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Research Article

From Catch-Up to Transcend: The Development of Emerging Countries' Green Economy

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As domestic concerns on clean economic growth arise, promoting green economy has become an urgent issue for emerging countries that are facing serious environment problems in industrialization. Through international imitation, emerging countries have the opportunity to adopt clean techniques of developed countries. Because of different industrial structures, it is unachievable to learn the green technology across all fields. Previous studies consider that innovations could create green production models to improve the production capacity that reduces energy input and waste discharge. However, while evaluating emerging countries' economic growth, the environment indicators were often neglected. Empirical investigation of the role of innovation in green economy's growth is still rare. The first objective of this study is to adopt an integrated framework to investigate emerging countries' green economy by considering environmental factors. Secondly, environmentally sensitive productivity growth index was employed to decompose the productivity progress of green economy into catch-up effect, innovation effect, and technical leadership to examine the role of innovation. Thirdly, implications were provided for the policy makers in relation to green growth. Thirty-nine emerging countries were chosen as samples, which were divided into America, Asia, and Europe according to their locations. We found that America is still an imitator in developing green economy. In contrast, Asia starts to transition to innovation, which has become another critical promoter for green growth. Europe was found to lead on the technology frontier because of proper industrial planning and technology accumulation. The progress to innovation and technical leadership could ensure a stable green growth in the future. This research could be a route to open up the possibility of extending current study of green economy.

1. Introduction

Emerging countries are experiencing rapid economic growth through industrial transfer and industrialization, which narrows the income gap with developed countries [1]. They accounted for almost 60% of the world gross domestic product (GDP) growth and half of new consumptions in the past 20 years. However, with rapid industrialization, many emerging countries have a tremendous number of environment problems, such as air pollution, depletion of natural resources, drinking-water contamination, and industrial waste [2]. Pollution has become a critical environmental challenge that threatens emerging countries currently. The influence of pollution is terrible, leading to illness, disabilities, and death of millions of people every year.

As domestic concerns on clean and sustainable economic growth arise, developing green economy has become an urgent issue since emerging countries are facing serious environmental problems [3]. The green economy is defined as a country's economy activity that integrates society, economy and environment in a balanced way. Green economy emphasizes that production process should contribute to efficient use of resources, materials, and energy, as well as reducing waste emissions [4]. The pattern of green economy represents transformation of economy growth that is promoted by resource use, emissions, and environmental damage to the creation of green products, consumption, and conservation behaviors. Solutions to emerging countries' environment problems need to be inextricably incorporated with policies that rebalance the economy for green growth [5].

Emerging countries used to learn developed countries' experience to promote their economy into "Green" [6]. However, emerging countries are possessing different industrial structures with developed countries. In addition, developing countries need to pay a huge fee for professional technology and patents in clean production that are monopolized by developed countries. Imitating developed countries' experience can no longer be suitable for their production. As innovation is critical in the green economy, some emerging countries begin to invest into R&D to promote technical innovation.

Some studies consider that innovation could create green production models to improve the production capacity that reduces energy input and waste discharge. However, the contribution of innovation is rarely empirically analyzed for emerging countries. While evaluating emerging countries' economic growth, the environment indicators were often neglected. There are three objectives in this study. Firstly, the study will adopt an integrated framework to investigate emerging countries' green economy by considering environmental factors. Secondly, environmentally sensitive productivity growth index that is a pioneering method will be used to decompose the productivity progress of green economy into catch-up effect, innovation effect, and technical leadership to analyze the role of innovation. Thirdly, implications were provided for the policy makers in relation to sustainable growth.

The rest of this study is presented as follows. Section 2 provides literature review. Section 3 presents research model, samples, data, and methodology. Section 4 conducts empirical analysis. Section 5 makes discussions while Section 6 addresses conclusions and suggestions for future study.

2. Literature Review

The literature will explore green economy by taking three perspectives into account: firstly, it is fundamental to address the necessity to develop green economy for emerging countries; secondly, the development of green economy in emerging countries would be presented; and thirdly, a research framework will be constructed for investigating green economy by summarizing previous studies.

Emerging countries are facing serious environmental problems while delivering a significant rate of growth over the past thirty years. Industrialization has initially increased the use of waterways and air and exploitation of raw materials as the repositories for industrial wastes. Furthermore, compared with developed countries, emerging countries are usually less willing to sacrifice current income to improve the environment since incremental addition to total economy is more important at a low level of income. They have risen to the front and even centers of the global economy [7]. These countries favored investment over exports and fixed assets rather than the environment, which leads to an economy described as uncoordinated, unbalanced, unstable, and ultimately unsustainable.

Emerging countries' rapid economic growth is accompanied by serious environment degradation, which leads to widespread illness and millions of deaths. The damage done is unacceptable even though some resources are devoted to improving the environment as incomes rise [8]. The cost of domestic environmental deterioration is still staggering, leaving aside global issues like climate change. The water and air pollution could contribute to numerous ailments, especially respiratory illnesses, cancer, and breakdown in the immune systems. The pollutions could also destroy natural resources essential for production, for instance, degrading water and soil so that they could no longer be exploited for manufacturing [9]. Increasing carbon dioxide with related global warming has raised numerous problems on the effort required to make economy growth more environmental and sustainable [10]. Richer lifestyles, increasing consumption, and supply chain issues like high level of logistics coordination have brought about more carbon emissions. Consumers will be more environmentally conscious and make purchasing choice with attention on environmental friendliness of its ingredients on a parallel basis [11]. Examples of this are environmentally friendly packaging and use of environmentally friendly logistic models.

Environment problems in emerging countries have received immense industry and academic attention currently. Since there are no proper policies to promote the trade-off between environmental deterioration and economic growth, emerging countries need to confront ever-increasing environment consequences that would constrain growth over the long term [12]. Administrative controls and penalties are necessary to prevent the destruction of essential resources in some cases. Some studies and organizations propose the "green economy" for emerging countries. Green economy denotes the economy activity that not only fosters economic growth but also ensures that the nature continues to offer the environmental services and resources [13]. The purpose of green economy is to reduce the use of natural resources and waste discharge while improving individuals' living environment [14]. To achieve this, it must catalyze investment and innovation that would support sustainable growth and bring about new economic opportunities [15]. A prominent characteristic of green economy is to integrate the natural resources into the economic decision. For this reason, the green economy could be proposed as a method to reduce environmentally harmful practices and improve the environment. Green economy could also facilitate the economy to grow while ensuring it more effective to use resources.

