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The Role of the Eco-Industrial Park (EIP) at the National Economy: An Input-Output Analysis on Korea

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Abstract: The eco-industrial park (EIP), which aims to minimize by-product and unused energy via reuse and recycling within the industrial complex, offers an innovative pathway to realize regional eco-industrial development. As an environmental, as well as business, innovation, the EIP enables changing the perception of industries and create new business values via the whole supply chain, but such evidences have been less reported to date. As one of the world famous promoter on EIPs, the Republic of Korea (ROK) initiated a national EIP project to enhance its competitiveness and solve environmental problems. While the existing literature reviewed and highlighted its economic outcomes in terms of direct performances of firms within the project, the indirect impacts on the supply chain of national economy were less investigated. Within this circumstance, this study performed a first attempt to apply an input-output analysis (IOA) to investigate the effects of the EIP project on the whole economic system of Korea, via an exogenous specification of the EIP sector in the input-output tables (IOTs). General economic effects in terms of value-added change, employment generation, as well as specific effects like the inducement effects and effects of supply shortage and price pervasiveness were evaluated based on the IOA approach (including demand-driven, supply-driven, and Leontief price models). Results highlighted that, from the supply chain perspective, implementing the EIP project made production and value-added grow by around 1264 billion KRW and 272 billion KRW, respectively (with a unit induction coefficient of 1.6201 and 0.3489 for production and value-added). While generating a direct employment around 1000, an indirect employment was also created of over 5000 persons in the whole supply chain (with an employment inducement effect of 6.4512 persons per 1 billion KRW investment). The production shortage cost from 1 KRW of supply failure is 1.1230 KRW. In summary, EIP was proved to be not environmentally friendly, but also a driver to improve the overall economic performance of upstream and downstream industries in the whole supply chain. As a first attempt to link IOA with EIP, the results of this paper are expected to enlighten policy-makers to forward continued improvement on EIP promotion and combine the EIP idea within national economic system reform and planning.

Keywords: input-output analysis; eco-industrial park; regional eco-industrial development; exogenous specification; Korea

1. Introduction

The green growth of industries is one critical issue for sustainable development goals (SDGs) [1,2], particularly industrialization and urbanization usual interact. It is well known that the industrial sector is the engine for national economy boosts. Meanwhile it also contributes to most of the environmental impacts globally, like carbon and resource footprints, as well as critical pollutants emissions [3–5]. With the surging population, rapid economic growth, industrialization, enhanced living quality, as well as the underlying resources and energy consumption, pure technological innovations are unlikely to entirely offset the environmental impacts generated, e.g., it was estimated that even with the best projections of technological solutions in the future, it was unlikely to achieve the optimistic 50% CO_2 mitigation target, due to sharp increasing demand driven by economic growth globally and rapid urbanization procedures [6,7]. With this circumstance, it urgently requires new and systematic solutions apart from pure technical options to push forward sustainability with consideration of the combined challenges including, but not limited to, optimal resource efficiency options, reduced ecological footprints, and fighting climate change.

As a high land productivity measure, industrial parks are a way to enhance resource productivity by locating industries in certain areas of land and offering to share of infrastructure and services inside the parks, and has already been the economic engine for many rapidly developing countries like China, Republic of Korea (ROK, which will be simplified as "Korea" in the following context), and most other developing countries [8–10]. While they have contributed to the economic growth and social development, they also play a negative role at generating significant environmental impacts, like GHG and air emissions, water pollution, land contamination, and over-consumption of resources and energy. Thus, a green transmission of industrial parks is an effective way to green the national economy [11,12].

Industrial ecology and industrial symbiosis concepts offer innovative pathways to "green" the industrial park. Under this concept, the industrial complex is designed to be an eco-industrial park [13–15]. An eco-industrial park (EIP) is defined as an industrial complex in which efforts to minimize the generation of waste, by-products, pollutants, and/or unused energy apply, by utilizing them in a closed loop among processes by companies in the industrial park [16–19]. In this way, various firms inside the park or processes of the firm try to use the waste/by-products as the raw material inputs and share the infrastructures correspondingly [4,11,20]. The sustainability of the built environment can be hereby improved as well [21,22]. Particularly, EIP is as a key component of the circular economy, which is already highlighted as an effective way to generate low-carbon benefits [6,23–25]. However, to our best knowledge, the evidence of how such practices lead to innovation on both economic and environmental systems is less reported [13,14].

Furthermore, EIP is recognized as an environmental as well as business innovation, enabling changing the perception of industries and creating new business values via the whole supply chain, but such evidence has been less reported to date [15,26]. From a supply chain perspective, sectors engaged in the EIP project not only generate benefits themselves, but also have indirect effects on the upstream and downstream sectors [15,27,28]. Therefore, EIP development was identified as a green growth agenda to generate incremental innovation and systematical innovation for green business [27–29]. Having a clear picture on how such innovation can affect the economic system is critical for policy-makers to incorporate EIP promotion into regional and national economic planning. However, a systematical investigation on this field was still rather limited.

Input-output analysis (IOA) is the prevailing and strong method to analyze the interdependencies between the various branches of a national economy by utilizing the statistical table in which the business relations among industries is recorded in matrix format. This analysis method can simply discern how the effect created at an industry impacts other industries [10,13,30]. As a well-acknowledged approach on economic system analysis, and with increasing application in environmental system analysis (e.g., environmental extended IOA, EEIOA), the IOA method is valuable to investigate the impacts of EIPs on the national economy, as it offers to bridge the EIP's related sectors to the national economic system via providing the economic information and interactions among sectors in the economic system (e.g., recognizing the EIP investment embodied in the sectorial output) [31–33]. While existing literatures reviewed and highlighted its economic outcomes in terms of direct performances of firms within the project, the indirect impacts on upstream and downstream firms were less investigated [12,13].

Finally, EIPs have been promoted globally, particularly for the Asia-Pacific region, which has been recognized as the fastest growing economic and resource-consuming region in recent decades [34,35]. As a key member in East Asia, Korea has been featured with transiting to a mature, developed country, the importance of industrial parks on the national economy, and the national strategy of green growth and circular economy. Particularly, Korea is one of the main practitioners of EIP. Since 2005, it has carried forward the national EIP development program (EIP program), the objective of which is to transform traditional industrial parks to eco-industrial parks to improve the competitiveness and solve the environmental problems of the industrial complex [36–38]. Hence it offers an ideal laboratory to test the role of EIP on national economic system.

