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Comparative Study in Software and Healthcare Industries between South Korea and US Based on Economic Input–Output Analysis

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Abstract: In the modern era, software technology is being used not only as a core technology for manufacturing but also in various industries, such as telemedicine services, and the importance of the healthcare industry is being emphasized due to the demand for improved quality of life from the increase in the general level of earnings. However, if the industry emits a lot of carbon dioxide (CO₂), it is questionable whether it is a sustainable industry. This study aimed to analyze the economic linkage effect of software and healthcare industries in South Korea and the United States by applying input–output analysis and examine whether these industries are sustainable in terms of CO₂ emissions. The input–output tables and CO₂ emissions from 2005 to 2015 were used for analysis from OECD. As a result of the analysis, CO₂ emissions from the software and healthcare industries were less than 1% in both South Korea and the United States, suggesting that these industries are well-suited for low-carbon development in these countries. The forward and backward linkage effects of the software industry are different between South Korea and the United States. Specifically, the backward linkage effect of the software industry is large in South Korea, and the forward linkage effect is large in the United States. The forward linkage effect of the healthcare industry is different in the two countries, but the backward linkage effect is not. It means that there are differences in the industrial structure of the two countries. The software and healthcare industries need to devise strategies to drive production in other industries while maintaining current low carbon emission levels.

Keywords: software industry; healthcare industry; CO₂ emission; input–output analysis; linkage effects

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1. Introduction

Global CO₂ emissions (1990 to 2019) continued to increase from 22.70 billion t in 1990 to 36.44 billion t in 2019 [1]. Accordingly, major countries around the world are recently responding to climate change by reducing carbon and greenhouse gas emissions [2,3]. South Korea is also making efforts for the harmonious development of the economy and the environment by introducing green technology to lay the foundation for low-carbon green growth and to realize a low-carbon society [4]. For the harmonious development of the economy and the environment, it is necessary to minimize carbon emission by industry and economic sector, and at the same time to increase the positive effect of industrial activities on the national economy. In Hungary, the industrial sector has been the main source of CO₂-emitting and contributed 72% of the total emissions between 1985 and

2018 [5]. Reservoirs created for the development of agriculture and the tourism industry are also an important source of methane, a powerful greenhouse gas [6]. Agriculture has attempted to capture and recycle CO₂, but challenges remain for most industrial-based utilization pathways, either associated with the high operating and supply chain costs, the low process efficiencies [7]. To this end, we need to understand the carbon dioxide emission pattern of vital industries and their economic role in the national economy to establish government policies that enable sustainable economic development.

In this digital age, one of the most important industries in the national economy and human life is the software industry. The influence of software technology is growing with the advancement of information and communication technologies (ICTs), such as artificial intelligence (AI) and block chain. ICT is the foundation of the fourth industrial revolution, and software is the most important component [8–10]. Recognizing the importance of the software industry, countries around the world are making efforts for the development of software technology and industry. Accordingly, the global software market has grown at a compound annual growth rate of 4.4% since 2014, reaching USD 1.34 trillion (about KRW 1500 trillion) in 2019. The software industry is an industry that supports other industries, and without software, the competitiveness of the other industries cannot be guaranteed [11]. However, the software industry emits large amounts of carbon dioxide. For example, many software companies provide their services through cloud computing technology. Cloud computing requires large data centers that consume a lot of power. Data centers are essentially operated 24 h a day and require air conditioning to cool down the heat emitted by computers. Therefore, power consumption is inevitably large. The greater the power consumption, the greater the CO₂ emissions [12,13]. Therefore, the software industry provides “substantial” services but is directly or indirectly responsible for CO₂ emissions [14].

Along with the software industry, one of the most necessary industries for human society and the national economy is the healthcare industry. The healthcare industry has also been recognized as a high value-added industry with high growth potential due to the increase in income and the development of medical technology, attracting attention as an industry that can drive economic growth [15–17]. ICT has been converged and used in all fields of the healthcare industry, and the form and scope of its application are expanding [18]. Healthcare services that incorporate ICT are already being provided by large companies, such as Apple and Samsung, as well as startups, allowing individuals to manage their health anytime, anywhere [8,19]. Fitbit’s “Wearable Band”, Google’s “Fit”, and Apple’s “Health Kit” are representative healthcare services, and data accumulated through these services can be shared between individuals and hospitals to provide telemedicine services [20,21]. The healthcare industry provides the services necessary for human life, but the healthcare industry emits large amounts of carbon dioxide. Specifically, the healthcare industry’s climate footprint represents 4.4% of global net CO₂ emissions. Healthcare facilities and carbon-intensive healthcare supply chains that use many energy sources such as electricity, gas, steam, air conditioning and heating account for most of the CO₂ emissions by the healthcare industry [22].