Emerging countries used to learn developed countries' experience to promote their economy into "Green" [6]. As a forerunner, developed countries assist emerging countries to handle their environment problems by providing funding for environmental projects and facilitating the transfer of clean technology. Through international imitation of green technology, emerging countries with heavy pollutions have the opportunity to adopt clean techniques of the leaders and hence catch up with high productivity countries. However, emerging countries are possessing different industrial structures with developed countries. The industrial structure of developed countries whose service industry has occupied almost 70 percent of the total GDP on average has been upgraded into service-oriented [16]. In contrast, most emerging countries are still in the process of industrialization. Industries such as mining, manufacturing, and building still occupy a large proportion of the total economy. These industries consume huge amount of energies in production process and discharge industrial waste water, carbon dioxide, and solid waste, which result in serious damage to the environment. It is unachievable to learn the green technology from developed countries across all fields [17]. In addition, developing countries need to pay a huge fee for professional technology and patents in clean production that are monopolized by developed countries. In general, emerging countries are lagging behind developed economies in environmental stewardship. Facing severe environment problems in industrialization, it is necessary for emerging countries to promote green economy independently. Imitating developed countries' experience can no longer be suitable for their production. Innovation plays a role of creating new production models to improve the production capacity, performance, and quality, which could reduce energy input and waste discharge. As innovation is critical in the green economy, some emerging countries begin to invest in R&D to promote technical innovation [18].

Research about green economy is often conducted through a system approach, in which the environment problems are produced from the growth of production inputs and outputs [19]. Studies treat green economy as a system, which needs resource and energy inputs that help it to work and generate products and wastes (Figure 1). Compared with traditional research in economic process, scholars add environmental and social issues in research of green economy [20]. They estimate the economy performance by considering the material resources and energy a country consumes and the wastes that are generated. The transition to green economy requires specific conditions to encourage private and public investment. Currently, the enabling condition is heavily weighted to the fossil fuel-reliant, resource-squandering, and environmentally detrimental "brown economy." The enabling condition usually consists of national policies, incentives, and regulations, as well as trade and technical assistance, international market, and legal infrastructure [21]. Government plays an essential role in fostering an environment conducive to green economic decision from both the public and the private sectors.

Some studies treat the green economy as an input-output system for empirical research. For input indicators, capital and labor are considered as primary factors for economy production [22]. Workers, services, and production processes play essential roles in environment improvement to promote environmental safety and prevent negative influences on the environment [23]. Electricity, crude oil, and water are essential input factors for production, which are also closely related to people's well-being and environmental protection [24]. Since demand for freshwater, electricity, and crude oil will increase dramatically over the next decade due to increasing industrialization, economy development, population, urbanization, and climate change, how to efficiently use these resources has been a critical issue for emerging countries.

For output indicators, GDP was widely used as a primary indicator for economic development. GDP denotes the desirable output. A high production in GDP indicates a good economy development for an emerging country [25]. Since the concept of green economy attaches great attention to the influence of economic activities on environment, the waste outputs are indispensable indicators for evaluating the performance of green economy. Solid wastes and carbon dioxide which are the main industrial emissions were selected as waste output indicators. They are all undesirable output indicators due to the negative influence on environment. Among pollutants, solid waste and carbon dioxide are also technologically applicable and economically affordable sources that emerging countries attempt to reduce [26]. High production in undesirable outputs is harmful to the environment. Reducing solid waste, sewage, air pollution, noise, and waste heat are critical for countries that are engaged in environmental innovations [23]. Therefore, they are expected to get decreased in the economy activity.

The main contribution of this study is to conduct an integrated framework to analyze the development of green economy in emerging countries by considering environmental factors. The role of innovation in green economy will be empirically examined. Finally, by comparing the empirical results among different countries through a pioneering method, more detailed improvement strategies could be proposed for each country to better promote their green economy.

3. Research Design

3.1. Dynamic Model for Evaluating Green Economy's Performance. Rising industrialization in emerging countries increases the demand for a better environment. The rise of green economy aims to reduce air and water pollution, the reliance of industrial processes on raw materials, and energy consumption. Green economy emphasizes to use energy more efficiently and exhaust fewer wastes. Many studies often treated green economy as an input-output production process, during which a country can transform capital, employees, energy, and other raw materials into products and wastes [27]. An integrated research framework for green economy will be proposed according to the bottom line of social, economic, and environmental aspects, which could evaluate its development and help to achieve green growth.

This study utilized a dynamic model to investigate green economy of emerging countries by defining it as achieving the goals of using fewer resources while producing more GDP and fewer wastes in the gross production process (Figure 2). Previous studies consider that resource inputs, GDP, and waste outputs are three foundations for green economy activity [28]. The dynamic productivity changes of green economy over time could be analyzed in this dynamic model. According to previous studies about productivity changes in green economy, the reasons that cause productivity changes were divided into catch-up effect,

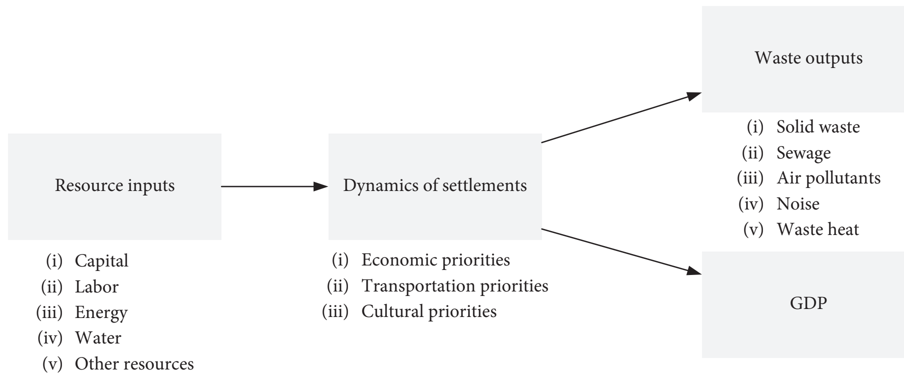

Figure 1: Research framework for green economy.

