Exploring Driving Forces of Green Growth: Empirical Analysis on China’s Iron and Steel Industry

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Abstract: Green growth of sectors with extensive energy and environmental impacts represented by the iron and steel (IS) industry plays a critical role in fostering sustainable and inclusive development. This paper constructs an updated evaluation model for green growth estimation by combining a global Malmquist–Luenberger index and an epsilon-based measure. A comprehensive decomposition framework is further posited to reveal underlying determinants of green growth. Research findings based on empirical tests from the panel data of Chinese IS firms spanning 2010–2017 demonstrate that the green growth level increased by 0.80% annually and followed the east–central–west gradient distribution. Technology progress and scale efficiency are two main contributors to China’s IS industrial green growth, whereas managerial inefficiency and scale bias of technical change hinder the productivity gains. The aforementioned factors also play different roles in enhancing the green growth of divergent regions. In accordance, context-specific practical implications and suggestions are put forward based on the research findings to facilitate the green growth of China’s IS industry.

Keywords: green growth; Chinese iron and steel industry; global Malmquist–Luenberger; epsilon-based measure; Zofio decomposition

1. Introduction

As a new pattern of growth, green growth has been promoted worldwide to address the dilemma of ecological deterioration and economic expansion for more than a decade [1,2]. This concept is also popular in emerging countries, such as China, especially during the post-crisis and post-Copenhagen era [3]. As the largest energy consumer and carbon dioxide emitter in the world, China has launched a series of green growth initiatives aiming to achieve inclusive and sustainable development, such as the Scientific Development View, Building of a Harmonious Society, and eco-civilization construction. In 2012, the 18th National Congress emphasized the importance of green, cyclic, and low-carbon development. In 2015, “greenization,” along with industrialization, urbanization, informatization, and agricultural modernization, was added to the national strategy to promote a resource-conservation lifestyle and resource-efficient value orientation. In 2017, the report issued at the 19th National Congress put forward the significance of establishing a sound economic system for green development.

As one of the most critical contributors to Chinese economic prosperity, the iron and steel (IS) industry also plays a critical role in resource exhaustion and ecological deterioration. Against this background, the Chinese government has issued a group of regulations, as well as a series of targets, to eliminate outdated production capacity and decontaminate the production process [4–6]. Despite remarkable progress in energy efficiency gains and pollution reduction, the greenness level of the industry is still rather low in many aspects at both international and national levels [7,8]. Currently,
the Chinese iron and steel industry is the largest producer and energy consumer in the world compared to other IS producing countries [9]. It also accounts for about 15% of the country’s total energy consumption and is currently the third biggest carbon dioxide emitter domestically [10]. Moreover, its industrial pollutants—represented by sulfur dioxide, nitrogen oxide, smoke, dust, waste water, and slag—significantly impact national environmental quality [11]. In addition, an excess capacity issue has also been hindering the value creation of the sector [12]. Accordingly, figuring out how to enhance economic viability with lower resource and environmental impacts plays a substantial role in achieving profound transformation of the Chinese industry.

Therefore, this study aims to comprehensively evaluate and decompose the green growth degree of China’s iron and steel industry by employing a proposed index and its decomposition. Spatial-temporal variations and determinants of industrial green growth levels are then observed before practical and specific suggestions are proposed. The reminder of the study is organized as follows: Section 2 summarizes the prior literature relevant to the topic. Section 3 presents the models used in the study and describes the selected variables, samples, and data sources. Section 4 demonstrates the research findings drawn from the empirical tests. Section 5 illustrates the conclusions and puts forward policy implications for the green growth of the industry.