Given the importance of software industry and healthcare industry in the national economy and sustainable development of such industries for the environment, the aim of this study is to analyze the economic linkage effects of the two industries by conducting input–output (I-O) analysis and examine whether these industries are sustainable in terms of CO₂ emissions. Additionally, in order to understand the results more deeply, this study compares the economic linkage effects and CO₂ emissions between South Korea and the United States, one of the developed countries that pay the most attention to the global environment. No matter how high the economic linkage effect and added value, industries that emit a lot of carbon are not suitable for the global task of reducing carbon and greenhouse gas emissions. Motivated by this line of thinking, this study seeks to answer the following research questions:

RQ1: What is the economic linkage effect of software and healthcare industries in South Korea and the United States?

RQ2: What is the difference between South Korea and the United States in terms of the economic linkage effect of the software industry and the economic linkage effect of the healthcare industry?

RQ3: Are the software and healthcare industries sustainable in South Korea and the United States in terms of CO₂ emissions?

To answer these research questions, we analyze the economic linkage effect and CO₂ emissions of software and healthcare industries in South Korea and the United States by applying input–output analysis using input–output tables and CO₂ emissions published by the OECD from 2005 to 2015.

This study is structured as follows. Section 2 classifies the software industry and the healthcare industry, introduces input–output and CO₂ emission-related prior studies, and establishes research hypotheses. Section 3 describes research methods and data. Then, Section 4 offers the results from the data analysis and interpretation of the results. Finally, in Section 5, we discuss the implications of this study, including policy recommendations.

2. Preliminary Knowledge and Hypotheses Development

2.1. CO₂ Emissions Data Using Inter-Industry Analysis

Reducing CO₂ emissions due to energy consumption is no longer a matter of choice but a global and international requirement and obligation [23]. Industries that cannot achieve energy efficiency or reduce CO₂ emissions are no longer able to compete in the global marketplace. Governments should continue to make efforts to minimize CO₂ emissions through investment as well as the enactment of environmental laws and regulations. To obtain the best results with limited cost and time, the government must first understand exactly which industries have the greatest impact on CO₂ emissions and apply environmental policies and regulations to those with the greatest impact. To this end, many studies are being conducted to measure carbon emissions of each country and major industries by applying a methodology that *considers economic linkage aspects* between industries, such as inter-industry analysis [17,24–30].

Specifically, Malmödin and Lundén [26] estimated the energy and carbon footprint of the global ICT and E&M sector from 2010 to 2015. As a result of the analysis, despite the continued growth in data traffic in the ICT and E&M sectors, the increased carbon footprint was smaller than expected. Wu [27] analyzed the carbon footprint and economic linkage effect of the healthcare industry in China and revealed that China's carbon emissions per unit of health expenditure were relatively high due to the overall spending structure of the economy and carbon intensity in the country, arguing that effective management was required to reduce the national carbon footprint.

The software industry and the healthcare industry are key industries for national economic development. A well-established software industry can drive future economic growth [8,11]. In addition, the application of software technology in the healthcare industry is increasing due to the development of ICT and the expansion of non-face-to-face services [16]. On the other hand, in the European Union and major countries, low carbon emissions and reducing greenhouse gas emissions are being implemented as major global policy measures. The United States announced the Climate Action Plan in 2013 to reduce carbon emissions and lead the international community's efforts to respond to climate change [31]. For the sustainable industrial development of future core industries such as software and healthcare industries, carbon emissions of such industries must be low compared to other industries, and the economic linkage effect must be high. If an industry is the main culprit of environmental pollution due to its excessive carbon emission, it cannot be identified as a sustainable industry at the national level.

2.2. Input–Output Analysis in Software and Healthcare Industries

The global software market has grown at compound annual growth rate of 4.4% since 2014, reaching USD 1.34 trillion in 2019, and the growth rate of the following years is expected to be slightly lower than the 2019 growth rate (6.4%) [32]. The US software market accounted for 45.3% of the global market in 2016, which has a unique position in the global software market [33]. Despite the global financial crisis in 2008, the US overcame the financial crisis well by focusing on fostering the high-tech software industry, and through steady development of the cutting-edge software industry, it has become a leading country in the fourth industrial revolution and software worldwide. In 2020, the software market in South Korea grew by 2.3% compared to the previous year, reaching a market size of USD 22.7 billion (KRW 27.0 trillion) [32]. The South Korean software market is expected to grow steadily [33]. As the importance of the software industry increases, various studies on the software industry are being conducted. In particular, the high growth rate since the 2000s, the contribution to economic development, and the characteristics of a knowledge-based industry have been highlighted as research topics. In addition, research studies on the analysis of the industrial structure and linkage effect of the software industry are also increasing gradually. These research studies mainly analyze the economic effects focusing on the linkage effect and suggest policies for the development of the software industry or the knowledge industry [8,34,35].