Based on the above knowledge gap and scientific highlights, this study performed an input-output analysis (IOA) to investigate the effects of the EIP project on the whole economic system of Korea, via an exogenous specification of the EIP sector in the input-output tables (IOTs). To our best knowledge, this was a first attempt to investigate this topic. General economic effects in terms of value-added change, employment generation, as well as specific effects like the inducement effects and effects of supply shortage and price pervasiveness, were evaluated based on the IOA approach (including demand-driven, supply-driven and Leontief price models). Our results are expected to enlighten policy-makers to forward continued improvement on EIP promotion and combine the EIP idea within national economic system reform and planning.

The remainder of this paper is organized as follows: after this introduction section, Section 2 has an overview on Korea's EIP program, as well as the related economic and environmental outcomes; Section 3 describes the detailed technical information on the IOA approach employed in this paper; Section 4 presents the analytical results and the related discussions; and, finally, Section 5 draws the conclusions and critical policy implications.

2. Overview on Korea's National EIP Program

From a war-torn and poverty-stricken country in the 1950s to the world's 11th largest economy in 2015, Korea has achieved economic growth that is often described as a "miracle". Korea's dramatic economic transition started in the 1960s with a series of government-led five-year economic development plans. Industrial Complexes (ICs), specialized areas for industrial clusters, played a significant role in the process and were the main engines of growth. The number of ICs grew from two in the 1960s to 1124 in 2015 with total land area of 1400 square kilometers, with approximately 80,000 companies operating in various types of ICs across the country. Economic outputs of the ICs totaled KRW 928.9 trillion in 2015, representing 63% of the national GDP. Exports supported by companies operating in ICs accounted for 73% of the national total for the same year.

Industrial complex in Korea had been promoted since 1960s, and played the role as the engine of national economy boost. Meanwhile, with intense clustering of the industries and the aging facilities, significant environmental impacts were generated from industrial parks. Under this circumstance, the Ministry of Environment (MOE) imposed stricter environmental regulations on the industrial parks, and as response, a number of early approaches were adopted in the parks, such as the installation of environmental infrastructures, end-of-pipe technologies, as well as industrial waste treatment facilities. As only reactive and constructive measures, end-of-pipe technologies were usually inefficient economically and environmentally in respond to pollution prevention and resource scarcity. As a result, more proactive actions were called for. To address such challenges, in 2005, the Ministry of Knowledge Economy (currently the Ministry of Trade, Industry, and Energy (MOTIE)), Korea initiated an ambitious 15 year, three-phase EIP program under the leadership of Korea National Cleaner

Production Center (KNCPC) [38] and revised continuously (illustrated as Figure 1). The EIP, which is applying the concept of a natural ecosystem to the industrial complex, is an eco-friendly industrial complex to establish an industrial symbiosis network by utilizing waste/by-product, wastewater, and unused energy produced within the industrial complex as a raw material or energy source of other firms or plants [39]. In late 2006, the ownership of this program was transferred to the Korea Industrial Complex Corporation (KICOX), affiliated with Korea's Ministry of Knowledge Economy, to strengthening EIP transition. A total of twelve regional centers were selected under this project, five in the first phase, four in the second phase, and three in the third phase [39] (Figure 1).

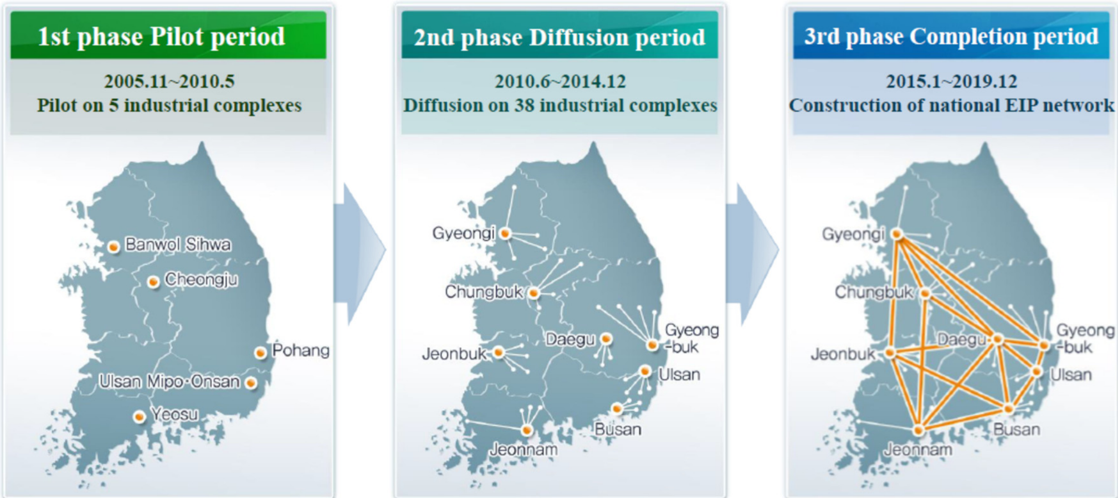

Figure 1. Regional EIP centers for the Korea's national EIP project (2005~2019). Source: KICOX EIP website (http://www.eip.or.kr/).

Particularly, the national EIP project is significant practice of linking environmental and economic system. The EIP project implemented prompted firms to invest over KRW 691 billion in energy efficiency, industrial symbiosis, waste management, and other eco-friendly investments. To date, this has helped firms save over KRW 857 billion and generate KRW 1.3 trillion in new revenues. Thus, by implementing the national EIP program, Korea was able to reduce 1.7 million tons of oil equivalent (TOE) energy consumed in the industry sector, 8.54 million tons of carbon dioxide (CO_2) emissions, and 6.85 million tons of waste generated from the industrial sector. The EIP initiative in Korea also helped to create nearly 1000 new jobs as well. The commercialization of environmental projects in the EIP program significantly forwarded the sustainable development and meanwhile boosted the economy. Table S1 in "Supplementary Information" summarized the commercialized projects in the EIP program.

In the EIP initiatives, industrial symbiosis (IS) was a main promotion, in which, companies in the various positions of the supply chain collaborated with each other to exchange waste and resources, share infrastructures and services and to generate co-benefit not only in the company level, but also in the whole supply chain. Table 1 shows the cumulative number of IS project development, feasibility support, commercialization, and in operation and success ratio (%) during Korea's EIP program operation between 2005 and 2016. As shown in the table, a total 655 IS projects were proposed and 436 projects were selected to support the feasibility study and 355 projects were completed in the feasibility study, while 235 IS projects were commercially implemented in operation by the end of 2016. A total of 1831 companies in 105 industrial parks in 12 regions participated in Korea's EIP program.

Table 1. Status of IS project feasibility support and commercialization.

