industry has not been optimistic in recent years, the industry has performed relatively well in reducing carbon dioxide emissions. After the Environmental Protection Law of the People's Republic of China was formally implemented in 2015, the environmental protection requirements that publication printing companies need to comply with became stricter. For this reason, relevant companies have invested more energy and financial resources in equipment transformation, technological updates, and talent introduction. To a certain extent, this explains why China's publication printing industry's TFP declined more slowly when considering carbon dioxide emissions reduction.

Table 2. Cumulative value and decomposition of green TFP of China's publication printing industry (2013-2019)

Year	TFP	TEC	TP	SEC
2013	0.000	0.000	0.000	0.000
2014	-0.034	-0.042	0.074	-0.066
2015	-0.095	-0.016	0.034	-0.113
2016	-0.149	-0.030	0.000	-0.119
2017	-0.153	-0.051	0.029	-0.131
2018	-0.152	-0.039	0.039	-0.152
2019	-0.159	-0.045	0.076	-0.189
Annual growth rate	-2.75%	-0.59%	0.54%	-2.70%
Contribution	100.00%	21.54%	-19.82%	98.29%

Note: The average annual growth rate is a random trend, calculated by Ordinary Least Squares (OLS).

Analyzing the driving factors of the green TFP change in the publication printing industry, we found that the technical efficiency change (TEC) and scale efficiency change (SEC) both showed negative growth during the sample period. The average annual growth rates were -0.59% and -2.70%, contributing 21.54% and 98.29% to the promotion of green TFP in China's publication printing industry, respectively. This shows that although changes in technical efficiency and changes in scale efficiency declined during the sample period, TEC and SEC had a very high contribution rate to

the green TFP compared with technological progress (TP). TEC and SEC were the main driving factors for the change in green TFP in China's publication printing industry, and they lowered the industry's green TFP level to a large extent. Thus, the improvement of technology and scale efficiency is crucial to driving the growth of green TFP in China's publication printing industry. In particular, the improvement of scale efficiency is the key aspect that the industry should focus on in the future development process.

In contrast to TEC and SEC, TP showed positive growth during the sample period, with an average annual growth rate of 0.54%. However, its contribution to improving the green TFP of China's publication printing industry was -19.82%. Although the technology, equipment and talent renewal of the publication printing industry improved during the sample period, the improvement in TP was relatively small compared with the reduction in scale efficiency changes and was not enough to be a main factor driving the growth of green TFP in China's publication printing industry. Moreover, TP first decreased and then increased during the sample period. From 2014 to 2016, the TP value in China's publication printing industry experienced a process of falling from a peak to a trough (i.e., from 0.074 to 0.000), which did not begin to ease until 2017 and returned to a peak of 0.076 in 2019. This shows that the Environmental Protection Law of the People's Republic of China implemented in 2015 had a significant impact on urging the publication printing industry to improve technology and update equipment.

5.2 Regional Differences in the Trend of Green TFP and Its Decomposition Indicators in the Publication Printing Industry

From the change of the green TFP of the publication printing industry in each region and province (Table 3), only 16 provinces have growth rates higher than the median annual average growth rate (-0.135%) of the green TFP of each province. The national publication printing industry's green TFP growth rate was -2.749%, and the eastern, central and western regions had growth rates of 0.129%, -1.039% and -1.839%, respectively. The green TFP of the publication printing industry in the eastern region had slow and positive growth, which is slightly faster than that in the central and western regions. Although the green TFP of the publication printing industry in the central and western regions decreased, the degree of reduction in the decomposition indicators of TFP in these two regions is not the same, and the main driving factors of green TFP growth are quite different among different regions. More notably, the publication printing industry in the western region not only had the largest decline in green TFP but also the TFP of individual provinces in this region had negative growth.