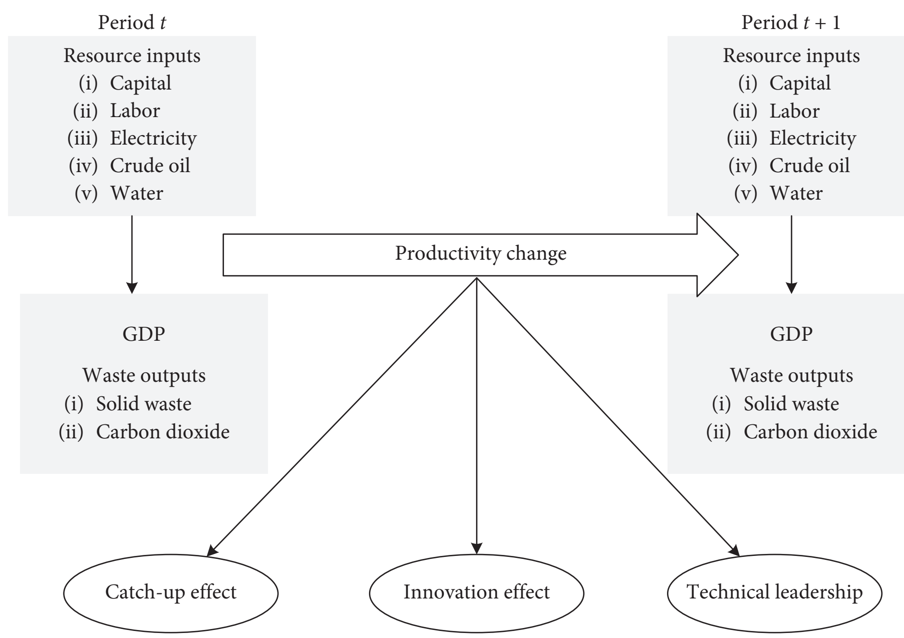

Figure 2: Dynamic model for emerging countries' green economy activity.

innovation effect, and technical leadership [29]. Catch-up effect indicates that a country imitates other country's technology in the development of green economy. Innovation effect measures technology innovation of green economy in the best practice gap ratio over periods. Technical leadership indicates technology differences between a country and global technological frontier, which stems from different availability of technical capacity caused by the regulations, social capital, and laws [30]. Table 1 presents the input and output indicators in the model.

3.2. Samples and Data Collection. This study chose 39 emerging countries from Africa, Asia, and Europe as research samples (See Table2). These countries have experienced rapid industrialization during the past years. Environment pollution is becoming an urgent issue for them. The research data are obtained from UNESCO Institute for Statistics, IMD World Competitiveness database, and World Development Indicators of World Bank for the period 2008–2017. The descriptive statistics for each indicator are provided in Table 3.

3.3. Methodology. Data envelopment analysis (DEA) is a suitable technique for assessing the performance of green economy. Considering multiple inputs and outputs, this method constructs a multifactor performance evaluation model using linear programming to derive a production frontier for measuring efficiency [38]. However, the performance changes across periods could not be well evaluated by this method [20]. Some studies analyze the productivity changes by incorporating the Malmquist–Luenberger productivity indicator (MLPI) [39]. Chen and Golley [40] used a directional distance function and the MLPI to assess green total factor productivity of China's industry. The estimate of sector-level and aggregate growth revealed that Chinese industry was not on the path to a low-carbon and sustainable growth yet. Li and Lin [41] introduced an improved MLPI to assess green productivity growth of China's manufacturing sector during 2006–2010.

Table 1: Indicators' definitions and resources.

Variable	Definition	References
Inputs		
Capital	Gross capital formation in a country	[22, 31]
Labor	Employment in a country	[22, 31, 32]
Electricity	Annual electricity consumption	[31–34]
Crude oil	Annual crude oil consumption	[33, 35]
Water	Annual water consumption	[34, 36]
Desirable outputs		
GDP	Annual market value of all the final goods and services	[25, 35]
Undesirable outputs		
Solid wastes	Solid wastes generated annually	[36, 37]
Carbon dioxide	Carbon dioxide generated annually	[32, 37]

Table 2: Average productivity change of the green economy for each country (2008–2017).

DMU	Catch-up effect	Innovation effect	Technical leadership	Metafrontier MLPI
America				
Brazil	0.9782	1.0210	1.0034	1.0056
Chile	1.0017	1.0096	0.9930	1.0042
Colombia	1.0027	1.0143	0.9903	1.0072
Costa Rica	0.9869	0.9853	1.0102	0.9913
Dominican	1.0010	1.0079	0.9986	1.0075
Mexico	0.9666	1.0337	1.0115	1.0107
Peru	1.0308	0.9901	1.0182	1.0446
Uruguay	1.0046	0.9951	0.9990	0.9987
Venezuela	1.0056	1.0153	1.0006	1.0216
Asia				
Bangladesh	0.9804	1.0024	0.9995	0.9823
China	1.0010	1.0255	1.0155	1.0426
India	1.0039	0.9943	1.0010	0.9996
Indonesia	0.9775	1.0161	0.9917	0.9850
Iran	1.0164	1.0261	0.9712	1.0128
Israel	1.0368	1.0093	1.0187	1.0660
Malaysia	1.0077	1.0125	1.0000	1.0203
Pakistan	0.9971	1.0251	0.9794	1.0011
Philippines	0.9884	1.0247	1.0046	1.0174
Sri Lanka	1.0066	1.0066	1.0049	1.0182
Tajikistan	1.0224	0.9928	0.9904	0.9985
Thailand	1.0072	1.0194	1.0255	1.0529
Turkmenistan	1.0342	1.0032	1.0100	1.0479
Uzbekistan	1.0443	0.9851	0.9911	1.0195
Viet Nam	0.9772	1.0175	1.0198	1.0140
Europe				
Belarus	1.0454	1.0096	1.0217	1.0783
Croatia	0.9969	1.0062	1.0110	1.0141
Czech	1.0153	1.0120	1.0179	1.0458
Estonia	0.9912	1.0061	1.0155	1.0127
Georgia	1.0029	0.9484	1.0114	0.9620
Hungary	1.0009	1.0053	1.0155	1.0218
Latvia	1.0136	1.0157	1.0154	1.0454
Lithuania	1.0190	0.9983	1.0176	1.0352
Poland	1.0185	1.0016	1.0177	1.0381
Romania	1.0214	1.0082	0.9948	1.0080
Russia	1.0363	1.0356	0.9942	1.0669
Serbia	1.0256	1.0027	0.9896	1.0177
Slovakia	1.0093	1.0043	1.0116	1.0254
Slovenia	0.9922	1.0176	1.0199	1.0297
Ukraine	1.0234	1.0142	1.0100	1.0483
Mean	1.0067	1.0058	1.0036	1.0165

Table 3: Descriptive statistics of indicators for the 39 emerging countries (2008–2017).