Year	IS Project Proposal (No)	Feasibility Support (No)	Participating Firms (No)	Feasibility Completion (No)	Commercialization and In Operation (No)	Success Ratio (%)
2005	22	22	90	-	-	-
2006	43	18	112	2	-	-
2007	35	24	160	5	1	14.3
2008	22	17	81	10	2	17.6
2009	53	35	150	31	10	27.1
2010	61	39	126	23	17	42.2
2011	72	44	203	48	20	42.0
2012	79	52	217	40	33	52.2
2013	65	45	143	46	35	57.6
2014	69	41	161	57	41	60.7
2015	74	51	182	41	38	65.0
2016	60	48	206	52	38	66.2
Total	655	436	1831	355	235	66.2

Note: data come from internal technical report of MOTIE. The authors are the participants of Korea national EIP project and hereby have access to such internal data.

Table 2 summarizes the annual environmental benefits generated from the IS projects operated since 2007. The environmental benefits were presented as the direct mitigation of energy consumption and waste generation reduction, such as by-products, wastewater and atmospheric emissions, as a result of IS implementation. With the annual benefits, cumulative benefits were further summarized. It was noted that such benefits were seen as the first-round estimates, as indirect impacts in the whole supply chain (a life cycle perspective) were not considered yet. As a summary, the total industrial symbiosis projects cumulatively reduced the generation of 6848.8 thousand metric tons of by-products, 1730.6 thousand TOE of energy, 110.9 thousand metric tons of wastewater, and 8539.6 thousand metric tons of CO_2eq of greenhouse gas emissions.

Table 2. Annual environmental benefits from IS projects operated from 2005–2016 *.

		Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Projects (in operation)		Number	1	3	13	30	50	83	118	159	197	235
1st	By-products	ton	0	38	154							
1st	Energy	toe	4	27	72							
1st	Wastewater	ton	0	0	37							
1st	CO_2	ton CO_{2eq}	12	73	184							
2nd	By-products	ton				501	930	1713	2541	3635		
2nd	Energy	toe				169	302	491	734	992		
2nd	Wastewater	ton				0	110	168	216	36,774		
2nd	CO_2	ton CO_{2eq}				442	564	916	1107	1406		
3rd	By-products	ton									5213	6849
3rd	Energy	toe									1347	1731
3rd	Wastewater	ton									36,790	36,791
3rd	CO_2	ton CO_{2eq}									1778	2058

Note: No environmental benefits were identified in 2005 and 2006, due to no projects were operated. As a result, investment and research support were not considered in this period. Data source: Internal report of MOTIE.

Similarly, economic benefits from IS projects were summarized in Table 3. The economic benefits were estimated as the sum of cost savings (e.g., reduction on raw materials consumption and purchase) and revenues (e.g., profits from by-products sales), which was annually reported to KICOX. With annual figures, cumulative benefits were estimated as well. The total economic benefits have significantly increased since 2007, when the first industrial symbiosis project was in operation. Over time, a higher proportion of the economic benefits came from revenue than cost savings. The size of economic benefits per project also increased overall, except for the year 2010. In addition to economic performance, the size of investment made by participating businesses increased over time.

The cumulative economic benefit represented by cost reduction and new sales were 943.2 billion and 1.479 trillion KRW, respectively. In addition, 761.3 billion KRW investment is attracted and 992 new job was created by Korea's EIP program, which is supported 81.1 billion KRW of EIP R and D fund from Ministry of Trade, Industry, and Energy, Korea.

Table 3. Economic benefits from IS projects operated from 2005–2014 *, and investments and research funding offered (unit: billion KRW).

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Projects (in operation), A	1	3	13	30	50	83	118	159	197	235
Economic benefits, B = C + D (B/A)	3.9 (3.9)	19.5 (6.5)	73.2 (5.6)	186.9 (6.2	357.8 (7.2)	614.9 (7.4)	926.4 (7.9)	1331.1 (8.4)	1848.1 (9.4)	2422.6 (10.3)
Cost savings, C	2.9	10.3	38.6	94.5	166.3	263.2	394.1	554.3	745.7	943.2
Revenue, D	1.0	9.2	34.7	92.5	191.5	351.7	532.3	776.7	1102.4	1479.4
Investments, E (B/E)	0.9 (4.3)	7.9 (2.5)	60.7 (1.2)	119.9 (1.6)	167.7 (2.1)	259.1 (2.4)	376.4 (2.5)	591.2 (2.3)	623.6 (3.0)	761.3 (3.2)

Data source: calculated by the author based on the financial data of the projects. Financial data was from internal reports of MOTIE.

This results show that Korea's eco-industrial park program results in strengthening industrial competitiveness and contributes to regional and national economic growth while reducing GHG emissions and improving environmental quality. Based on this evidence it is valuable to link with macro-economic models to investigate its further impacts on a broader economic system.

3. Methodology

For the sake of analyzing the effects of the national eco-industrial park project on Korea's economy, this study utilized the input-output method in three steps, as shown in Figure 2. In operation, 2013 Korea's national IOT was applied. The process of investigating the economic effect of EIP on Korea's national economic is described as follow:

- Firstly, the eco-industrial park industry was externalized based on the literature and classification of 251 reported commercialized EIP projects.
- Secondly, input-output coefficients and inducement coefficients for production, value-added, and employment were calculated by reconstructing the input-output table with externalization of the eco-industry park industry.
- Thirdly, the effect of investment for eco-industry park was analyzed based on the calculated coefficients, and estimated the impact with the actual investment data available.

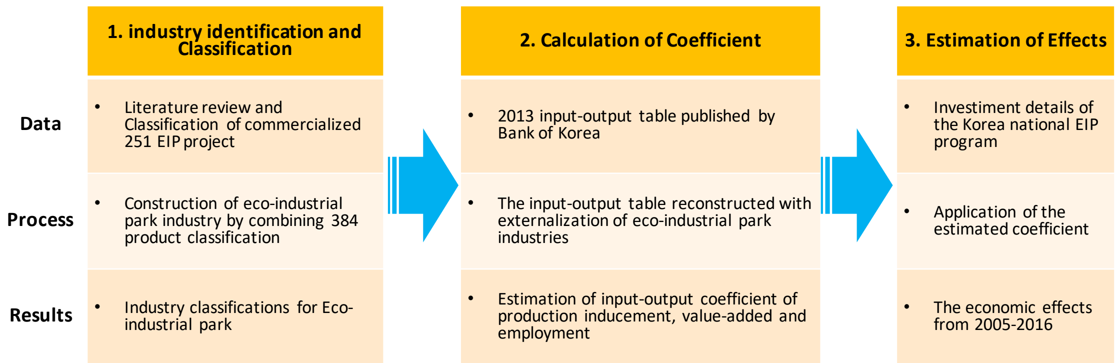

Figure 2. Schematic diagram of the process of investigating the economic effect of EIP on the national economy of Korea.