2. Literature Review

The UNESCAP (the United Nations Economic and Social Commission for Asia and the Pacific) defines green growth (or environmentally sustainable economic growth) as economic growth that maintains or restores environmental quality and ecological integrity [1]. OECD (Organization for Economic Co-operation and Development) identifies green growth as a new pattern of economic growth without harming the capacity of natural capital that society and economic systems rely on [13]. Although no unanimous definition has been formed so far (i.e., each organization/government defines it slightly differently), the concept of green growth has reached a consensus across countries and organizations, i.e., to amount environmentally-sound and resource-efficient growth [14]. In other words, the goal of green growth is to minimize resource use as well as negative environmental impacts while maximizing economic benefits [2]. Green growth is not a substitute for sustainable development. Rather, green growth is a way to make measurable progress, both economically and environmentally [15,16]. Therefore, green growth is a paradigm shift from the traditional economic growth pattern (i.e., business as usual), in addition to being a policy focus and a feasible path toward sustainability [17].

Along with the expansion and popularity of the concept of green growth, a growing body of studies has emerged to form a niche research field regarding the theme.

With regard to the analytical perspective, total factor productivity (TFP) has long been a substantial approach to reflect the quality of economic growth. Amid the increasing concerns of ecological deterioration attributed to economic activities, the initial estimation framework has been revised by taking into account negative externalities, including resource depletion and environmental pollution. Against this background, green TFP was then proposed and developed by scholars. For example, Yörü̈k and Zaim constructed a revised productivity index that dealt with the discharge of pollutants in production processes to estimate the green TFP of OECD countries [18]. Zhang et al. proposed a hybrid index to measure industrial green productivity by using hazardous by-products as bad outputs [19]. Zhang and Liu also took into account chemical oxygen demand (COD) and sulfur dioxide (SO₂) when evaluating China’s industrial green TFP [20]. Compared to the conventional TFP analysis, green TFP brings in a new perspective for unveiling the sources and efficiency of real growth and is more valuable for sustainable policy making [21,22]. For example, Li and Lin incorporated resource utilization and carbon dioxide emissions as constraints when measuring the green productivity growth of 36 Chinese industrial subsectors [23]. Lin and Benjamin further considered different types of wastes as undesirable byproducts when estimating green development performance of provinces of China [24]. Wang et al.
estimated the green TFP of China with SO2 emissions as unexpected output and green GDP as expected output [25].

With regard to the analytical methods, stochastic frontier analysis (SFA) and the Malmquist index drawing on data envelopment analysis (DEA) are commonly used to reflect the changes in total factor productivity [26]. Compared to parameter-based SFA, DEA is a non-parameter approach that can deal with multiple input and output variables and can be operated without setting a restriction function first. Such flexibilities of DEA have made the DEA-based Malmquist index the most popular tool for growth evaluation, especially from a dynamic viewpoint [27–29]. The initial Malmquist index was then expanded into a Malmquist–Luenberger (ML) index by incorporating unexpected byproducts of production activities [30,31]. However, infeasibility may occur when computing and decomposing the index for a conventional Malmquist approach. A global Malmquist index including technology formed with data of all observers in all time periods was then introduced by Pastor and Lovell to avoid possible infeasibility issues [32]. Such an index based on global technology will lead to more robust calculating results [33] and has gradually been used in productivity discourse [34–37]. Moreover, traditional DEA techniques used in the Malmquist or ML index are either radial or non-radial, yet both of the former types and the latter approaches have their own flaws that may result in a biased estimation outcome. A hybrid model was then proposed to tackle such drawbacks in traditional DEA measures by Tone and Tsutsui to obtain unbiased results [38].

With regard to the decomposing results, divergent outcomes are formed due to the differences in research objective, observation time window, analytical technique, and research perspective. Accordingly, conclusions regarding various determinants are inconclusive [39]. For example, Liu et al. pointed out that progress in technology development played a critical role in fostering China’s green growth, yet scale and managerial factors both inhibited the green productivity improvement [40]. Zhu et al. found that green growth of China’s mining and quarrying industry was mainly boosted by technical gain, yet was inhibited due to scale inefficiency and managerial failure [41]. Feng’s research reached a similar conclusion for China’s metaling industry as technological progress was the major contributor to green growth, whereas deterioration in scale and efficiency change exerted a negative impact [42]. Nevertheless, the influencing factor of scale bias in technical change has been overlooked in the current debate.