Globally, there is an increasing need to expand the healthcare industry and develop related technologies through the convergence of ICT and the healthcare industry. According to Statista [36], the global digital healthcare market was valued at over USD 200 billion in 2020. Accordingly, South Korea declared the bio-healthcare industry a promising industry with great future growth potential employment potential. In addition, the South Korean government announced the goal of creating 300,000 new jobs by achieving 6% of the global market share, USD 50 billion in exports, and USD 3.3 billion (KRW 4 trillion) in R&D expenses [37]. Not only South Korea but also major developed countries are establishing policies to activate the ICT convergence in the healthcare industry to solve the problems of high unemployment and increase in medical expenses due to aging [18]. The healthcare industry is forming a value chain that provides healthcare services through continuous feedback from related industries, such as the pharmaceutical industry, medical and wearable device manufacturing, and clinical trials. Through inter-industrial linkage, they influence each other and continuously create new added values. Therefore, the vitalization of the healthcare industry can enhance national competitiveness, create jobs and provide high-quality healthcare services. Therefore, the government should promote economic growth and job creation strategies by fostering the healthcare industry. Kim et al. [16] analyzed the economic linkage effect of the South Korean healthcare industry using the input–output analysis technique. As a result of the analysis, it was revealed that the healthcare industry has a strong production inducement effect, weak price sensitivity, insignificant backward and forward linkage effects compared to other industries. Additionally, the healthcare industry was found to be closely related to the electronic/electronic device industry and the precision machinery industry. Yamada and Imanaka [15] used the input–output analysis technique to analyze the economic effects of the Japanese healthcare industry and showed that the healthcare industry has similar productivity to other industries.

2.3. Hypotheses Development

The software industry is defined as a sub-industry of the information industry related to software development-, production-, production-, and distribution-related services and information system construction and operation. The UN's International Standard Industrial Classification (ISIC) established the Information and Communication sector to classify the information, communication, and content/media industries into major categories, and the software industry could be derived from this structure. According to the OECD standards, the software industry was included in software publishing (5820), computer programming,

consultancy and related activities (62), as well as data processing, hosting and related activities (6311), as shown in Table 1.

Table 1. Definition of the software industry by ISIC.

Division	Group	Class	Description
Division 58	582	5820	Publishing activities
			Hospital activities
Division 62	620	6201	Computer programming, consultancy and related activities
			Computer programming activities
			Computer consultancy and computer facilities management activities
			Other information technology and computer service activities
Division 63	631	6311	Information service activities
			Data processing, hosting and related activities
			Web portals
			Other information service activities n.e.c.

Source: International Standard Industrial Classification of All Economic Activities (ISIC), Revision 4, by United Nations New York, 2008.

The healthcare industry (or medical industry) refers to the entire field of the economic system that provides products and services to treat, prevent, rehabilitate, and alleviate diseases. ISIC defines the healthcare industry as an industry that includes not only the services provided by skilled professionals in facilities, such as hospitals, but also all health-related activities performed in daily life, even if such specialists do not provide them. This is expressed as an industry classification code, as shown in Table 2.

Table 2. Definition of the healthcare industry by ISIC.

Division	Group	Class	Description
Division 86	861	8610	Human health activities
			Hospital activities
			Medical and dental practice activities
			Other human health activities

Source: International Standard Industrial Classification of All Economic Activities (ISIC), Revision 4, by United Nations New York, 2008.

The three categories include nurses, midwives, physical therapists, pathology clinics, and other health-related occupations, such as medical massage, yoga therapy, speech therapy, foot therapy, and acupuncture. The Global Industry Classification Standard classified this industry into Healthcare Equipment and Services (3510) along with Pharmaceuticals, Biotechnology and Life Sciences (3520).

The software and healthcare industries have great competitiveness compared to other industries, and after the 2008 financial crisis, the US overcame the financial crisis by intensively fostering the high-tech software industry [28,29]. The healthcare industry is attracting attention as an industry that can overcome the global economic crisis and low growth.