3.1. EIP Industry Identification and Sector Integration

3.1.1. EIP Definition and Relationship to the National Economic System

In the literature, an eco-industrial park (EIP) is defined as an industrial complex, in which a delimited area to apply efforts to minimize the environmental impacts and to maximize the efficiency of resources is designated, by utilizing waste, by-product, pollutants, and/or unused energy in a closed loop (e.g., to use by-products generated in the course of manufacture of products, and wastes into raw materials or energy) among processes and companies in the industrial park (illustrated as Figure 3) [4,6,8,10]. In this way, industries (companies) enable enhanced resource efficiency and land use productivity via optimizing the material and waste flows and sharing the infrastructure and services. Compared to the traditional industrial park, EIP can forward the change of the perception of industries, enhance business benefits and opportunities, as well as increase environmental benefits.

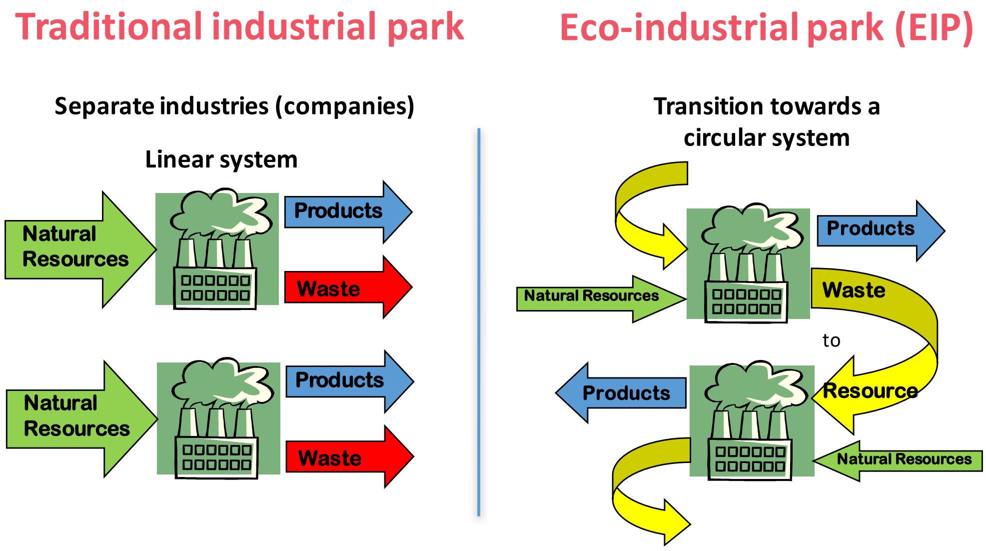

Figure 3. Schematic chart of transforming an industrial park to EIP.

According to the definition of EIP, it can be seen as a set of industries that promote green innovation. Based on this assumption, we can digest the industries (and their economic inputs and outputs) from the national economic system to form the EIP industries.

3.1.2. Sector Integration Scheme for EIP Industries

Though there is no standardized definition of the eco-industrial park, main activities are resource and energy optimization through industrial symbiosis networks. For the EIP-based IOA, we used the original 2013 benchmark IOT. The original benchmark IOT was composed of 384 sectors. To avoid the arbitrariness of aggregation and minimize sectoral bias, we used the Bank of Korea's 30-sector classification method. Because there is no the EIP sector in the original table, we need to rearrange the original table to include the EIP sector. This study defined the industries regarding the 37 representative product and service technologies (Table S1, Supplementary Information), categorized based on the 235 commercialized EIP projects, as the EIP sector. We match these representative product and service to the sectors in the economic system (Table S2, Supplementary Information). In the 30-sector classification method, 11 sectors (2–10, 16, and 17) are related to the EIP. In the 384-sector classification method, 46 sectors are related to the EIP. We classified these sectors as the EIP sector. Therefore, we considered a total of 31 sectors. Sectors 1 to 30 are non-EIP sectors; sector 31 is the EIP sector. The section classification adopted in this study is described in Table 4.

Table 4. Sector reclassification adopted in this study.

Codes	Sectors	Codes	Sectors	Codes	Sectors
01	Agricultural, Forest, and Fishery Products	11	Machinery and Equipment	21	Food Services and Accommodation
02	Mined and Quarried Products	12	Electronic and Electrical Equipment	22	Communications and Broadcasting Services
03	Food and Beverages Products	13	Precision Instruments	23	Finance and Insurance Services
04	Textile and Leather Products	14	Transportation Equipment	24	Real Estate and Leasing
05	Wood and Paper Products, Printing	15	Other Manufactured Products and Outsourcing	25	Professional, Scientific, and Technical Services
06	Coal and Petroleum Products	16	Electricity, Gas and Steam	26	Business Support Services
07	Chemical Products	17	Water Supply, Waste and Remediation Service	27	Public Administration and Defense
08	Non-metallic Mineral Products	18	Construction	28	Educational Services
09	Primary Metal Products	19	Wholesale and Retail Trade	29	Health and Social Welfare Services
10	Metal Products	20	Transportation	30	Cultural and Other Services
-	-	-	-	31	**Eco-industrial park products and services**

Note: name of sector is based on source [40,41].

3.2. Calculation of EIP Sector Related Coefficient and Evaluation on the Economic Impacts

According to above scheme, new EIP sector is constructed and integrated with current Korea's national IOT. Based on this, a series of sectorial coefficients will be calculated based on a general IOA approach. They are the basis for further evaluation on economic effects of EIP promotion on the national economy of Korea.

IOA is the analysis method to quantitatively grasp the interrelation among the industries produced through production activity by using the input-output table covering the whole of national economy [42]. It is possible for this analysis to analyze the interrelation among the industries which does not deal with macro-analysis. It is useful to analyze a concrete economic structure [43]. Exogenous specification can examine the influence which one variable has on the endogenous economy sector by treating the variable exogenously. By using the exogenous specification, we can clearly know the influence which the output of a specific sector has and the effect that the output causes other industries. Various sub-models are described as follows.

3.2.1. Demand-Driven Model

The inducement effects on production, value-added, and employment can be evaluated in the demand-driven model. These effects mean that how much the production, value-added, and employment of other industries, excepting for the target industry increase, when the production of the target industry which is the industry related to the Korea's EIP program increases with 1 KRW. Table 5 summarizes the equations to evaluate the inducement effects of the production, value-added, and employment by treating the industry regarding with the Korea's EIP program (hereinafter referred to as "H sector") as exogenous. The process to induce each equation can refer to a large number of papers on IOA [42,43].