With regard to discussion on the development of iron and steel industry, negative externalities generated from the production process of the IS sector are at the forefront of today’s industrial and academic discourse. Scholars have attempted to quantify the environmental impacts of the industry from different perspectives based on various theories and approaches. For example, Chen et al. forecasted the energy demand and carbon dioxide emissions of China’s steel production using a bottom-up analysis technique [43]. Milford et al. combined mass flow analysis and process emissions intensities to predict emissions of the global IS industry based on different CO2 abatement scenarios [44]. Matino et al. constructed a simulation model to evaluate the energy consumptions and emissions during the steel production process [45]. Song et al. posited a comprehensive decomposition framework to observe the determinants of CO2 emissions of China’s IS industry [46]. Chen et al. employed substance flow analysis (SFA) and energy and economic assessment to estimate and compare the carbon utilization in the steelmaking process under four scenarios [47]. Such studies provide decision-makers with useful and effective guidance and support to facilitate the green transition of the sector. However, despite extensive research on the subject of environmental impacts, little investigation has been given to the variation and determinants of green growth levels of China’s iron and steel industry so far.

In accordance, the contributions of this study are three-fold: first, a global Malmquist index based on an epsilon measure is proposed to evaluate green growth comprehensively and dynamically. Second, scale effect on technical change has been considered along with other influencing factors...
such as allocative efficiency variation, scale efficiency change, and technical progress when discussing the determinants of green growth. Last but not least, China’s iron and steel industry has been observed as the research sample to generate practical and policy implications to benefit the green development of the sector.

3. Models and Data

3.1. Model Construction

With reference to the studies conducted by Oh [48] and Tone and Tsutsui [38], we construct a global Malmquist–Luenberger (GML) index based on the epsilon-based measure to comprehensively evaluate the green growth degree of a given decision-making unit (DMU). Accordingly, if we have \( n \) DMU\(_{i}\) (\( j = 1, 2, \ldots, n \)) that use \( m \) inputs to generate \( q \) expected outputs and \( p \) undesirable outputs produced in \( t \) (\( t = 1, 2, \ldots, T \)) time periods, the GML index for any DMU\(_{k}\) can be estimated using the following equations:

\[
GML = ML^G(x^{t+1}, y^{t+1}, b^{t+1}, x^t, y^t, b^t) = \frac{D^G_C(x^{t+1}, y^{t+1}, b^{t+1})}{D^G_C(x^t, y^t, b^t)}
\]

\[
D^G_C(x^t, y^t, b^t) = \min \left\{ \frac{\theta - \epsilon \sum_{i=1}^{m} w_i y_{it} - \epsilon \sum_{j=1}^{q} w_j z_{jt}}{\phi + \epsilon \sum_{i=1}^{m} w_i x_{it} + \epsilon \sum_{j=1}^{q} w_j \lambda_j} : \begin{array}{l}
\sum_{i=1}^{m} x_{ij} \lambda_i + s^{-}_i = \theta x_{ij}; \sum_{j=1}^{q} y_{ij} \lambda_j - s^+_i = \phi y_{ij} \\
\sum_{i=1}^{m} z_{ij} \lambda_i + s^{-}_j = \theta z_{ij}; \sum_{j=1}^{q} y_{ij} \lambda_j - s^+_j = \phi y_{ij} \\
i = 1, 2, \ldots, m; \theta = 1, 2, \ldots, q; l = 1, 2, \ldots, p; j \in T^G
\end{array} \right. 
\]

where \( D^G_C \) represents the efficiency value of \( DMU_k \) at time \( t \) under a constant return on scale change while \( T^G \) is the global production set. \( \lambda \) represents the intensity vector. \( s^- \) and \( s^+ \) denote the input and output slacks, respectively. Correspondingly, \( w_i \) are the weights of input \( t \) that satisfies \( \sum_{i=1}^{m} w_i = 1 \), and similarly for \( w_j \) and \( \phi \). \( \varepsilon \) is a parameter reflecting the relative importance of non-radial slacks, and is decided by the objective nature of the data. If \( GML > (= or <) 1 \), then the green growth level of \( DMU_k \) is enhanced (stayed stable or declined) during the observation period.