Variable	Unit	Mean	Max	Min	S.D.
Capital	Million US Dollars	259,384	7,201,938	3,891	449,293
Labor	Thousand persons	52,310	795,561	614	25,934
Electricity	TWh	235	6173	11	116
Crude oil	Million tons	112	588	7	87
Water	Million tons	87	677	22	127
GDP	Million US Dollars	319,382	12,237,758	4,989	829,381
Solid wastes	Million tons	109	3,758	4	203
Carbon dioxide	Thousand tons	19,294	103,571	259	11,592

MLPI could analyze productivity changes by decomposing them into efficiency change (catch-up effect) and technical change (innovation effect). In spite of the remarkable feature, it should be mentioned that there are defects within this method [42]. MLPI assumes that all the decision making units (DMUs) drawn in the evaluation possess the same function that invalidates the direct comparison between countries from different regions or continents. As the heterogeneity during each region would lead to different production environments, the production activity of a country within one region could be different from that of other regions. Each region has its specific production technology that defines the production activity mode in that region. The productivity of a green economy that operates under a given production technology could not be compared with that operating under a different technology directly. The measured productivity will be biased without taking the region heterogeneity into account.

Many studies point that the comparison between countries contending with different technological restrictions is suggested to employ the metafrontier approach when assessing the performance [43]. Oh [44] proposed the metafrontier MLPI in consideration of the heterogeneity of each region. This method could present the environmental sensitive productivity growth index by incorporating each region's heterogeneity into traditional MLPI. The metafrontier MLPI incorporates ex-ante region heterogeneities and undesirable outputs in productivity change evaluation by following the DEA technique. This technique is framed from the distance function that is computed with respect to the metafrontier. It could be split into separate measures: efficiency change, technical change, and technical leadership [45]. Together with the above contributions that primarily focus on methodology issue, a substantial body of research empirically evaluated the productivity changes at different geographical levels, which accounted for environment impacts [27, 42, 43].

The metafrontier MLPI could be analyzed through the following three steps:

(i) Basic modelling assumptions of metafrontier MLPI

Assume that there are $l = 1, \ldots, L$ emerging countries. Each country will employ M inputs ($x \in R_{+}^{M}$) to generate Q undesirable outputs ($z \in R_{+}^{Q}$) and N desirable outputs ($y \in R_{+}^{N}$) in its green economy (inputs include capital, labor, electricity, crude oil, and water; undesirable outputs refer to waste outputs; desirable output is represented by GDP). The process can be expressed through the possibility set [10]:

$$P = \{(x, y, z) | x \text{ generate} (y, z)\}. \tag{1}$$

The output should be freely disposable as we assume the production possibility set is bounded and closed. The following axioms are needed [44]:

$$\text{if } (x, y, z) \in P \text{ and } 0 \leq \theta \leq 1, \text{ then } (x, \theta y, \theta z) \in P, \tag{2}$$

$$\text{if } (x, y, z) \in P \text{ and } y' \leq y, \text{ then } (x, y', z) \in P, \tag{3}$$

$$\text{if } (x, y, z) \in P \text{ and } z = 0, \text{ then } y = 0. \tag{4}$$

Equation (2) entails that it is costly to reduce the undesirable outputs. Reductions in the undesirable outputs need to be coupled with synchronous reductions in the desirable outputs. There is a strong disposability that is presented by equation (3), which assumes the desirable outputs are not necessarily reduced with declines in the undesirable outputs. Equation (4) implies no desirable outputs could be generated until a few undesirable outputs have been generated.

The directional distance function will be employed for its empirically applying after we define the production possibility set. This directional distance function here reduces the undesirable outputs and maximizes the desirable output production simultaneously [46]. We define the directional distance function as

$$\overrightarrow{D}\left(x, y, z, \overrightarrow{g_y}, \overrightarrow{g_z}\right) = \max\left\{\beta\colon \left(x, y + \beta \overrightarrow{g_y}, b - \beta \overrightarrow{g_z}\right) \in P\right\}. \tag{5}$$

The vector $\overrightarrow{g} = (\overrightarrow{g_y}, \overrightarrow{g_z})$ describes the direction of the output, where the undesirable outputs decrease while the desirable outputs increase.

(ii) Formulation of the metafrontier MLPI

There are three sets of benchmark technology essential for the metafrontier MLPI: the contemporaneous benchmark, the intertemporal benchmark, and the global benchmark [46]. The technology of contemporaneous benchmark can be defined as

$$P_{R_h}^{t} = \left\{\left(x^t, y^t, z^t\right) \middle| x^t \text{ can produce}\left(y^t, z^t\right)\right\}, \quad t = 1, \ldots, T. \tag{6}$$

Equation (6) builds up a reference production set during the given time. The technology of intertemporal benchmark is formed from the single reference production set acquired from observations for a specific region R_h over the whole period:

$$P^I_{R_h} = P^1_{R_h}\%\cup P^2_{R_h}\%\cup \cdots \%\cup P^T_{R_h}. \quad (7)$$

There are H different technologies of intermodal benchmark. An emerging country that uses a specific intertemporal benchmark technology could not get different intertemporal benchmark technology.

The technology of global benchmark would establish the single reference production set according to samples that are made for all types of technology that are compared over the whole time period. It can be defined as

$$P^G = P^I_{R_1}\%\cup P^I_{R_2}\%\cup \cdots \%\cup P^I_{R_H}. \quad (8)$$

The contemporaneous benchmark technologies ($P^{Ct}_{G_l}$ and $P^{Ct+1}_{G_l}$) were enveloped in a specific intertemporal benchmark technology of ($P^I_{G_l}$) while all intertemporal technologies were enveloped in the global benchmark technology (P^G). These definitions about benchmark technology sets can define metafrontier MLPI as a developed form of the MLPI [44]:

$$\mathrm{MMLPI}\left(x^t, y^t, z^t, x^{t+1}, y^{t+1}, z^{t+1}\right) = \frac{\overrightarrow{D^G}\left(x^t, y^t, z^t\right) + 1}{\overrightarrow{D^G}\left(x^{t+1}, y^{t+1}, z^{t+1}\right) + 1}. \quad (9)$$