Table 5. Economic effects based on the demand-driven model.

Effects	Model Equation	Content
Production inducement	$\Delta X^e = (I - A^e)^{-1}(A_H^e \Delta X_H)$	ΔX^e represents the emission variation of the other sectors with except of sector H, $(I - A^e)^{-1}$ is the Leontief inverse matrix of reduced input coefficient matrix, with elimination of the row and column of sector H, A_H^e denotes a column vector except for an element of sector H, $(A_H^e \Delta X_H)$ identifies the scalar of the change in the sectorial gross output of H
Value-added inducement	$\Delta V^e = \hat{A}_v^e (I - A^e)^{-1}(A_H^e \Delta X_H)$	ΔV^e represents the value-added of the other sectors with except of sector H, $\hat{A}_v^e$ represents the matrix of reduced diagonal matrix of value-added coefficient upon eliminating the row and column of sector H
Employment inducement	$\Delta M^e = \hat{m}^e \Delta X^e = \hat{m}^e (I - A^e)^{-1}(A_H^e \Delta X_H)$	M^e represents the number of employees for each sector expect for sector H, ΔM^e represents the variation, $\hat{m}^e$ represents the matrix of a reduced diagonal matrix of employment coefficient upon eliminating the row and column of sector H

In addition, the inter-industry linkage effect is applied to measure the degree of interdependence among industries. It is applied to measure the causation effects among industries, which is based on the assumption that from the perspective of the supply chain of the economy, related industries can be boosted via linking the input and output activities. The linkage effects can usually be classified into backward and forward linkage effects [32,44,45]. The backward linkage effect represents that the production activities of a sector may induce greater use of other sectors as inputs for the sector's products. On the other hand, forward linkage effect means that a sector's output is used as an input to other sectors for their own production activities [31]. The forward linkage effects can be expressed as the sensitivity of dispersion. The sensitivity of dispersion index quantifies the increase in the output of an industry, driven by a unit increase in the final demand for all industries in the economic system. In the IOA based approach, it is presented as an average of N elements in row i of the Leontief inverse matrix, divided by all N^2 elements [32]. This index is defined as Equation (1):

$$FL_i = \frac{\frac{1}{n}\sum_{j=1}^{n} a_{ij}}{\frac{1}{n^2}\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij}} = \frac{n\sum_{j=1}^{n} a_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij}} \quad (1)$$

where a_{ij} represents an element of the Leontief inverse matrix.

Similar to the forward effect, the so called "backward linkage effects" is represented as the power of dispersion. The dispersion index presents the relative extent to which an increase in final demand for the products of a given industry is dispersed throughout the total supply chain of industries. It is presented as an average of N elements in column j of the Leontief inverse matrix, divided by the average of all N^2 elements [32]. The power of dispersion index is defined as Equation (2):

$$BL_j = \frac{\frac{1}{n}\sum_{i=1}^{n} a_{ij}}{\frac{1}{n^2}\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij}} = \frac{n\sum_{i=1}^{n} a_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij}} \quad (2)$$

3.2.2. Supply-Driven Model

The traditional demand-driven model is applied to investigate how the change of final demand will result in the change on the whole supply chain. In application, the Leontief inverse matrix relates sectorial gross outputs to the final demand, which is a unit of products leaving the interindustry system at the end of the process. The conventional demand-driven model is based on the assumption of fixed input coefficients with an ideally elasticity of supply to inputs, and emphasizes the analysis on the impacts originated from final demand, or backward linkage, and output-oriented activities [46]. One limitation of the traditional model is that it may not be suitable to deal with the impact of primary supply, the forward linkage, and input-oriented activities [42,43]. As alternative, the supply-driven model enables to link sectorial gross output to the primary inputs, which can be seen as a unit value entering the economic system at the very beginning of the process. Hence, in this study, a supply-driven model is developed to address the direct and indirect impacts from the supply side [46].

In application, the developed supply-driven I-O model is presented as $X'=V'\ (I-R)^{-1}$. In which, V' is the transpose of the final value added by sector j, while R is presented as the output coefficient matrix. $(I-R)^{-1}$ presents the output inverse matrix, while ($q_{ij} = \partial X_j/\partial V_i$) are the elements in the matrix, presenting the total direct and indirect requirements in sector j, with per unit of final value added in sector i. Similar to the applications in demand-driven model, this study treats the EIP sector as exogenous and assumes that there is no change in value-added in all other sectors yield (Equation (3)):

$$\Delta X^{e'} = R_H^e \Delta X_H (I - R^e)^{-1} \tag{3}$$

where R_H^e is row vector excluding the element of sector H; $(I - Re)^{-1}$ is the output inverse matrix with elimination of row and column elements of sector H. With Equation (1), it enables to investigate the impacts generated from one-unit shortage in the EIP industry on the outputs of all other sectors in the supply chain. In this way, it can be applied as a basis to define the shortage or failure costs of the EIP sector [31].

3.2.3. Leontief Price Model

The three above-mentioned sub-models are based on the IOT in monetary units. In reality, interacted sectors in the economic system can be better presented (and more accurately) with physical values. However, in the practical condition, IOT with physical value is rather difficult to get, the same condition for Korea national IOTs. Hence, some alternative ways deserve to be explored.

In the IOT structure, the constitution of each sector can be treated as the cost structure of the production activity of each sector, hence, it is able to analyze the price impacts based on this. Such analysis can be conducted with the help of Leontief price model [31]. Based on the simplified assumption that one-unit output in each sector is normalized price (e.g., 1 US dollar), it can be applied to estimate the impacts derived from the change in EIP rates on prices throughout the economy, with the help of IOT with physical units.

Enlightened by previous studies, this study treats the EIP sector as exogenous and put into the primary inputs group. Assuming there are no price changes in the value-added sector, the conventional Leontief price model can be modified as Equation (4) [31]:

$$\Delta \overline{P}_e = \left(I - A^{e'}\right)^{-1} A_H^{e'} \Delta \overline{P}_H \tag{4}$$

where $\Delta \overline{P}_e$ denotes the vector of the price change excluding sector H; $\Delta \overline{P}_H$ presents a scalar of the price change of sector H. Assuming that the cost change in each sector is able to completely transferred, plus the annual sectorial outputs are offered, how the cost change of the EIP sector will drive the wholesale price changes on the economic system can be investigated by Equation (4).