Table 3. Changes in green TFP and its decomposition indicators of China's publication printing industry (% , 2013-2019)

Province	TFP	TEC	TP	SEC
Eastern region	0.129	-0.112	0.483	-0.242
Beijing	0.387	0.094	0.472	-0.179
Tianjin	0.116	0.175	-0.013	-0.046
Hebei	-0.189	-0.043	0.029	-0.175
Liaoning	-0.224	-0.060	-0.014	-0.150
Shanghai	0.224	0.000	0.065	0.159
Jiangsu	0.187	0.043	0.143	0.001
Zhejiang	-0.172	-0.238	0.182	-0.117
Fujian	-0.295	-0.080	-0.327	0.113
Shandong	-0.207	0.000	-0.228	0.021

Table 3 continued on next page

Table 3 continued

Province	TFP	TEC	TP	SEC
Guangdong	0.324	0.000	0.183	0.141
Hainan	-0.022	-0.002	-0.009	-0.010
Central region	-1.039	-0.351	0.291	-0.979
Shanxi	-0.308	-0.015	-0.003	-0.290
Jilin	0.018	-0.115	0.313	-0.180
Heilongjiang	-0.033	0.018	-0.050	-0.001
Anhui	-0.132	-0.181	0.007	0.043
Jiangxi	-0.023	-0.014	0.017	-0.026
Henan	-0.334	-0.020	-0.013	-0.302
Hubei	-0.271	-0.051	-0.051	-0.169
Hunan	0.044	0.027	0.071	-0.053
Western region	-1.839	-0.129	-0.229	-1.481
Inner Mongolia	-0.004	0.015	-0.009	-0.010
Guangxi	-0.379	-0.002	-0.003	-0.374
Chongqing	-0.202	0.057	-0.171	-0.088
Sichuan	-0.138	-0.152	-0.032	0.046
Guizhou	-0.169	0.001	-0.001	-0.169
Yunnan	-0.297	-0.011	-0.002	-0.284
Tibet	-0.010	0.000	0.002	-0.012
Shaanxi	-0.384	-0.029	-0.003	-0.352
Gansu	-0.074	-0.004	-0.012	-0.058
Qinghai	-0.004	0.005	-0.002	-0.007
Ningxia	-0.012	0.000	0.006	-0.018
Xinjiang	-0.166	-0.009	-0.002	-0.155
Total	-2.749	-0.592	0.545	-2.701

From Figure 1, the green TFP of China's publication printing industry had a linear downward trend from 2013 to 2014. The trend of the SEC was the most consistent with that of the TFP. TP showed a sharp downward trend similar to total factor productivity until 2016 after experiencing short-term growth from 2013 to 2014. The change in green TFP in China's publication printing industry stabilized after 2016. During this period, SEC showed a continuous decline, and the continuous improvement of TP played a certain role in the growth of TFP. During the entire sample period, the TEC of the publication printing industry showed a trend of ups and downs, and the range of changes was not as large as the SEC and TP. Therefore, TEC has not been a significant driver or hindrance of the green TFP of China's publication printing industry.

Figure 1. Change trend of Green TFP and its decomposition indicators of China's publication printing industry