Input–output analysis derives the effect of inducing the production of an industry and expresses the influence of one industry on another and the degree of interdependence between industries in relative size based on the average value of all industries. It is useful to explain the linkage effect of an industry and to understand the structure of the national economy. Ye and Yin [38] used Input–output analysis as a study on the relevance and competition between industries in the UK. Chiu and Lin [39] presented the linkage effect of the transportation industry using Input–output analysis in a study on its role and effect on Taiwan’s economy. Mattioli and Lamonica [40] presented the linkage effect of the

ICT industry when quantitatively analyzing its economic effects on the global economy. Morrissey and O'Donoghue [41] studied the linkage effect of the marine industry on the Irish economy. Sari and Arifin [42] studied the linkage effects of technology-intensive industries before and after Indonesia's economic crisis. As such, this study will also use Input–output analysis to examine the linkage effects of the software and healthcare industry on the economy of each country and verify whether there is a difference in the linkage effects between South Korea and the US through several hypotheses in Table 3.

Table 3. Statistical hypotheses.

Hypotheses	
Hypothesis 1 (H1)	The linkage effect between the Korean software industry and the US is different.
H1	The backward linkage effect between the Korean software industry and the US is different.
H2	The forward linkage effect between the Korean software industry and the US is different.
Hypothesis 2 (H2)	The linkage effect between the Korean healthcare industry and the US is different.
H1	The backward linkage effect between the Korean healthcare industry and the US is different.
H2	The forward linkage effect between the Korean healthcare industry and the US is different.

3. Materials and Methods

3.1. Data Sources

This study uses the I-O table and the CO₂ emissions from the OECD. The input–output table for the last 10 years was used to examine the change in the production-inducing effect. When analyzing the production-inducing effect, the output at the basic price was used. As for CO₂ emissions, data measured according to industry-specific total output (CO₂ emissions embodied in final output) was used in the I-O analysis, as shown in Table 4. Using data from the last 10 years, the changes in CO₂ emissions were analyzed as the production-inducing effect of the changing industry.

Table 4. Range of the industries corresponding to the OECD Industry Classification.

Industry	Sector	Sub-Sector
Software	Information and communication	Publishing, audiovisual, and broadcasting activities IT and other information services
Healthcare	Human health and social work	Human health activities Social work activities without accommodation

Source: International Standard Industrial Classification of All Economic Activities (ISIC), Revision 4, by United Nations New York, 2008.

3.2. I-O Analysis and CO₂ Emissions

The input–output table is a chart that shows how the goods and services produced by a specific industry in a country are distributed among other industries or sectors for a certain period and how many products from other industries or sectors are placed into each industry for production. The quantitative analysis of the correlations between industries using the I-O table is called inter-industry analysis or I-O analysis [43]. Since the output produced in one industry is the input as a raw material for the production of the output of another industry, each industry is directly or indirectly related. The inter-industry analysis quantitatively shows such a relationship between multiple industries. Therefore, the inter-industry analysis using the I-O table examines the relationship between input and output among industries from a structural point of view, which identifies the relationship between

the primary input factor sector and the industry, as well as the transaction volume between the final output sector and each industry in Table 5.

Table 5. Format of the input–output table.

Producing Sector	Intermediate Goods and Services						Total Intermediate Demand	Total Final Demand	Total Output
	S ₁	S ₂	S ₃	S ₄	...	S _n			
S ₁	X ₁₁	X ₁₂	X ₁₃	X ₁₄	...	X _{1n}	SX _{1n}	D ₁	X ₁
S ₂	X ₂₁	X ₂₂	X ₂₃	X ₂₄	...	X _{2n}	SX _{2n}	D ₂	X ₂
S ₃	X ₃₁	X ₃₂	X ₃₃	X ₃₄	...	X _{3n}	SX _{3n}	D ₃	X ₃
	Quadrant I						SX _{4n}	Quadrant II	
...							...	...	...
S _n	X _{n1}	X _{n2}	X _{n3}	X _{n4}		X _{nn}	SX _{nn}	D _n	X _n
	Total Purchase								
	Value Added								
	Total Input								

Since inter-industry analysis is a method that analyzes the input and output relationships of each industry under the assumption that they are interrelated, a change in the input of one industry indicates a change in the output of another industry. Therefore, it can be used as a useful analysis tool for national economic forecasting or planning.