4. Results and Discussions

4.1. Inducement Effects for Production, Value-Added, and Employment

The EIP sector's inducement effects for production, value-added, and employment on all other sectors are shown in Table 6. The production inducement effect shows the impacts of a change in the target sector's supply investments on the output of all other sectors. A KRW 1.0 change in the EIP sector investment induces KRW 0.6201 of the output of other sectors and KRW 1.6201 of the output of the national economy. 'Chemical products' ranks the highest in the sectorial impacts of a KRW 1.0 change in the EIP sector investment at KRW 0.1368. In sequence, 'Coal and Petroleum Products' and 'Primary Metal Products' ranks the second and third highest at KRW 0.0717 and KRW 0.0626. The result highlights that the costs of 'Chemical products', 'Coal and Petroleum Products', and 'Primary Metal Products' are the largest contributors in the production costs of the EIP sector. That is because chemical products are produced by using waste/by-products as raw material, and waste/by-products, wastewater, and unused energy act as intermediary products to be recycled as raw-material and energy. On the other hand, 'Educational Services' ranks the lowest in the sectorial impacts at KRW 0.0003.

The value-added inducement effect highlights the impacts of the change in the target sector's supply investments on the value-added of all other sectors (Table 6). A KRW 1.0 change in the EIP sector investment induces KRW 0.1820 of the value-added of other sectors and KRW 0.1670 of the value-added of the EIP sector. Therefore, a KRW 1.0 change in the EIP sector investment induces KRW 0.3489 of the value-added of the national economy. In the sectorial impacts of a KRW 1.0 change in the EIP sector investment, 'Wholesale and Retail Trade' ranks the highest at KRW 0.0277, and 'Chemical products' and 'Transportation' ranks the second and third highest at KRW 0.0270 and KRW 0.0142 in sequence. On the other hand, 'Educational Services' ranks the lowest in the sectorial impacts at KRW 0.0002.

The employment inducement effect indicates the impacts of 1 billion KRW change in the target sector's supply investments on the employment of all other sectors (Table 6). This result indicates that the EIP sector supply increase of 1 billion KRW induces 2.9576 persons of all other sectors and 3.4937 persons of the EIP sector. Therefore, 1 billion KRW of the EIP sector investment induces 6.4512 persons in the national economy. In the sectorial impacts, 'Wholesale and Retail Trade' induces the highest employment at 0.7368 persons. In sequence, 'Transportation' and 'Agricultural, Forest, and Fishery Products' induces the second and third highest employment at 0.4610 persons and 0.2947 persons. Thus, the employment inducement effect is high in service industry. On the other hand, 'Water Supply, Waste and Remediation Service' induces the lowest employment at 0.0014 persons.

Table 6. The EIP's inducing effects on all other sectors.

Codes	Sectors	Inducing effect					
		Production		Value-Added		Employment	
		(KRW)	Ranks	(KRW)	Ranks	(Person/billion KRW)	Ranks
001	Agricultural, Forest, and Fishery Products	0.0112	15	0.0061	10	0.2947	3
002	Mined and Quarried Products	0.0042	25	0.0024	20	0.0142	21
003	Food and Beverages Products	0.0114	14	0.0018	23	0.0286	19
004	Textile and Leather Products	0.0104	17	0.0024	21	0.0453	14
005	Wood and Paper Products, Printing	0.0122	13	0.0032	18	0.0479	13

Table 6. *Cont.*

Codes	Sectors	Inducing effect					
		Production		Value-Added		Employment	
		(KRW)	Ranks	(KRW)	Ranks	(Person/billion KRW)	Ranks
006	Coal and Petroleum Products	0.0717	2	0.0049	13	0.0036	29
007	Chemical Products	0.1368	1	0.0270	2	0.0563	11
008	Non-metallic Mineral Products	0.0060	22	0.0017	24	0.0118	24
009	Primary Metal Products	0.0626	3	0.0097	6	0.0490	12
010	Metal Products	0.0151	8	0.0046	14	0.0377	16
011	Machinery and Equipment	0.0142	11	0.0040	16	0.0443	15
012	Electronic and Electrical Equipment	0.0089	20	0.0024	22	0.0132	22
013	Precision Instruments	0.0026	26	0.0008	27	0.0095	26
014	Transportation Equipment	0.0055	23	0.0012	25	0.0111	25
015	Other Manufactured Products and Outsourcing	0.0148	9	0.0061	9	0.1072	8
016	Electricity, Gas and Steam	0.0439	5	0.0114	4	0.0319	18
017	Water Supply, Waste and Remediation Service	0.0073	21	0.0044	15	0.0014	30
018	Construction	0.0016	27	0.0005	29	0.0127	23
019	Wholesale and Retail Trade	0.0539	4	0.0277	1	0.7368	1
020	Transportation	0.0412	6	0.0142	3	0.4610	2
021	Food Services and Accommodation	0.0106	16	0.0039	17	0.1799	5
022	Communications and Broadcasting Services	0.0127	12	0.0055	12	0.0704	10
023	Finance and Insurance Services	0.0198	7	0.0101	5	0.1096	7
024	Real Estate and Leasing	0.0102	18	0.0075	8	0.0375	17
025	Professional, Scientific, and Technical Services	0.0147	10	0.0083	7	0.1658	6
026	Business Support Services	0.0090	19	0.0060	11	0.2382	4
027	Public Administration and Defense	0.0007	29	0.0005	28	0.0061	27
028	Educational Services	0.0003	30	0.0002	30	0.0049	28
029	Health and Social Welfare Services	0.0015	28	0.0008	26	0.0219	20
030	Cultural and Other Services	0.0052	24	0.0025	19	0.1052	9
	Impacts on Other Sectors	0.6201		0.1820		2.9576	
	EIP sector	1.0000		0.1670		3.4937	
	Total	1.6201		0.3489		6.4512	

Note: Name of the sector is based on [40,41].

4.2. Inter-Industry Linkage Effect

Inter-industry linkage effect analysis evaluates the sensitivity and power of the dispersion index of 31 sectors and horizontally compares them to catch the relative position of target sectors in the whole economy. If the product of an industry is widely used as the intermediary products in other industries, the sensitivity of dispersion index of the industry is increased. If the industry need the intermediary products from other industries in production process, the power of the dispersion index of the industry is increased [40]. Table 7 summarizes the forward and backward linkage effects of EIP and other sectors in 2013.

Table 7. Sectoral forward and backward linkage effects.