Furthermore, drawing on the approach proposed by Fare et al. [49], Zofio [50] further decomposed the efficiency change into pure efficiency change (PEC) and scale efficiency change (SEC), and decomposed technical change into pure technical change (PTC) and scale bias of technical change (STC, also known as scale effect on technical change [51]).

Accordingly, the decomposed indexes under a global technology production set can be expressed as global pure efficiency change (GEC), global scale efficiency change (GSEC), global pure technical change (GPTC), and global scale bias of technical change (GSTC), respectively.

\[
GEC = GPEC \times GPTC \times GSEC \times GSTC
\]

\[
= \frac{D^G_C(x^{t+1}, y^{t+1}, b^{t+1})}{D^G_C(x^t, y^t, b^t)} \times \left\{ \frac{D^G_C(x^{t+1}, y^{t+1}, b^{t+1})}{D^G_C(x^t, y^t, b^t)} \times \frac{D^G_C(x^{t+1}, y^{t+1}, b^{t+1})}{D^G_C(x^t, y^t, b^t)} \times \frac{D^G_C(x^{t+1}, y^{t+1}, b^{t+1})}{D^G_C(x^t, y^t, b^t)} \right\}
\]

Specifically, if \( GPEC > (= or <) 1 \), then the pure efficiency change (also known as management efficiency) of \( DMU_k \) increases (stays neutral or declines), which in turn, accelerates (does not affect or hinders) the green growth level of the DMU during the observation period. In other words, management efficiency is a non-technical factor that reflects a DMU’s managerial level and governance.
capability. Similarly, if \( GPTC > (= or <) 1 \), then technical progress (neutral or regress) happens between time \( t \) and \( t + 1 \). If \( GSEC > (= or <) 1 \), then scale economics increases (stays neutral or decreases) over time. If \( GSTC > (= or <) 1 \), then technical change falls behind (matches or outgrows) the existing scale, and thus, should be augmented (maintained or decreased) to produce change at an optimal scale. The indicator of \( GSTC \) reflects the synchronizing degrees between technical progress and scale economics [52].

3.2. Variables and Data

This study identifies the following variables according to the concept of green growth (i.e., to minimize resource use and negative environmental impacts while maximizing the benefits generated by the economy [2]), as well as by referencing related studies.

In addition, indicators from related research in the discourse including citation [24] are also referenced to improve the validity of our selection. Input variables are the number of employees, fixed asset net value, total energy consumption, and fresh water consumption. Value added is selected as an expected/good output, while wastes and hazardous byproducts (i.e., waste water, waste gas, and waste residue) are identified as undesirable/bad outputs. Specifically, waste water includes volatile phenol, cyanide, petroleum, suspended matter, and ammonia nitrogen; solid waste includes steel slag, blast furnace slag, and dust sludge; and waste gas includes sulfur dioxide, smoke and dust, and nitrogen oxides [53].

Considering the timeliness, accessibility, and reliability of data, this study obtains the research sample and indicators from the following reports: the Environmental Protection Statistics of China’s Iron and Steel Industry (2010–2017), Annual Financial Report of Large and Medium-Sized Metallurgical Enterprises (2010–2017), and Statistics on Energy Conservation and Environmental Protection of China’s Iron and Steel Industry (2010–2017). Collectively, yearly data for 51 large and medium-sized China’s IS firms from eastern, central, and western China from 2010 through 2017 are obtained for the empirical tests. A description of the selected variables used in deriving GML is presented in Table 1.