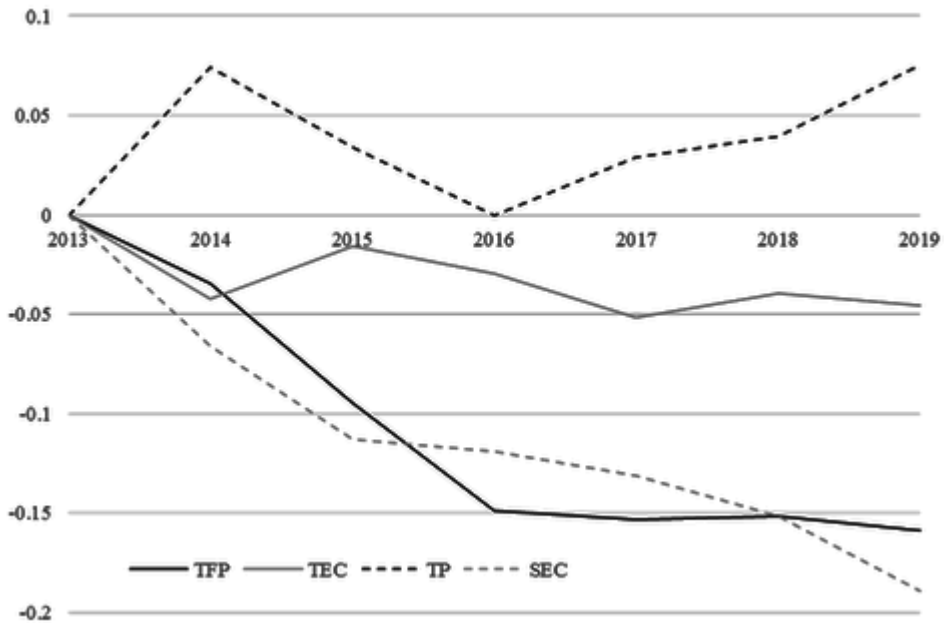


Figure 2 shows that the green TFP of the publication printing industry in the eastern region from 2014 to 2016 changed similarly to the TFP at the national level. However, during the periods of 2013-2014 and 2016-2019, the green TFP in the eastern region showed significant positive growth. According to Table 2, only Beijing, Tianjin, Shanghai and Jiangsu had a positive green TFP growth rate in the publication printing industry, indicating that these four provinces ensure the healthy operation of the publication printing industry by attending to environmental protection, especially in Shanghai and Jiangsu provinces. Shanghai and Jiangsu not only had increased TFP during the sample period but also improved TEC, TP and SEC. In contrast, the increase in TFP of the publication printing industry in Beijing was mainly due to TP, and the increase in technical efficiency of the publication printing industry in Tianjin had to a large extent enabled its TFP to maintain positive growth. The trend of SEC of the publication printing industry in the eastern region was completely consistent with the trend of SEC of the publication printing industry at the national level but also had a greater range. This indicates that the SEC in the eastern region played a key role in driving the SEC of the publication printing industry of China. In contrast to TP and SEC, the TEC of the publication printing industry in the eastern region had no obvious regularity and was not similar to the trend at the national level.

Figure 2. Change trend of Green TFP and its decomposition indicators of publication printing industry in the eastern region