A key part of the linkage effect analysis using inter-industry analysis is the linkage effect between industries. The linkage effect refers to an output unit directly or indirectly required to satisfy changes in exogenous sectors, such as consumption, investment, and export, on the basis that the input coefficient from a specific industry is fixed. In other words, the output requirement coefficient indicates the level of production induced directly or indirectly in each sector to satisfy one unit of final demand, indicating the level of output directly or indirectly induced in each sector, which is also called the Leontief inverse matrix coefficient as the Leontief inverse matrix is used in the calculation process [43].

The industrial linkage effect presented by Hirschman [44] draws the output requirement coefficient using the industry association table and indicates the degree of industry activation through the drawn production induction coefficient. One industry directly or indirectly induces production in all industries in the country, and the larger the induced coefficient, the more revitalized the entire industry in the country. These industrial linkage effects can be divided into backward and forward linkage effects. The backward linkage effect refers to the effect of the pulling power on the entire national industry caused by the input of intermediate goods into product processing owned by the industry. The forward linkage effect is defined as the interaction that is directly induced in the structure of the industry-wide intermediary demand and supply relationship caused by the input of products by business customers [38]. It is an industry-wide production-inducing effect caused by the input of a product of the relevant industry as an intermediate product of another industry. The backward linkage effect is expressed as Equation (1), and the forward linkage effect is expressed as Equation (2) [45].

Backward linkage effect (BL_i) = Column sum of output requirement coefficient matrix / All-industry average of the row sum of the output requirement coefficient matrix

$$BL_j = \frac{\frac{1}{n} \sum_i B_{ij}}{\frac{1}{n^2} \sum_{ij} B_{ij}} \quad (1)$$

Forward linkage effect (FL_i) = Row sum of the output requirement coefficient matrix / All-industry average of the row sum of the output requirement coefficient matrix

$$FL_i = \frac{\frac{1}{n} \sum_j B_{ij}}{\frac{1}{n^2} \sum_{ij} B_{ij}} \quad (2)$$

BL_i = Power of diffusion;

FL_i = Level of excitement caused by diffusion;

r_{ij} = Elements of Leontief inverse matrix;

$\sum_{j=0}^n r_{ij}$ = Row sum of Leontief inverse matrix;

$\sum_{i=0}^n r_{ij}$ = Column sum of Leontief inverse matrix.

This study used not only the input–output table but also the CO₂ emission data, and CO₂ emission data used in the analysis were analyzed by dividing them based on industrial classification standards, such as the I-O table. We calculated the total output of an industry using the sum of intermediate and final demand from the I-O table. As for CO₂ emissions, the total CO₂ emissions measured in the production activities of a country were divided according to the total output of a certain industry to compare the emissions generated when an industry produces the total output.

4. Results

4.1. The Results of the Linkage Effects from 2005 to 2015

Tables 6 and 7 show the forward and backward linkage effects of the software industry in Korea and the United States from 2005 to 2015.

Table 6. Comparison of linkage effects of software industry between Korea and the USA.

Year	Forward Linkage of Software Industry		Backward Linkage of Software Industry	
	Korea	USA	Korea	USA
2005	0.733	0.794	0.949	0.850
2006	0.747	0.797	0.932	0.864
2007	0.762	0.798	0.920	0.851
2008	0.881	0.810	0.984	0.843
2009	0.881	0.903	1.006	0.877
2010	0.718	0.884	0.885	0.852
2011	0.878	0.858	1.023	0.846
2012	0.702	0.861	0.930	0.848
2013	0.742	0.861	0.884	0.848
2014	0.766	0.860	0.897	0.850
2015	0.746	0.906	0.920	0.831
Avg.	0.778	0.848	0.939	0.851

Table 7. Comparison of linkage effects of the healthcare industry between Korea and the USA.

Year	Forward Linkage of Healthcare Industry		Backward Linkage of healthcare Industry	
	Korea	USA	Korea	USA
2005	0.601	0.521	0.896	0.869
2006	0.613	0.523	0.892	0.869
2007	0.637	0.518	0.891	0.873
2008	0.602	0.515	0.685	0.860
2009	0.644	0.558	0.689	0.894
2010	0.685	0.545	0.875	0.885
2011	0.641	0.532	0.681	0.878
2012	0.472	0.530	0.839	0.875
2013	0.660	0.534	0.875	0.881
2014	0.711	0.529	0.882	0.877
2015	0.747	0.546	0.884	0.903
Avg.	0.638	0.532	0.826	0.878

As shown in Figure 1, for the software industry of South Korea, the average backward linkage effect from 2005 to 2015 was 0.939, which was close to 1. In contrast, the average for-

ward linkage effect was 0.778. During the analysis, the backward linkage effect was higher than the forward linkage effect. In the years when the forward and backward linkage effects of the South Korean software industry exceeded 1, the backward linkage effect exceeded 1 in 2009 and 2011 at 1.006 and 1.023, respectively. The forward linkage effect was somewhat high at 0.8 in 2008 and 2009. This showed that there were various pressures, as well as technological competition to ensure competitiveness in an export-driven economy, along with a decrease in growth rate due to the global economic crisis. Although the software was widely used throughout the industry, it seemed that the adoption of software produced abroad, other than software produced in South Korea, increased relatively quickly.