Codes	Sectors	Forward Linkage Effects	Ranks	Backward Linkage Effects	Ranks
001	Agricultural, Forest, and Fishery Products	0.7119	17	0.7174	23
002	Mined and Quarried Products	0.4261	28	0.7555	20
003	Food and Beverages Products	0.6787	19	1.0262	11
004	Textile and Leather Products	0.6722	21	0.9456	13
005	Wood and Paper Products, Printing	0.7762	14	1.2110	6
006	Coal and Petroleum Products	1.2511	6	0.5551	30
007	Chemical Products	2.2272	3	1.4570	4
008	Non-metallic Mineral Products	0.5702	24	1.1041	10
009	Primary Metal Products	3.2954	2	2.8641	1
010	Metal Products	0.8436	10	1.5222	3
011	Machinery and Equipment	0.7685	15	1.1761	7
012	Electronic and Electrical Equipment	0.8865	9	0.8183	16
013	Precision Instruments	0.4822	26	0.9105	14
014	Transportation Equipment	0.6744	20	1.1607	8
015	Other Manufactured Products and Outsourcing	0.7847	13	1.0049	12
016	Electricity, Gas and Steam	1.6058	4	1.3705	5
017	Water Supply, Waste and Remediation Service	0.8265	12	2.2068	2
018	Construction	0.4337	27	1.1318	9
019	Wholesale and Retail Trade	1.4616	5	0.7261	22
020	Transportation	1.1016	7	0.6663	26
021	Food Services and Accommodation	0.6645	22	0.8534	15
022	Communications and Broadcasting Services	0.8314	11	0.7390	21
023	Finance and Insurance Services	0.9597	8	0.6839	24
024	Real Estate and Leasing	0.6992	18	0.5760	29
025	Professional, Scientific, and Technical Services	0.7216	16	0.6766	25
026	Business Support Services	0.6355	23	0.6162	27
027	Public Administration and Defense	0.3986	30	0.5385	31
028	Educational Services	0.3783	31	0.5818	28
029	Health and Social Welfare Services	0.4133	29	0.7854	19
030	Cultural and Other Services	0.5250	25	0.8034	18
031	EIP	4.2947	1	0.8155	17

Note: name of sector is based on source [40,41].

Figure 4 illustrates the forward and backward linkage effects of EIP sectors and other sectors, as well as their comparison. In sectorial forward linkage effects, 'EIP (target sector)' is the highest at 4.2947, and 'Primary Metal Products' and 'Chemical Products' are the second and third highest at 3.2954 and 2.2272. The forward linkage effect of the EIP sector is the largest, indicating that the EIP sector has strong driven effects to push forward other sectors to change. On the other hand, it is also highlighted that due to functioned as an input to other sectors for their production, EIP sectors is also highly stimulated by economic growth than others which, meanwhile, means being more sensitive to economic fluctuations.

In the sectorial backward linkage effects, 'Primary Metal Products' is the highest at 2.8641, and 'Water Supply, Waste and Remediation Service' and 'Metal Products' are the second and third highest at 2.2068 and 1.5222. The backward linkage effect of the EIP sector holds the 17th rank at 0.8155. Result highlight that the backward linkage effect of EIP sector is lower than 1.0, indicating the EIP sector presents a lower impacts of investment expenditures on the national economy than other sectors.

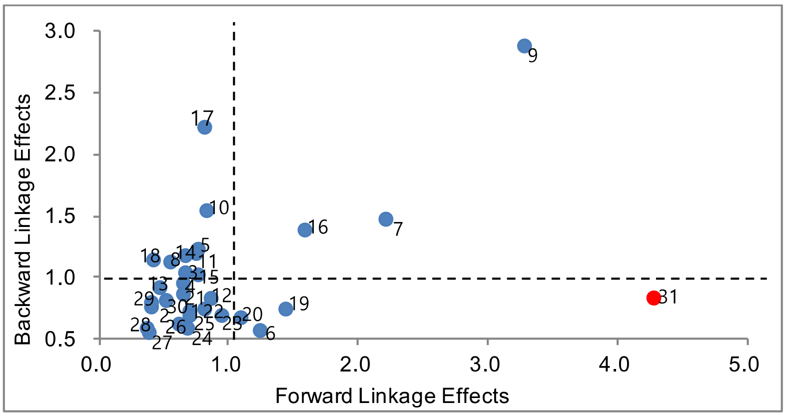

Figure 4. Comparison of the forward and backward linkage effects for the 31 main industrial sectors.

4.3. Sectoral Supply Shortage Effect

The supply shortage effect indicates the impacts of a KRW 1.0 shortage in the target sector's output on the output shortage of all other sectors, and this result is shown in the Table 8. The total supply shortage effect of the EIP sector is KRW 1.1230. This result means that if there was no the target's sector supplied with 1 billion KRW, the shortage cost by the target sector would have been KRW 1.1230 billion. In the sectorial impacts, high supply shortage effects are found in 'Primary Metal Products', 'Chemical Products', and 'Electricity, Gas and Steam'. 'Primary Metal Products' is the highest at KRW 0.2659, and 'Chemical Products' and 'Electricity, Gas and Steam' are the second and third highest at KRW 0.1157 and KRW 0.0772 in sequence. This means that if there is no target sector supplied, the 'Primary Metal Products' sector would be the hardest hit. On the other hand, the industry with low shortage effects is 'Mined and Quarried Products' at KRW 0.0007.

Table 8. The supply shortage effects and sectoral price effects under 10% price increase in EIP sectors.

Codes	Sectors	Supply Shortage Effects		Sectoral Price Effects	
		(KRW)	Ranks	(%)	Ranks
001	Agricultural, Forest, and Fishery Products	0.0304	9	0.0523	6
002	Mined and Quarried Products	0.0007	30	0.0094	25
003	Food and Beverages Products	0.0282	10	0.0399	9
004	Textile and Leather Products	0.0218	14	0.0609	4
005	Wood and Paper Products, Printing	0.0138	19	0.0902	1
006	Coal and Petroleum Products	0.0162	18	0.0034	29
007	Chemical Products	0.1157	2	0.0068	26
008	Non-metallic Mineral Products	0.0115	23	0.0675	3
009	Primary Metal Products	0.2659	1	0.0068	27
010	Metal Products	0.0618	7	0.0697	2
011	Machinery and Equipment	0.0426	8	0.0290	15
012	Electronic and Electrical Equipment	0.0757	5	0.0332	14
013	Precision Instruments	0.0077	26	0.0449	7
014	Transportation Equipment	0.0727	6	0.0264	17
015	Other Manufactured Products and Outsourcing	0.0208	15	0.0525	5
016	Electricity, Gas and Steam	0.0772	3	0.0034	30
017	Water Supply, Waste and Remediation Service	0.0050	28	0.0056	28
018	Construction	0.0769	4	0.0346	13
019	Wholesale and Retail Trade	0.0271	11	0.0139	21
020	Transportation	0.0199	16	0.0358	11