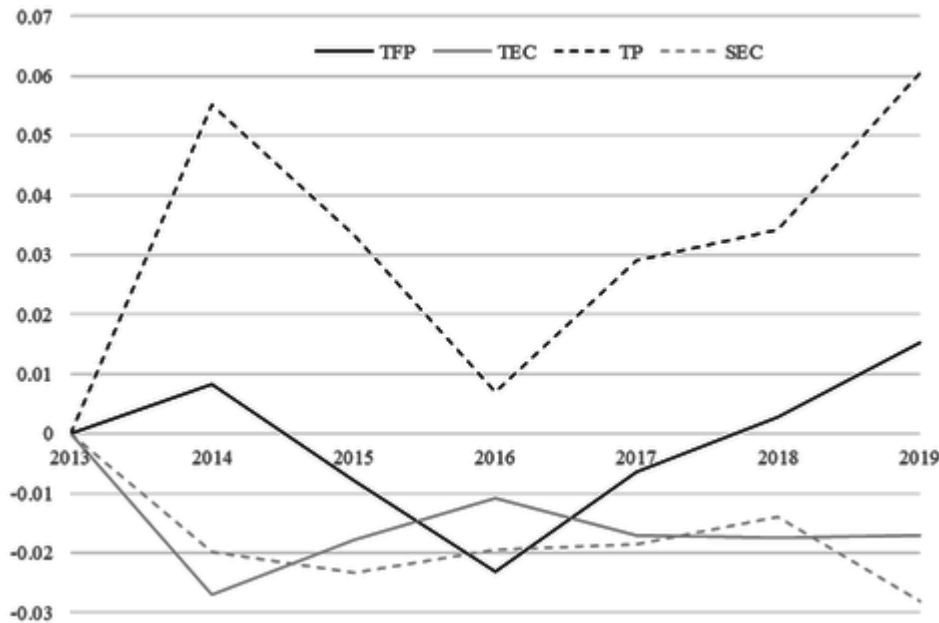
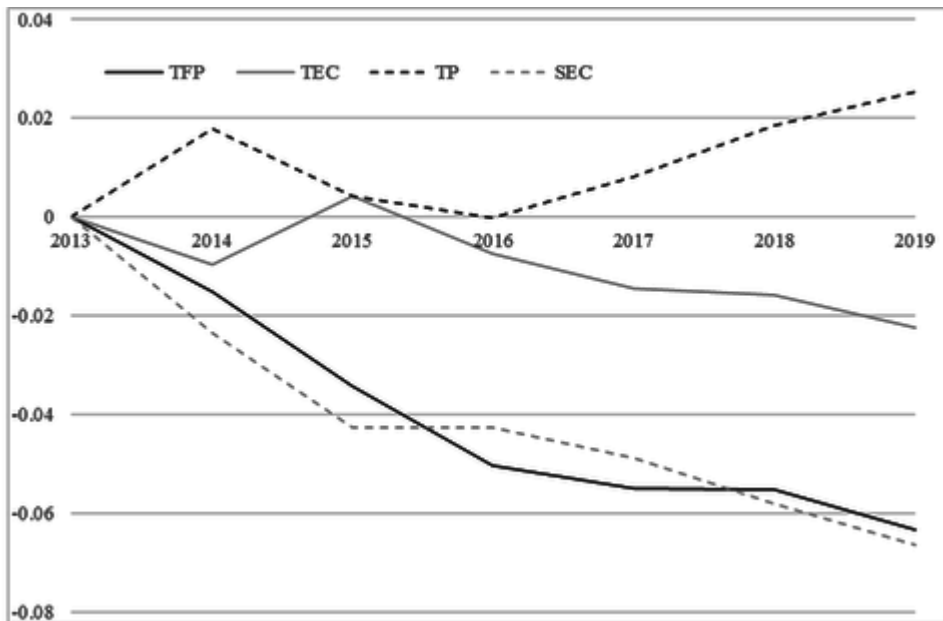