Figure 1. Backward and forward linkage effects of the software industry: (a) in Korea (left); (b) in USA (Right).

In the US software industry, the average backward linkage effect from 2005 to 2015 was 0.851, and the average forward linkage effect was 0.848. This meant that the degree of driving other businesses, which was the economic linkage effect of investment in the US software industry, was recovering, and the impact on the production of other industries through software was increasing [46]. The year with the largest backward linkage effect on the US software industry was 2009, and the forward linkage effect was as high as 0.903 and 0.906 in 2009 and 2015, respectively. The ICT sector had the characteristics of general-purpose technologies, which were widely used in various industries [47]. In particular, if ICT convergence was strengthened at the product level, this would lead to an increase in intermediate demand for ICTs, telecommunication and broadcasting functions, and software, affecting the forward linkage effect.

In the South Korean healthcare industry, the average backward linkage effect from 2005 to 2015 was 0.826, and the average forward linkage effect was 0.638. During the analysis period, the backward linkage effect was higher than the forward linkage effect (Figure 2a). The backward linkage effect of the South Korean healthcare industry decreased to 0.685 and 0.689 in 2008 and 2009, respectively, recovered to 0.875 in 2010, and then sharply dropped to 0.681 in 2011 the following year. It was stabilized after 2012. The forward linkage effect was significantly lower than the backward linkage effect, which was significantly lower than the average of the analysis period but recovered after 2013. The healthcare industry is an end-demand industry that is demanded as a final product rather than an intermediate product in other industrial sectors [48].

Figure 2. Backward and forward linkage effects of the healthcare industry: (a) in Korea (left); (b) in the USA.

For the US healthcare industry, the average backward linkage effect was 0.878, and the average forward effect was 0.532 from 2005 to 2015. During the analysis, the backward linkage effect was consistently higher than the forward chaining effect, and both the forward and backward linkage effects were the highest in 2015 (Figure 2b). These results suggested that the healthcare industry should no longer be viewed as an independent industry with low linkage to other industries but as a linked industry [49,50]. Combining the results of the forward and backward linkage effect, the influence coefficient on the software industry and the healthcare industry in South Korea and the US overall was less than 1, which meant that the industry was largely independent.

Table 8 shows the results of hypothesis testing in this study. Hypothesis 1, suggesting that the linkage effect of the South Korean and US software industries would be different, was accepted ($p < 0.000$). In contrast, Hypothesis 2, suggesting that the linkage effect of the South Korean and US healthcare industries would be different, was partially accepted. Hypothesis H2 of H1, suggesting that the backward linkage effect of the two industries would be different, was rejected ($p < 0.088$), and Hypothesis H2 of H2, suggesting that the forward linkage effect of the two industries, would be different was accepted ($p < 0.000$).

4.2. Contributions of Software and Healthcare Industries to CO₂ Emissions

Tables 9 and 10 show the trends of CO₂ emissions in software and healthcare industries in South Korea and the US. The total CO₂ emissions in the US gradually decreased from 5445.863 Mt in 2005 to 4598.403 Mt in 2015, showing a decrease of about 16% compared to 10 years ago. Average CO₂ emissions in the US software industry were very low, accounting for 0.33% of the total emissions. However, despite the decrease in total CO₂ emissions, the CO₂ emissions of the software industry have been increasing gradually since 2006, requiring attention.

In contrast, average CO₂ emissions in the US healthcare industry were very low, accounting for 0.70% of the total emissions, but it was twice the level of the software industry, a comparative industry. CO₂ emissions of the healthcare industry seemed to increase gradually from 2012 to 2014 but then decrease again in 2015. As shown in Figure 3, the US software industry, as well as the healthcare industry, were analyzed as industries with small CO₂ emissions and small linkage effects. Although the production-inducing effect of the two industries was small, software and healthcare industries should be recognized as sustainable industries in the US with lower CO₂ emissions compared to total emissions.

Table 8. Statistical hypotheses.