### Table 1. Description of variables in deriving GML.

<table>
<thead>
<tr>
<th>Variable Type</th>
<th>Indicator</th>
<th>Measurement</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>Labor</td>
<td>Number of employees</td>
<td>Annual Financial Report of Large and Medium-Sized Metallurgical Enterprises</td>
</tr>
<tr>
<td></td>
<td>Capital</td>
<td>Fixed asset net value</td>
<td>Statistics on Energy Conservation and Environmental Protection of China’s Iron and Steel Industry</td>
</tr>
<tr>
<td></td>
<td>Resource</td>
<td>Total energy consumption</td>
<td>Environmental Protection Statistics of China’s Iron and Steel Industry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Freshwater consumption</td>
<td>Environmental Protection Statistics of China’s Iron and Steel Industry</td>
</tr>
<tr>
<td>Desirable Output</td>
<td>Economic benefit</td>
<td>Value added</td>
<td>Annual Financial Report of Large and Medium-Sized Metallurgical Enterprises</td>
</tr>
<tr>
<td>Undesirable Output</td>
<td>Pollutant</td>
<td>waste water, waste gas, waste residual</td>
<td>Environmental Protection Statistics of China’s Iron and Steel Industry</td>
</tr>
</tbody>
</table>

4. Empirical Test

4.1. Measurement of Green Growth

Based on Equations (1) and (2), we have obtained the outcome of green growth level for the China’s IS industry at both regional and national levels represented by the GML index from 2010 to 2017. The results are listed in Table 2.
Table 2. GML of the IS industry in China during 2010–2017.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>1.047</td>
<td>0.891</td>
<td>1.035</td>
<td>0.986</td>
<td>0.931</td>
<td>1.014</td>
<td>1.177</td>
<td>1.008</td>
</tr>
<tr>
<td>East</td>
<td>1.090</td>
<td>0.891</td>
<td>0.996</td>
<td>1.001</td>
<td>0.937</td>
<td>0.976</td>
<td>1.235</td>
<td>1.013</td>
</tr>
<tr>
<td>Central</td>
<td>0.999</td>
<td>0.921</td>
<td>1.081</td>
<td>0.968</td>
<td>0.931</td>
<td>1.017</td>
<td>1.146</td>
<td>1.006</td>
</tr>
<tr>
<td>West</td>
<td>1.023</td>
<td>0.837</td>
<td>1.059</td>
<td>0.976</td>
<td>0.916</td>
<td>1.117</td>
<td>1.084</td>
<td>0.998</td>
</tr>
</tbody>
</table>

Note: mean values of the indexes are calculated based on a geometric average.

As can be seen from Table 2, China’s IS industry merely meets green growth at the national level spanning 2010–2017 with an average yearly growth rate of 0.8%. The outcome reflects the challenges of harmonizing value added and pollution control faced by the IS firms in general. At the regional level, the eastern IS industry performed the best, followed by the central IS industry. However, challenges on balancing economic benefits and environmental protection still exist for the western IS industry as its yearly mean value of GML was lower than 1 during the observation period.

It can also be seen from the results that these yearly ups and downs matched with the changes in the macro environment of the industry in the past few years. Specifically, the industry performed well from 2010–2011 thanks to the Iron and Steel Industry Adjustment and Revitalization Plan released by the National Development and Reform Commission (NDRC) in 2009. However, the GML dropped greatly through 2011 to 2012 owning to the severe over-capacity issue of the industry [54].

Although the GML index picked up slightly for the period of 2012–2013, the traditional growth pattern featured as low cost, low price, and low profit could not be sustained when market demand and product price both decreased around the year 2015. Moreover, environmental regulations became stricter in the meantime and aggravated competition in the market. Such dual pressures caused the remarkable drop of the index spanning 2014–2015 [55].

Fortunately, the green growth level started to bounce back in 2016 due to the promotion and implementation of a green growth strategy. A series of regulations and bylaws were released to advocate the development and application of clean technologies in energy-intensive sectors. For example, the Made in China 2025 issued by the Ministry of Industry and Information Technology (MITT) set a clear agenda for green transition in manufacturing sectors including the IS industry. In accordance with the 13th five-year plan for National Economic and Social Development, the MITT further issued the Transformation and Upgrade Plan for the Iron and Steel Industry (2016–2020) to make the IS industry profitable and environmentally-friendly through technology innovation and effective management.