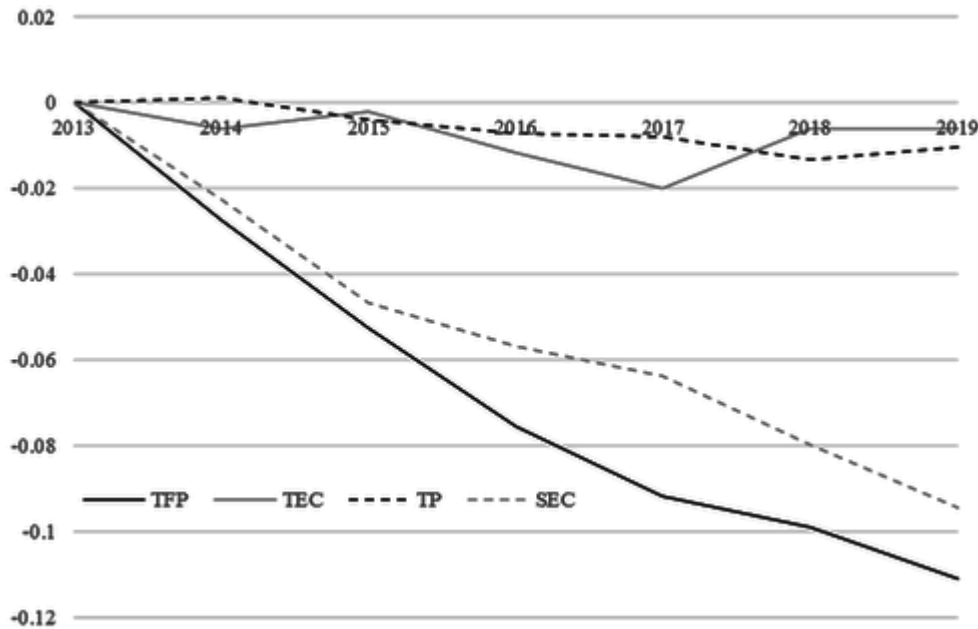
Figure 3 presents the green TFP and its decomposition indicators for the publication printing industry in the central region. The years of significant increase and decrease in the central region during the sample period are consistent with those of the national level. This indicates that the central region played a significant role in the changes in the green TFP at the national level. The green TFP of the publication printing industry in the provinces of the central region showed negative growth during the sample period, except for Jilin and Hunan. The TEC of the publication printing industry showed negative growth in the provinces of the central region during the sample period, except for Heilongjiang and Hunan. The SEC of the publication printing industry in the provinces of the central region grew negatively during the sample period, except for Anhui. The TP of the publication printing industry showed negative growth during the sample period only in Shanxi, Henan and Hubei. This shows that the provinces in the central region have different focuses for improving the green TFP of the publication printing industry in the future, and each province should take corresponding improvement measures based on its own shortcomings. For example, only TP in the central region showed positive growth, with an average annual growth rate of 0.291%, but there were also large differences among the provinces. The average annual growth rate of TP in the publication printing industry of Jilin Province was 0.313%, and this province played a very important role in stimulating the TP of the publication printing industry in the central region and even the whole country. In the future, it is necessary to strengthen technical exchanges and cooperation between the central provinces and to promote the TP of the publication printing industry in this region and the whole country.

Figure 3. Change trend of Green TFP and its decomposition indicators of publication printing industry in the central region



Combining the results in Figure 4 and Table 1, the green TFP, SEC, TEC and TP of the publication printing industry in the western region all decreased during the sample period. Among them, the green TFP and SEC declined during the sample period without fluctuations. Moreover, the average annual growth rate of SEC of all provinces in this region was negative, which not only shows that SEC was the main driver of changes in TFP of the publication printing industry in the central region but also shows that there is much room for improvement in SEC in most provinces in the region. Although the TEC and TP of the publication printing industry in the western region showed a downward trend in the end, they did not decrease continuously during the sample period but showed a relatively flat fluctuation. The five provinces of Guangxi, Yunnan, Shaanxi, Gansu and Xinjiang were similar to the overall performance of the region; that is, the green TFP and its decomposition indicators of the publication printing industry showed negative growth throughout the sample period. This implies that these five provinces have a large opportunity for improvement in terms of TEC and TP, and their improvement plays a very important role in stimulating the overall green TFP of the publication printing industry in this region.

Figure 4. Change trend of Green TFP and its decomposition indicators of publication printing industry in the western region



5.3 Discussion

From an overall perspective, the green TFP in China were below 0, and declined yearly. And the TEC, SEC, were also negative, and showed a downward trend. However, the remaining decomposition indicator, the TP, presented an increasing tendency in China, and was the only indicator which was positive. Therefore, the rise of TP promoted the growth of green TFP in the whole Chinese printing industry.

Moreover, the differences in different regions of China were significant. The green TFP in the eastern region became positive after 2017, though the TEC and the SEC were still negative. The TP in the eastern region demonstrated the similar movement of the whole China, which was always above 0 in the period of 2013-2019. In the central region, the green TFP was lower than that in the eastern region, and descended sharply. The SEC was negative, while the TP was positive. The TEC, which is different from that in eastern region, increased from 2014 to 2015, reaching its positive top. However, the green TFP in western region fell significantly compared to the other two regions. And the decomposition indicators were approximately negative during 2013-2019.