The global directional distance function $\overrightarrow{D^G}(x, y, z) = \max\{\beta | (x, y + \beta y, z - \beta z) \in P^G\}$ in equation (9) is formed from the global technology set. According to Oh [44], the metafrontier MLPI could be decomposed as

$$\begin{aligned}
\mathrm{MMLPI}\left(x^t, y^t, z^t, x^{t+1}, y^{t+1}, z^{t+1}\right) &= \frac{\overrightarrow{D^t}\left(x^t, y^t, z^t\right) + 1}{\overrightarrow{D^{t+1}}\left(x^{t+1}, y^{t+1}, z^{t+1}\right) + 1} \times \frac{\left(\overrightarrow{D^I}\left(x^t, y^t, z^t\right) + 1\right)/\left(\overrightarrow{D^t}\left(x^t, y^t, z^t\right) + 1\right)}{\left(\overrightarrow{D^I}\left(x^{t+1}, y^{t+1}, z^{t+1}\right) + 1\right)/\left(\overrightarrow{D^{t+1}}\left(x^{t+1}, y^{t+1}, z^{t+1}\right) + 1\right)} \\
&\quad \times \frac{\left(\overrightarrow{D^G}\left(x^t, y^t, z^t\right) + 1\right)/\left(\overrightarrow{D^I}\left(x^t, y^t, z^t\right) + 1\right)}{\left(\overrightarrow{D^G}\left(x^{t+1}, y^{t+1}, z^{t+1}\right) + 1\right)/\left(\overrightarrow{D^I}\left(x^{t+1}, y^{t+1}, z^{t+1}\right) + 1\right)} \\
&= \frac{\mathrm{TE}^{t+1}}{\mathrm{TE}^t} \times \frac{\mathrm{BPC}^{t+1}}{\mathrm{BPC}^t} \times \frac{\mathrm{TGR}^{t+1}}{\mathrm{TGR}^t} = \mathrm{EC} \times \mathrm{BPC} \times \mathrm{TGC},
\end{aligned} \quad (10)$$

where EC (efficiency change) denotes the technical efficiency change of how much an emerging country shifts towards the technology of contemporaneous benchmark at time period $(t, t+1)$. If $\mathrm{EC} > 1$, it indicates the efficiency is improved over time; otherwise, $\mathrm{EC} < 1$ denotes the efficiency is deteriorated.

BPC (best practice gap change) denotes the innovation efficiency. It measures the technology change of green economy in the best practice gap. It could measure the innovation effect. If $\mathrm{BPC} > 1$, the technology frontier of contemporaneous benchmark moves to the technology frontier of intertemporal benchmark; otherwise, $\mathrm{BPC} < 1$ implies the technology is leaving the technology frontier.

TGC (technical gap change) denotes the technology shifts from the intertemporal benchmark to the global benchmark over the period $(t, t+1)$. TGC indicates the technology leading effect under different external environment. If $\mathrm{TGC} > 1$, it indicates the technical gap between a given region and global frontier technology gets narrowed; otherwise, $\mathrm{TGC} < 1$ implies the technical gap is widening.

EC, BPC, and TGC represent the catch-up effect, innovation effect, and technical leadership of green economy, respectively. Metafrontier $\mathrm{MLPI} > 1$ implies the productivity has improved overtime; otherwise, it implies the productivity has declined.

(iii) Calculating the metafrontier MLPI

Equation (9) needs to be measured to calculate the metafrontier MLPI. The following six directional distance functions need to be estimated to obtain the value of EC, BPC, and TGC: $\overrightarrow{D^S}(x^s, y^s, z^s)$, $\overrightarrow{D^I}(x^s, y^s, z^s)$, and $\overrightarrow{D^G}(x^s, y^s, z^s)$. The DEA technique will be employed to calculate the directional distance function. The following linear programming model will be solved:

$$\overrightarrow{D}^d\left(x^{l',s}, y^{l',s}, b^{l',s}\right) = \max \beta$$
$$\text{s.t.}$$
$$\sum_{\text{con}} \lambda^{l,s} y_n^{l,s} \geq (1+\beta) y_n^{l's}, \quad n = 1, \ldots, N,$$
$$\sum_{\text{con}} \lambda^{l,s} z_q^{l,s} \geq (1-\beta) z_q^{l's}, \quad q = 1, \ldots, Q, \tag{11}$$
$$\sum_{\text{con}} \lambda^{l,s} x_m^{l,s} \leq x_m^{l's}, \quad m = 1, \ldots, M,$$
$$\lambda^l \geq 0,$$

where $d\,(d = S, I, G)$ represents each type of the directional distance function, $\lambda^{l,s}$ denotes the intensity variable, representing the intensity of how much a particular activity would be used in construction of the production possibility set, and con denotes the condition for building a production possibility set.

4. Empirical Analysis

4.1. Productivity Changes in Green Economy of Emerging Countries. The productivity changes and their divided components for the sample of 39 emerging countries' green economy during 2008–2017 were calculated to evaluate their performance by incorporating regional heterogeneity. These countries were grouped into three regions according to their locations: America, Asia, and Europe. The productivity changes were decomposed into three effects to investigate its productivity progress patterns: catch-up effect, innovation effect, and technical leadership, the detailed values of which are listed in Table 2.

The total productivity has increased 1.65% from 2008 to 2017 on average. Regardless of the methodologies employed, if factor input of an emerging country is fixed during the period, its GDP would increase by 1.65% while solid wastes and carbon dioxide were reduced by 1.65% every year. Among these emerging countries, Belarus (7.83%) was found to be the fastest growing country, followed by Russia (6.69%) and Israel (6.60%). The protection of ecological environment was not neglected in these countries while developing domestic economy. Industries with high energy consumption and serious pollutions have been restricted in these countries.

Through decomposing the productivity change, it presents that catch-up effect (0.67% on average) plays a primary role in promoting productivity progress. Through catch-up effect, the gap between a country's present technology level and the frontier technology was narrowed. The average value of innovation effect is 0.58%, ranking second in promoting productivity progress, which means that some countries begin to attach importance to technology innovation. The current increasing concern and policy about environment and resource have fostered advances in technology innovation, which has become another way to cope with environment problems. The average annual changes in technical leadership is 0.36%, denoting gaps between the total emerging countries and the regional technology frontier were slowly narrowed.

4.2. Productivity Changes for Each Region. An emerging country located in a given region usually has different production technology from those are located in other regions. The different production technologies often originate from different economic development, regulations, and government policies. For instance, Asia's average growth rate of GDP is higher than that of America and Europe, whereas Europe's average GDP is highest. The regulations about emissions of solid wastes and carbon dioxide are different during each region. These differences across each region justify the mechanism inherited in the method of metafrontier MLPI. In order to investigate the productivity changes of emerging countries' green economy in detail, the 39 countries were classified into three regions according to their locations, which are America, Asia, and Europe.