Table 8. *Cont.*

Codes	Sectors	Supply Shortage Effects		Sectoral Price Effects	
		(KRW)	Ranks	(%)	Ranks
021	Food Services and Accommodation	0.0219	13	0.0437	8
022	Communications and Broadcasting Services	0.0101	24	0.0133	22
023	Finance and Insurance Services	0.0096	25	0.0115	23
024	Real Estate and Leasing	0.0137	20	0.0139	20
025	Professional, Scientific, and Technical Services	0.0128	21	0.0175	19
026	Business Support Services	0.0039	29	0.0185	18
027	Public Administration and Defense	0.0069	27	0.0112	24
028	Educational Services	0.0121	22	0.0277	16
029	Health and Social Welfare Services	0.0230	12	0.0361	10
030	Cultural and Other Services	0.0173	17	0.0350	12
	Total and Weighted Average	Total: 1.123		Weighted Average: 0.0269	

4.4. Pervasive Effect of Price Change

The result of sectorial percentage changes of a 10% increase in the EIP sector rates is shown in Table 8. This value is calculated as a weighted average of the sectoral price impacts in regard to the total output of each sector. This result indicates that the national economic effect of a 10% increase in the EIP sector rate is 0.0269%. While high sectoral price impacts are found in ‘Wood and Paper Products, Printing (0.0902%)’, ‘Metal Products (0.0697%)’, and ‘Non-metallic Mineral Products (0.0675%)’, and low sectoral price impact is found in ‘Electricity, Gas and Steam’ as 0.0034%.

5. Conclusions and Policy Implications

5.1. Main Findings and Conclusions

This study innovatively evaluated the role of EIP on Korea’s national economy by applying an IOA-based evaluation, including the demand-driven model, inter-industry linkage effects, the supply-driven model, and the Leontief price model. Except for our inter-industry linkage effects analysis, the EIP sector was treated as exogenous to evaluate the net effects by changes in investment, supply, or price in each sector.

Based on the analytical results from the demand-driven model, a KRW 1.0 change in the EIP sector investment induced KRW 1.6201 of the output and KRW 0.3489 of the value-added in the national economy. Additionally, 1 billion KRW of the EIP sector investment induced 6.4512 persons in the national economy. It highlighted from the supply chain perspective, with implementation of the national EIP project, production and value-added was grown by around 1264 billion KRW and 272 billion KRW, respectively, while generating a direct employment around 1000 persons, and an indirect employment by over 5000 persons.

In the inter-industry linkage effect, the forward linkage effect of the EIP sector was found greater than one, as 4.2947, and the backward linkage effect was less than one, as 0.8155. This indicated that the EIP sector can be classified under the intermediate primary production category. The sector was much influenced by business fluctuations and presented a relatively weak capacity to pull in other industries.

According to the analytical results from the supply-driven model, the supply shortage effect of the EIP sector was 1.1230. In detail, sectors including ‘Primary Metal Products’, ‘Chemical Products’, and ‘Electricity, Gas and Steam’ presented high shortage effect.

Finally, according to the analysis based on Leontief price model, the national economic effect under 10% increase in the EIP sector rate was 0.0269%. High sectoral price impacts were found in ‘Wood and Paper Products, Printing’, ‘Metal Products’, and ‘Non-metallic Mineral Products’.

In conclusion, EIP was proved to be not only environmental friendly, but also a driver to improve the overall economic performance of upstream and downstream industries in the whole supply chain. The results were critical to enlighten policy-makers to forward ever-improvement on the EIP promotion and combine the EIP idea within national economic system reform and planning, by offering a clear vision on how EIP will affect the various sectors in the supply chain and the economic system as a whole.

5.2. Implications

While our analytical results verified the positive effects of EIP on national economy based on the evidence of Korea, much more work needs to be done to really incorporate EIP as an economic system innovation. Enlightened by the experiences of Korea and the key findings from our analysis, several policy implications were proposed and discussed as follows:

- Our results reveal that there are actual forward and backward linkage effects between the EIP sector and other economic sectors. However, current EIP evaluation indicators are actually focused on material flow analysis-based indicators (environmental performance), such as direct pollutant mitigation and resource conservation effects, which lack an identification on such economic push and pull effects. A better investigation on this issue can be good incentives for more companies to engage in the industrial symbiosis and hereby support a better EIP construction, e.g., future EIP evaluation indicators can reflect that the future trajectory of EIP development puts stronger emphasis on industrial symbiotic links.
- The IOA approach was approved to be an effective tool to quantify such economic effects of EIP promotion, while the knowledge is not well included into the national economy accounting system. Hence it is suggested to reform the current system (e.g., current sector classification cannot reflect such business innovation) to better present the cost-benefits of such environmentally-oriented business innovation, so that the policy-makers can read more clear market response signals of EIP promotion. By doing so, it will help top designers to incorporate EIP into national economic system planning.
- Finally, Korea has done well on EIP project commercialization, while, for most countries, EIP is still a pure environmental innovation. Hence the knowledge of this paper is hoped to forward a mind change to treat industrial symbiosis and EIP as an environmental, as well as a business, innovation, which enables changing the perception of industries and create new business values via the whole supply chain. Based on such perceptions, more market-oriented incentives can be designed to support EIP promotion.

5.3. Research Limitations and Future Concerns

This paper contributed somewhat to methodology innovation on the evaluation on EIP via the IOA approach. We newly defined the EIP sector, which was critical as a new business innovation but not defined in the industrial classification system of the original benchmark IOT. This study also provided meaningful information in which we apply the supply-driven model and the Leontief price model, as well as the demand-driven model and the inter-industry linkage effect analysis, and focuses on the EIP sector by treating the EIP sector as exogenous to evaluate the net effects by changes in investment, supply, or price in each sector.

There are also some limitations on current conditions to be improved in the future. Due to the lack of national standard sector classification concerning EIP, we built a "new" EIP sector by carefully digesting the very micro information from a commercialized EIP project, which is not available for most regions in the world. This is time-consuming and somehow generates uncertainty for further analysis. Hence it suggests an improvement on national sector classification system or guidance of sector classification to make this work more standard and efficient. The other limitation is that we treat the investments of EIP projects as accumulative value rather than on-site survey data, while the IOT is published every five years, hence the data match issue might generate some uncertainty on the result.

Finally, based on current progress, the extension of the present framework needs to be undertaken in a future study. In this regard, dynamic IOA, which allows the changing of input coefficients over time, will provide more insights for both policy-makers and researchers by significantly increasing the precision of the analytical results.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/10/12/4545/s1, Table S1: Summary of commercialized projects in the National EIP program of Korea; Table S2: Match of products and services in the commercialized EIP projects with economic sectors.

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