	Hypotheses	<i>p</i> -Value	Results
Hypothesis 1 (H1)	The linkage effect between the Korean software industry and the US is different.	-	Accept
H1	The Backward linkage effect between the Korean software industry and the US is different.	0.000	Accept
H2	The Forward linkage effect between the Korean software industry and the US is different.	0.013	Accept
Hypothesis 2 (H2)	The linkage effect between the Korean healthcare industry and the US is different.	-	Partial Accept
H1	The Backward linkage effect between the Korean healthcare industry and the US is different.	0.088	Reject
H2	The Forward linkage effect between the Korean healthcare industry and the US is different.	0.000	Accept

Table 9. The proportion of CO₂ emissions of software and healthcare industries in the USA.

Year	The Proportion of CO ₂ Emissions in the Software Industry (%)	The Proportion of CO ₂ Emissions in the Healthcare Industry (%)	Total CO ₂ Emissions (Mt)
2005	0.30	0.59	5445.863
2006	0.29	0.59	5325.436
2007	0.30	0.60	5378.97
2008	0.31	0.65	5154.128
2009	0.34	0.76	4840.339
2010	0.33	0.73	5009.381
2011	0.33	0.76	4781.944
2012	0.33	0.72	4565.141
2013	0.35	0.77	4686.173
2014	0.36	0.78	4694.472
2015	0.36	0.74	4598.403

Table 10. The proportion of CO₂ emission of software and healthcare industries in South Korea.

Year	The Proportion of CO ₂ Emissions in the Software Industry (%)	The Proportion of CO ₂ Emissions in the Healthcare Industry (%)	Total CO ₂ Emissions (Mt)
2005	0.20	0.01	13.5
2006	0.23	0.01	13.9
2007	0.24	0.01	15.2
2008	0.21	0.01	14.2
2009	0.29	0.02	10.1
2010	0.32	0.02	13.1
2011	0.33	0.01	13.5
2012	0.31	0.02	12.1
2013	0.37	0.02	11.8
2014	0.36	0.02	12.8
2015	0.29	0.02	12.3

Figure 3. Annual CO₂ emissions and proportion of emissions of the software and healthcare industries in 2005 to 2015: (a) in the USA; (b) South Korea (right).

In particular, total CO₂ emissions increased from 2005 to 2007 and have continued gradually decreasing since then, but with an insignificant level of reduction in total CO₂ emissions compared to the US. Average CO₂ emissions of the South Korean software industry were very low, accounting for 0.29% of the total emissions. However, it increased steadily from 2005 to 2014 and then decreased in 2015, indicating that efforts were needed to prevent CO₂ emissions from increasing again.

Average CO₂ emissions of the South Korean healthcare industry were 0.02% of the total emissions at a much lower level than those of the software industry, indicating no significant change over the last 10 years. In particular, the CO₂ emissions of the healthcare industry in South Korea were very different from those in the US.

As can be seen in Figure 3, when considering the linkage effects and CO₂ emissions, the production-inducing effect of the South Korean healthcare industry was smaller than that of the software industry. In other words, the small amount of CO₂ emissions in the healthcare industry had a small impact on other industries. This suggested that South Korea would need to devise a new strategy that could increase the production-inducing effect while maintaining the low-carbon emission structure of the healthcare industry.

5. Discussion and Conclusions

This study analyzed CO₂ emission and economic linkage effect through I-O analysis to find out what role the software and healthcare industries play in the US and South Korea.

Whereas previous studies focused on the influence of an industry on other industries through input–output analysis, this study examined whether the industry is a sustainable industry by considering both the industry’s economic linkage effect and the industry’s CO₂ emissions. CO₂ emissions are now a direct cost. Countries have to pay to emit carbon dioxide. Even if an industry has a large impact on a country, it is necessary to reconsider whether it is an industry that should be continued if the cost is high. Therefore, analyzing both an industry’s economic linkage effect and its CO₂ emissions is very important. Additionally, when comparing the two countries, OECD official data were used. These data are reliable because they are measured by the same standards.