The time period was divided into two interval periods (2008–2012 and 2013–2017) to analyze trends of productivity change (Table 4). Evidence of the categorization has been discussed as proper grouping of the dataset was pivotal. In general, Europe performs best in the productivity change, with an average of 2.26% every year. America performs worst with an average of 1.13%, which falls far behind Asia (2.05%).

The three regions present different development trends. Catch-up effect occupies the main role in promoting productivity progress for America. However, low productivity in innovation effect and technical leadership have restricted its productivity growth. Furthermore, the catch-up effect is increasing, from 0.25% (2008–2012) to 1.17% (2013–2017), which indicates that it relies on more experience from other countries.

Catch-up effect occupied critical role in improving Asia' productivity for the period 2008–2012. However, the catch-up effect decreased, from 1.61% (2008–2012) to 0.70% (2013–2017), which indicates that it does not rely on imitation seriously as before. The role of innovation effect began to dominate since 2013. As the industrial structure becomes increasingly complicated during the industrialization, it is not suitable to imitate developed countries' experience for their green production. Asia turned to developing innovation technology in the green production, rather than squeezing their inputs to overtake the frontier technology.

The country-based examination of technical leadership indicates that obvious heterogeneity exists across each region, in spite of the overall trend in technical advance to the global frontier technology. Unlike the other two regions, technical leadership occupied main role in promoting Europe's productivity progress (1.02%). Europe is leading on the technology frontier because of proper industrial planning and technology accumulation, which also indicates that the technology is led by Europe. In contrast, compared to global technology progress, the technical level of America has decreased.

The contour plots of a kernel density were drawn based on the catch-up effect and innovation effect with respect to each region to investigate different patterns across the three regions more thoroughly. As presented in Figure 3, each region appears to have its own growth pattern. The distribution of America is rather scattered. Catch-up effect is still

Table 4: Average productivity change of each region.

Regions	Productivity change	2008–2012	2013–2017	2008–2017
America	Catch-up effect	1.0025	1.0117	1.0081
	Innovation effect	1.0050	0.9989	1.0031
	Technical leadership	0.9960	0.9978	0.9972
	Metafrontier MLPI	1.0118	1.0101	1.0113
Asia	Catch-up effect	1.0161	1.0070	1.0085
	Innovation effect	1.0002	1.0159	1.0091
	Technical leadership	1.0028	1.0027	1.0027
	Metafrontier MLPI	1.0192	1.0215	1.0205
Europe	Catch-up effect	1.0015	1.0072	1.0039
	Innovation effect	1.0012	1.0086	1.0047
	Technical leadership	1.0106	1.0100	1.0102
	Metafrontier MLPI	1.0171	1.0268	1.0226

dominating compared to innovation effect. In contrast, Asia tends to pursue technology innovation. The catch-up effect and innovation effect perform similar distributions in Europe, where the productivity changes during each country are relatively close.

A kernel density estimation was drawn to better investigate the technical leadership of each region (Figure 4). The technical leadership distribution suggests that America is under conditions that are more restrictive than other regions. The average values of technical leadership of America lead to a decrease of productivity under the current external environment. Europe's technical leadership performs best, which could bring about 10% of the productivity under their external environment.

4.3. Innovative Emerging Countries. The result of decomposed TGC has indicated countries that own technical leadership; however, it could not distinctly identify who are innovative emerging countries. The vagueness in identifying the innovative emerging countries by TGC originates that TGC only presents the technical gap changes from the regional technology frontier to the global technology frontier, rather than the locations of a country on the technology frontier. Therefore, capturing the innovative countries is still needed. The following conditions could help to determine the regional innovative emerging countries [10]:

$$\text{BPC} > 1, \tag{12}$$

$$\overrightarrow{D^{t}}\left(x^{t+1}, y^{t+1}, z^{t+1}\right) < 0, \tag{13}$$

$$\overrightarrow{D^{t+1}}\left(x^{t+1}, y^{t+1}, z^{t+1}\right) = 0. \tag{14}$$

Equation (12) implies that the frontier of contemporaneous technology is moving to the technology level that will produce more GDP and fewer wastes, which indicates that relative to period t, it is possible to increase GDP and reduce the emissions of waste outputs in period $t + 1$. Equation (13) designates that production activity of innovative regions in period $t + 1$ happens outside the contemporaneous production possibility set of period t. Equation (14) implies that this country must be located on the frontier of environmental technology in period $t + 1$. Subsequently, the following two conditions could determine the global innovative countries:

$$\text{TGC} > 1, \tag{15}$$

$$\overrightarrow{D^{G}}\left(x^{t+1}, y^{t+1}, z^{t+1}\right) = 0. \tag{16}$$

Equation (15) implies that a region's technological level group is progressing to the global technology frontier. Equation (16) indicates this emerging country is located on the frontier of global technology at the period $t + 1$. These given countries are the set of global innovative countries.

All the regional (within-region) and global innovative countries for each year are presented in Table 5. In America, Costa Rica and Venezuela were recognized as innovative countries. Among them, Venezuela was registered seven times. Within Asia, only Israel was found as the innovative country. In Europe, Czech, Hungary, Poland, and Slovakia were identified as the innovative countries. Czech was registered seven times as a regional innovative country, followed by Slovakia (three times), Hungary (two times), and Poland (one time). The identification of global innovative countries indicates that there are no global innovative countries in America. Among the regional innovative countries from Asia and Europe, Israel (four times), Czech (two times), and Slovakia (one time) were identified to be global innovative countries. They could be employed as good examples for policy makers to learn.

As a country poor in natural resources, Israel continuously make strides in sustainable innovation since it was established. At present, the country has become the global leading innovator in cleaner technology, for instance, green construction and infrastructure, cutting-edge water shortage solutions, energy conservation, and sustainable health care. As a small country with limited resources, Israel has invested a lot to promote innovative strategies through advances in recycled resource use. For instance, a large part of the residential water comes from desalination facilities, and 85% of the water used residentially will be recycled then and employed for irrigation. The water infrastructure in Israel is highly efficient, with only a total of 8% leakage. Furthermore, the government policy is made according to the principles of sustainable development practice that combines protection of ecosystems, smart use of natural resources, and granting of equality of opportunity to all, which could guarantee a response to the need of the current and future generations.