To conclude, the green TFP in China was declining. And the development of the green TFP was greatly promoted by that in the eastern region, while there was still large room for the central and western region to increase the efficiency. It is noted that the TEC and the SEC were negative almost every year in the three regions of China. But the TP made great progress, and was positive except in the western region.

6. CONCLUSION AND POLICY IMPLICATION

6.1 Conclusion

This paper takes data on the publication printing industry of 31 provinces in China from 2013 to 2019 as a sample, uses the additive LHM-TFP indicators and the aggregate DDF to measure the green TFP of the publication printing industry in China, and further decomposes the TFP into TEC, SEC and

TP. The results show that during the sample period, the green TFP (-2.75%) of China's publication printing industry decreased year-to-year. The TEC (-0.59%) and the SEC (-2.70%) both showed negative growth. However, compared with the positive growth of TP (0.54%), the former two had a relatively high contribution rate to the green TFP. They were the main driving factors for the change of green TFP in China's publication printing industry and depressed the industry's performance to a large extent. And there were still large room for the two factors to develop and promote.

6.2 Policy Implications

To improve the green TFP level of China's publication printing industry as a whole, this article proposes the following policy recommendations.

First, the proportion of resource elements in the publication printing industry should be adjusted, the scale and structure of the publication printing industry should be optimized, and the utilization efficiency of production factors should be increased. Under the current combination of input factors, technological level, operation, and management conditions, China's publication printing industry has not yet achieved a production state of scale economy. This requires each region and province to expand or reduce the scale based on its own specific conditions to achieve the best match between various input and output elements, thereby driving the green TFP level of the publication printing industry as a whole. One of the problems China's publication printing industry faces is low technical efficiency. This requires that, under the premise of optimizing the production scale of the current publication printing industry, adjusting the ratio of production factors, and improving the technology and management level, the production factors are more fully utilized to maximize output.

Second, the development strategy driven by scientific and technological innovation and the technological progress of the publication printing industry should be promoted. The report "Guiding Opinions on Promoting the Integrated Development of Traditional Publishing and Emerging Publishing" (Xinhua News Agency, 2015) clearly stated, "We must adhere to advanced technology as the support, content construction as the foundation, and make full use of new technologies, innovative publishing methods, and improving publishing efficiency". Although the research results showed that the technological progress of China's publication printing industry had positive growth during the sample period compared with changes in scale efficiency and technical efficiency, under the background of "carbon peak and carbon neutrality included in the overall layout of China's ecological civilization construction" (Xinhua News Agency, 2021), strengthening technical support for energy conservation and emission reduction are essential for improving the green TFP of the publication printing industry in China. In addition, emerging information technologies such as the internet are having an increasingly severe impact on the publication printing industry. Under this background, the government should control the overall situation, promote the technological innovation and development of the publication printing industry through top-level design, and provide guarantees for the dissemination of advanced printing technology, the cultivation of professional talent with modern information technology, and the promotion of the development of the publishing industry in the direction of intelligence and digitization.

Third, regional exchanges and cooperation in the publication printing industry should be strengthened, and the unified and coordinated development of different regions and provinces should be promoted. Considering the great differences in the green TFP and its decomposition indicators among the regions and provinces, the different regions have different directions and focuses for improving the performance of the publication printing industry. For example, the publication printing industries of Beijing and Jilin are obviously driven by technological progress. These provinces should take advantage of their existing advantages to further innovate production technologies, strictly implement the CO₂ emission reduction work, spread relevant beneficial experience to other provinces, and play a demonstrative role in comprehensively improving the technological progress of China's publication printing industry. The government should lead and establish a mechanism to strengthen the regular exchange and discussion of the publication printing industry between provinces in the

region. Organizing regional cooperation forums of the publication printing industry, could promote the exchange of experience and existing needs, enhance cooperation, reduce differences, promote technology diffusion, and promote high-quality coordinated development. Eventually, the continuous and steady growth of green TFP in China's publication printing industry will be realized.

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