4.2. Decomposition of Green Growth Index

According to Equation (3), drawing from the concept of Zofio, we decomposed the green growth indexes of the firms into global pure efficiency change (GPEC), global pure technology change (GPTC), global structural efficiency change (GSEC), and global scale bias of technical change (GSTC), respectively. The decomposition results from 2010 to 2017 are presented in Table 3.

<table>
<thead>
<tr>
<th>Year</th>
<th>GPEC</th>
<th>GPTC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>China</td>
<td>East</td>
</tr>
<tr>
<td>2010–2011</td>
<td>1.0134</td>
<td>1.0568</td>
</tr>
<tr>
<td>2011–2012</td>
<td>0.9549</td>
<td>0.9833</td>
</tr>
<tr>
<td>2012–2013</td>
<td>1.0019</td>
<td>0.9808</td>
</tr>
<tr>
<td>2013–2014</td>
<td>1.0043</td>
<td>0.9994</td>
</tr>
<tr>
<td>2014–2015</td>
<td>0.9177</td>
<td>0.9594</td>
</tr>
<tr>
<td>2015–2016</td>
<td>1.1026</td>
<td>1.0339</td>
</tr>
<tr>
<td>2016–2017</td>
<td>0.9684</td>
<td>1.0006</td>
</tr>
<tr>
<td>Mean</td>
<td>0.9933</td>
<td>1.0016</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>GSEC</th>
<th>GSTC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>China</td>
<td>East</td>
</tr>
<tr>
<td>2010–2011</td>
<td>1.0213</td>
<td>1.0342</td>
</tr>
<tr>
<td>2011–2012</td>
<td>0.9816</td>
<td>0.9660</td>
</tr>
<tr>
<td>2012–2013</td>
<td>1.0488</td>
<td>1.0297</td>
</tr>
<tr>
<td>2013–2014</td>
<td>1.0023</td>
<td>1.0220</td>
</tr>
<tr>
<td>2014–2015</td>
<td>0.9569</td>
<td>0.9212</td>
</tr>
<tr>
<td>2015–2016</td>
<td>1.0039</td>
<td>1.0252</td>
</tr>
<tr>
<td>2016–2017</td>
<td>1.0258</td>
<td>1.0331</td>
</tr>
<tr>
<td>Mean</td>
<td>1.0054</td>
<td>1.0036</td>
</tr>
</tbody>
</table>

Note: mean values of the indexes are calculated based on a geometric average.

As can be seen from Table 3, the four types of factors play divergent roles in the green growth level of the IS industry, and even for the same determinant exert different impacts on the GML of various regions.

For China as a whole, technical progress was the main source responsible for the productivity gains, with a yearly growth rate of 1.40%, followed by a scale efficiency change with an annual growth rate of 0.5%. Therefore, the green growth of the IS industry came from both technical and scale perspectives. However, the green growth was hindered by managerial failure and the scale bias of technical change. Accordingly, non-technical aspects should be paid more attention regarding productivity gains in China’s IS industry.

For the eastern IS industry, its green growth was attributed to management, technical progress, and scale effects. Among others, technical improvement played the most critical role in green productivity gains with an average yearly growth rate of 1.28%, followed by scale and management efficiency with annual growth rates of 0.16% and 0.36%, respectively. Nevertheless, the change in the scale of technology was below unity, thus exerting negative impacts on green growth. In other words, technical change should be lowered in the amount necessary to match productivity change at an optimal scale.

For the central and western IS industries, similar outcomes have been found where the green growth of these two areas mainly arise from both technical progress and scale effect. The average yearly growth rates of scale effects in these two areas reached 0.87% and 0.41%, respectively. Compared to the scale efficiency, technical progress yielded greater positive impacts on green growth with 1.19% and 2.11% annual increases in the central and western areas, respectively. In the meantime, “double deterioration” appeared in both central and western IS industries in terms of managerial failure and regression of scale effects on technology change. Therefore, priorities should be given to the enhancement of governance effectiveness and synergies between economic scale and technology. Compared to the central area, managerial inefficiency of the western IS industry was more notable and had become the major inhibitor of productivity gain of the area.
5. Conclusions and Implications

This study investigated green growth and its determinants of China’s IS industry covering the period 2010–2017. The empirical results are summarized as follows.