This study provides several important implications for policymakers. First, CO₂ emissions from the software and healthcare industries are less than 1% in both South Korea and the US, indicating that they are suitable as base industries for low-carbon national development. Although the carbon emission of the US has decreased by about 16% since 2005, we revealed that the carbon emission of the software industry has been gradually increasing since 2006. The healthcare industry accounted for twice as high CO₂ emissions as the software industry. Its CO₂ emissions stem from direct activities, such as energy-

intensive hospital operations, as well as indirect activities related to healthcare, such as procurement and waste management [51–54]. The buildings for the healthcare industry (e.g., hospitals) are more energy and water-intensive than normal buildings, consume more resources, and generate a lot of waste from patient care [48]. The healthcare industry also contributes CO₂ emissions from the manufacture and disposal of pharmaceuticals and biohazardous products, including inhaled anesthetics, which are themselves potent greenhouse gases (GHGs) [55–57]. Therefore, it is not surprising that the healthcare industry entails high CO₂ emissions. As the healthcare industry is an essential field for human life, it is difficult to change because there are many institutional and customary barriers that prevent improvement. However, changes are inevitable to reduce CO₂ emissions. In this digital age, the healthcare industry will be able to reduce energy use in hospital buildings by integrating advanced ICT into healthcare services such as telemedicine services, which is expected to contribute to reducing CO₂ emissions.

Although the US software and healthcare industries account for small CO₂ emissions compared to other industries, attention should be paid to the increase in CO₂ emissions by each industry, which shows no sign of decreasing. Meanwhile, there was no significant change in South Korea's total CO₂ emissions during the period we analyzed. In addition, the CO₂ emissions of the South Korean software industry was 0.3%, similar to that of the US software industry, and the CO₂ emission of the South Korean healthcare industry was 0.02%, lower than that of the US healthcare industry. This result shows that the US healthcare industry emits more CO₂ than the software industry, but the South Korean healthcare industry emits less CO₂ than the software industry. The reason that the software industry emits more carbon dioxide than the healthcare industry in South Korea is that the power consumption of IT products has rapidly increased with the development of the Internet and the spread of smartphones. In addition, cooling costs, material costs, and electronic waste generated when disposing of IT products also contribute to an increase in carbon dioxide emissions. According to recent studies of CO₂ emissions in the IT industry, the IT sector was expected to account for 2–6% of global CO₂ emissions in 2020 [57]. In addition, Belkhir and Elmeligi [58] predicted that the ICT industry's CO₂ emissions will account for up to 14% of the global CO₂ emissions by 2040. Therefore, policies to minimize CO₂ emissions in the software industry need to be implemented. Specifically, as the number and use of auxiliary devices are expected to increase as modern software technology advances day by day, it is necessary to implement policies to minimize the CO₂ emissions and energy use of such IT equipment [59].

Second, the forward and backward linkage effects of the software industry in South Korea and the US were different, indicating that there is a difference in the industrial structure. According to Miller and Blair [60], if the forward linkage effect is greater than 1, the responsiveness to the demand for intermediate goods from other industries is high, and if the backward linkage effect is greater than 1, the industry has a large influence on the supply of intermediate goods to other industries. In South Korea, the backward linkage effect was higher than the forward linkage effect from 2005 to 2015, particularly in 2009 and 2011, and the backward linkage exceeded 1 in 2009 and 2011. In contrast, in the US, the backward linkage effect was higher than the forward linkage effect from 2005 to 2008, but the forward and backward linkage effects were reversed in 2009. This means that the extent to which the economic linkage effect of investments in the US software industry, which is leading other industries, is recovering, and the impact of software on the production in other industries have been increasing since 2009 [46]. In South Korea, the forward linkage effect was quite low as most of the South Korean software companies supply finished products, not intermediate products, to other industrial sectors. The backward linkage effect, which is the effect on the production in other industries, was also not high because creative labor must be intensively input into software development.

Third, as a result of analyzing the structure of the healthcare industry in South Korea and the US, the backward linkage effect showed a similar level with no significant difference between South Korea and the US; however, the forward linkage effect of the South Korean

healthcare industry is significantly higher than that of the US. In addition, during the analysis period, the backward linkage effect of the healthcare industry was consistently higher than the forward linkage effect in both South Korea and the US. This means that the healthcare industry should no longer be viewed as an independent industry but as a linked industry. In particular, the forward linkage effect of the South Korean healthcare industry was 0.472 in 2012, which was remarkably low, but it recovered to 0.660 in 2013 and rose to 0.747 in 2015, which is higher than the average of 0.638. These results indicate that the healthcare industry was in demand as a final product rather than an intermediate product in other industry sectors [34].

Software and healthcare industries are essential to the national economy and human life. Therefore, the US and South Korea need to make strategic investments that can enhance the linkage effects while maintaining the low-CO₂ emission structure of both industries as it is now. The limitation of this study is that only the linkage effect was analyzed. By analyzing both the value-added inducement coefficient and the employment inducement coefficient, the role of the industry could not be presented in various aspects. Further research should be directed by analyzing these effects more in order to be helpful in establishing government policies.

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