The Czech economy has made a long-term plan for its green economy that emphasizes the balance between economy development and environment protection. Its strategy defines the principal goals, as well as partial goals and instruments, so as to remove imbalances between the

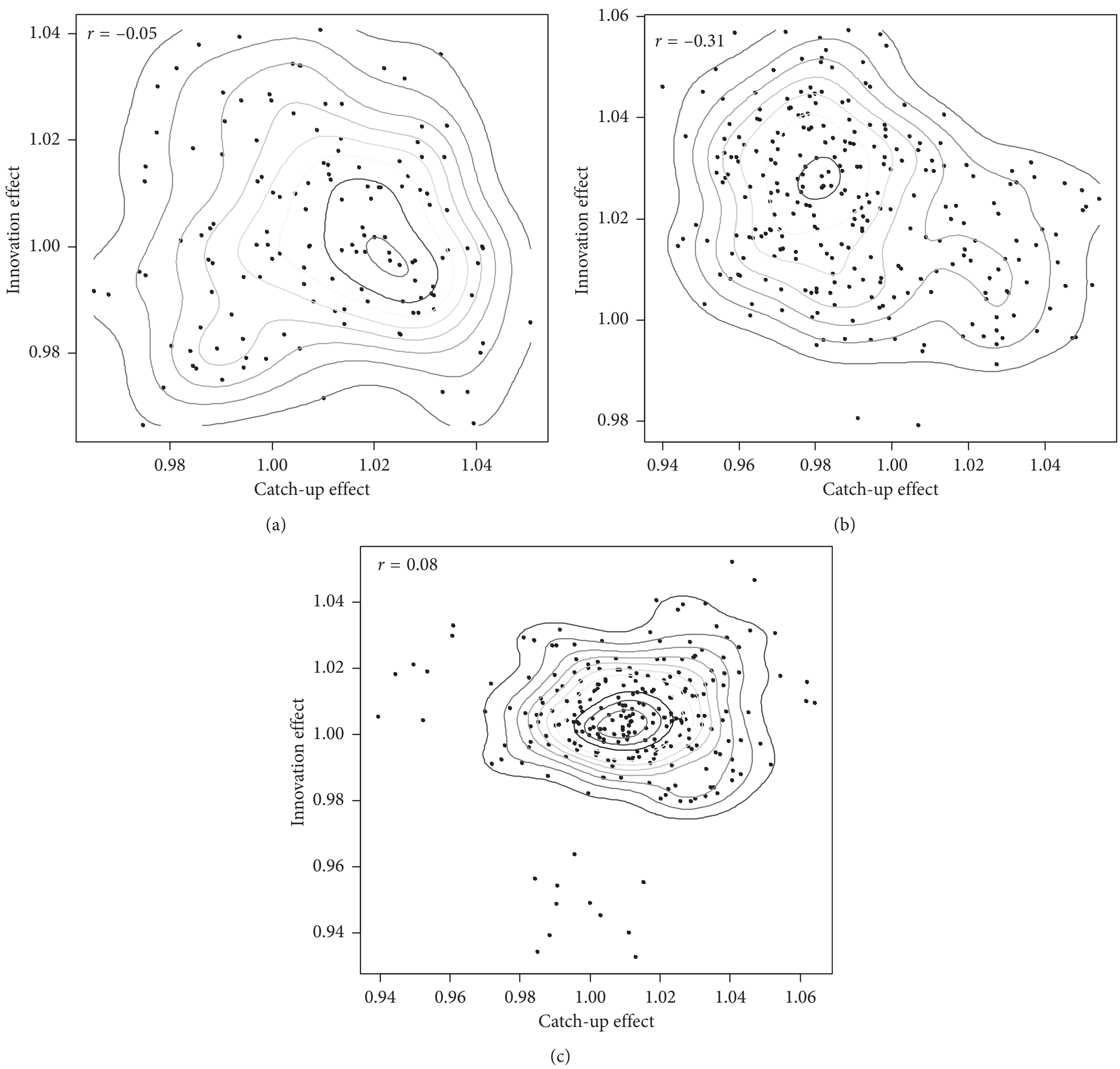

Figure 3: Contour plot of 2D kernel density estimation by catch-up effect and innovation effect. (a) America. (b) Asia. (c) Europe.

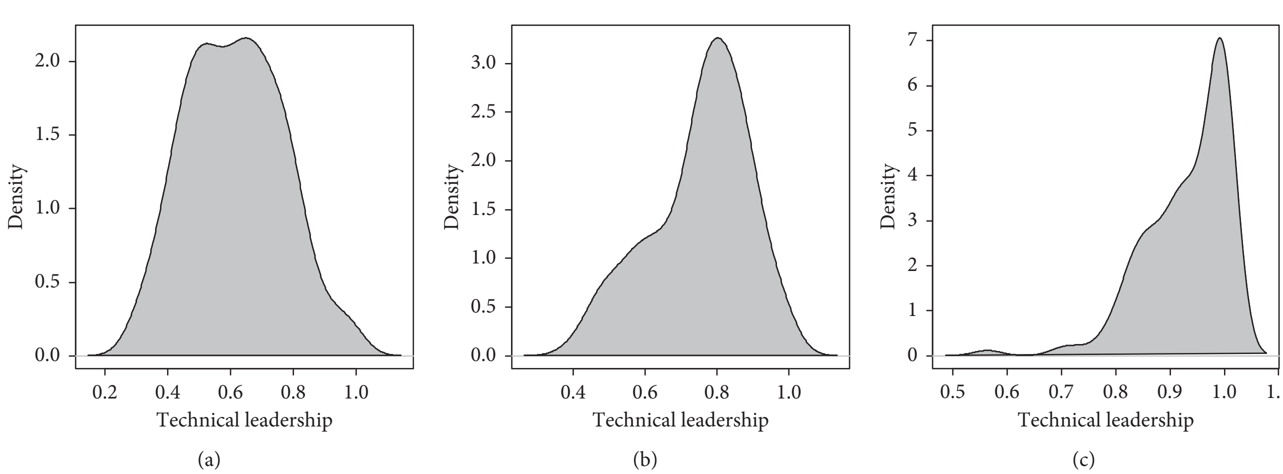

Figure 4: Kernel density estimation of each region's technical leadership. (a) America. (b) Asia. (c) Europe.

Table 5: Regional global innovative countries.