The green growth level of China’s IS industry experienced a moderate increase of 0.80% annually on average from 2010–2017. Despite several drawbacks that happened during 2011–2012 and 2014–2015, improvement in productivity gains recently accelerated. At the regional level, the eastern IS industry performed the best, followed by the central area. Notably, regression of green growth happened in the western industry and made it the worst performer. Furthermore, green growth of the IS industry was boosted mainly by technical change and scale gains, yet was inhabited by managerial inefficiency and the scale bias of technical change on a national level. For the eastern IS industry, multiple factors were driving green growth, except for the factor of scale bias of technical change. Green growth of the central and western IS industries was attributed to technical change and scale efficiency, yet was inhibited by managerial failure and discordance between scale and technology.

Both the economic theory and practice indicate that ecological deterioration and resource constraints always came along with economic prosperity, especially during the process of industrialization. Fortunately, effective governance, suitable technology improvements, and optimal industrial scale can offset and correct the downward slide of economic expansion. Thus, ways to refine policy for better achievement are posited according to the research findings.

First, effectiveness of green management should be upgraded to a great extent. Managerial quality and governance effectiveness are critical to facilitating green growth of the IS industry. Although certain strategic plans and policies have been released for the industry, a more comprehensive governance system should be set up to improve the level of green growth. Concept, institutional renovation, managerial transition, and organizational innovation for green growth should be advocated, implemented, and perfected on macro, meso, and micro levels to form the sources and guarantees of industrial green development. Furthermore, an updated and upgraded evaluation framework on green governance capacity should be applied at both the industrial and firm levels to comprehensively and dynamically estimate management effectiveness.

Second, green technological transitions should be paid a great deal of attention. Technological transitions not only stress technical progress, but also focus on the compatibility between technology and society [56]. Therefore, this study pinpoints three types of propositions to prompt green growth in the IS industry. Based on the concept of lifecycle assessment (LCA), green technologies, especially the ones aimed at pollution prevention and waste abatement in the process of IS production, should be given greater priority to increase the efficiency of resource development and utilization and reduction of the three wastes. Moreover, to improve the scale effect on technological change, appropriate technologies encompassing technological choice and application that is small-scale, decentralized, labor-intensive, energy-efficient, environmentally sound, and locally autonomous for the IS industry should be further fostered to better suit the optimal scales of firms with different sizes [57,58]. In addition, achievements transformation, production industrialization, and scale application and expansion should also be fostered to suit the optimal scale of technical improvement.

Last but not least, specific supporting policies should be issued based on regional heterogeneity. As discussed in the empirical test section, divergent findings have been observed for different regions. The green growth level followed the east–central–west gradient distribution. Challenges faced by the western IS industry were serious as a regression of green productivity appears during the observation period. Hence, initiatives and arrangements should be accelerated to narrow down the regional gap. With regard to influencing factors, improvement of management efficiency will exert considerable positive impacts on the non-eastern IS industry, especially for the western area. Therefore, advanced managerial experience from the eastern IS industry should be learned and absorbed by firms from other areas. In addition, scale effects on technical change also play a critical role in facilitating industrial green development on general. Corresponding policies and actions should be prompted to increase synergetic effects between optimal scale and appropriate technologies.
6. Future Studies

While we offer insights into the green growth estimation of China’s IS industry, our study has several limitations that could be addressed in future research.

First, more IS firms, especially the small-sized enterprises, can be incorporated to increase the representativeness of the research sample. Second, other influencing factors besides the ones discussed in this paper, such as structural change effect, can be further considered in future studies. Third, heterogeneity originating from enterprise property (i.e., state-owned company, private enterprise, and foreign-owned firm) can be taken into account for green growth estimation and decomposition. Last but not least, qualitative case studies based on typical IS corporations in terms of a catching-up effect (i.e., chasers), leading effect (i.e., leaders in technology), and best practice effect (i.e., best practitioners) can be conducted as a supplement to quantitative analyses.

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