Period	Regional (within-region) innovative countries			Global innovative countries
	America	Asia	Europe	
2008-2009	Venezuela	Israel	Czech	Czech
2009-2010	—	Israel	Czech; Slovakia	—
2010-2011	Costa Rica; Venezuela	Israel	Czech	Israel
2011-2012	Venezuela	Israel	Czech; Slovakia	Israel; Slovakia
2012-2013	Venezuela	—	Hungary	—
2013-2014	Venezuela	Israel	Czech; Poland	Israel
2014-2015	Venezuela	Israel	Hungary	Israel
2015-2016	—	Israel	Czech; Slovakia	Czech
2016-2017	Venezuela	Israel	Czech	-

social, environmental, and economic pillars of sustainability. The plan was designed to attain the best achievable quality of life for current generation and create conditions for a higher quality of life for future generation. Its national strategic framework for green economy was formulated from four priorities: (1) the economy and innovation; (2) landscape, ecosystems, and biodiversity; (3) society, people, and health; and (4) regional sustainable development.

5. Discussion and Implications

Through an empirical analysis about green economy in developing countries by a dynamic model, this study identified the heterogeneity of growth pattern within them. The above empirical analysis presents that Asia was gradually transformed into innovation oriented while America still developed imitation. The energy and environment-related technologies were currently led by Europe. Even though catch-up effect still plays an important role in many countries of America and Asia, its contribution begins to get weakened. Low progress in innovation effect and technical leadership has restricted America's total productivity changes. In contrast, innovation effect and technical leadership have been promoters for productivity progress of Asia and Europe, respectively. The following implications can be obtained from empirical results.

Firstly, emerging countries are suggested to foster innovation for green growth. A combination of policy instrument could be used drive green innovation from both supply side and demand side. Policy from supply side includes generic incentive to promote private investment in research, government investment in R&D, more targeted measures to steer innovation to given sectors, and encouragement to support commercialization for green innovation. Policy from demand side could be proposed to formulate public procurement, regulation, and standard in specific market and circumstance. Green industrial policies could help to disseminate new technologies and develop new competitive and clean sectors.

Secondly, since the green economy advocates proper governance as essential prerequisite to achieve sustainable development, the government of emerging country is suggested to prepare a national socioeconomic growth strategy that makes efficient use of natural resources, discharges fewer wastes to the environment, and creates green jobs while maximizing opportunities for the use of clean growth engines. The government should develop balanced fiscal policies to reallocate sources and funds. For example, the fuel subsidy could be reallocated to spending on infrastructure, education, and health to increase economic growth and reach environmental objectives. The green sectoral intervention can help to push out the production frontier and thereby enhance energy efficiency, reduce emission improve resilience, and create green jobs.

Finally, we propose a strategy route map for each region to better promote their green economy (Figure 5).

For America that is lagging in technology and innovation of green economy, it is suggested to develop green production at first. The government needs to remove obstacles to green production, including regulatory failures. The design of products and production processes should achieve these goals: (1) efficient use of energy and natural resources during the life cycle of the production; (2) decrease in the amount of pollutions that are discharged by construction or operation of a facility; and (3) maintaining economic viability and efficiency. Clean-tech industries should be encouraged in these countries later, such as accelerating green innovation and developing markets for green products and services.

Since Asia is gradually transitioning to green innovation, governments could appeal to the public for green consumption. For instance, develop consumers' knowledge about sustainable manufacturing and agriculture products and encourage sustainable and recycling disposal of wastes. Consumers could be guided to responsibility for handling the environment problems by adoptions of environmentally friendly behaviors, such as the use of organic products and renewable energy. Transitioning to the green economy will require a new pattern for doing business. It would require a new caliber of skilled professionals and labor that could work across sectors and work as parts of multidisciplinary teams. Transition to green economy would also require preparing these calibers by formal education and training. Vocational training packages need to be developed with focus on greening the sectors in order to achieve this objective. The supplementary education system should be considered to incorporate the social and environmental considerations into the various disciplines.

As the technical leader, Europe is suggested to promote green innovation continuously. From the macro perspective,

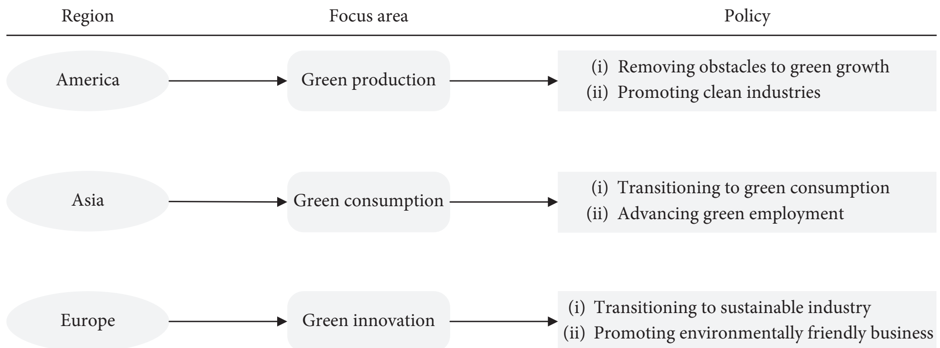

Figure 5: Strategy route map for improving green economy.

the industrial structure could transition to be sustainable and recycled. For instance, the circular economy mindset could be applied while designing services and products so that there would be improved end-of-product lifecycle recycling and reuse. From the micro perspective, more green brands and environmentally friendly business sectors should be encouraged by government policies. The green branding can bring about environnment consious from consumers that desire to prefer eco-friendly products.

6. Conclusions

Since the environment concern has grown in recent years, the green economy that incorporates the effect of environmentally harmful by-product has been an urgent issue. The increasing complexity of industrial structure requires a new development path for emerging countries to develop technology in cleaner production. This study has created an environmentally sensitive economy growth analysis by incorporating the study of green economy and metafrontier MLPI. The concept of green economy was taken into account when investigating emerging countries' economy development in this study. The productivity growth of green economy was divided into catch-up effect, innovation effect, and technical leadership. We found that America is still an imitator in developing green economy. In contrast, Asia is stepping into an innovation region, which has become another critical promoter for green growth. Europe was found to lead on the technology frontier because of proper industrial planning and technology accumulation. The progress to innovation and technical leadership could ensure a stable green growth in the future. The research could be a route to open up the possibility of extending current study of green economy. Furthermore, the empirical result could also provide implications for the policy makers in relation to sustainable growth.

Despite its contribution, there are limitations associated within this study. This study selected 39 emerging countries as research samples, without considering developed countries. Future studies could make investigations by including developed countries to provide more insights and suggestions. Innovation effect and technical leadership are found to be important driving forces for emerging countries' green economy growth. However, innovation can be classified into environmental innovation and nonenvironmental innovation, which could bring about different impacts on growth [23]. Factors that influence the performance of green economy were not explored. Future studies could address empirical analysis by investigating these issues to provide more detailed implications for practitioners.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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