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Economic and Non-economic Determinants of Environmental Sustainability in the Long Run: Evidence from G20 Economies*

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Abstract

Purpose – This paper analyzes the economic and non-economic factors that contribute to environmental sustainability by reducing CO_2 emissions, based on G20 panel data.

Design/methodology – We conduct a comparative analysis of advanced and developing economies during 1995–2016. To examine the impact, an environmental Kuznets curve (EKC) model was employed, incorporating additional explanatory variables such as internet use, renewable energy, and services trade.

Findings – The empirical findings show the existence of an inverted U-shaped EKC phenomenon between GDP per capita and CO_2 emissions in G20 economies, with the turning point at a per capita GDP level of US$ 38,340. Moreover, an inverted U-shape relation exists between internet use and CO_2 emissions, with the turning point at a 44% internet use rate. The comparative analysis show that the inverted U-shape curve only exits in advanced economies, with turning points of US$ 42,356 per capita GDP and 27% internet use rate, respectively. Renewable energy and services trade have a greater negative impact on CO_2 emissions in advanced economies than in developing economies.

Originality/value – Renewable energy and services trade have a greater negative impact on CO_2 emissions in advanced economies than in developing economies. Overall, the results suggest the role of internet use, renewable energy and services trade in sustainable development in G20 countries.

Keywords: CO_2 Emissions, Internet Use, Renewable Energy; Services Trade; Sustainable Development, The Environmental Kuznets Curve

JEL Classifications: D31, F14, O57

1. Introduction

Carbon dioxide (CO_2) is a greenhouse gas (GHG) that is known to absorb and emit thermal radiation, contributing to the "greenhouse effect." Energy-driven consumption of fossil fuels has caused expeditious growth in CO_2 emissions since the industrial revolution, disrupting the global carbon cycle and contributing to global warming. Emissions have more than doubled since the early 1970s and risen by around 40% since 2000, much of which can be linked to increased economic output.

For the environmental effect of economic factors, the most widely considered type of

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relation between environmental pollutants and economic activity, usually measured by gross domestic product (GDP), is that of an "inverse U", referred to as the "environmental Kuznets curve" (EKC). Much of the empirical evidence indicates that economic growth initially causes increased environmental damage, but once they become sufficiently rich, they become more environment friendly (Grossman and Krueger, 1991; Farhani et al., 2014; Fujii et al., 2018; Omri et al., 2019). Moreover, the effect of trade on the environment has been examined by many scholars, but there are few studies that consider services trade for realizing environmental sustainability. In particular, the Group of Twenty (G20) economies contributed more than 55% of services trade in the world in 2016 (see Table 1). Considering the rapid increase of services trade, it is important to identify the role of service trade in environmental sustainability.

For the non-economic factors, the role of internet use in CO_2 emissions reduction has drawn wide attention. Some studies have confirmed the negative impact of internet use on CO_2 emissions (Zhang and Liu, 2015; Asongu, 2018; Ozcan and Apergis, 2018; Zhang and Meng, 2019; Shabani and Shahnazi, 2019). However, other studies support its positive impact on CO_2 emissions, arguing that the use of ICT, especially internet use, has direct positive effects on electricity consumption, which also leads to a rise in energy consumption related to the production of equipment and operation of infrastructure (Lee and Brahmasrene, 2014; Salahuddin et al., 2016a; Zhou et al., 2018). In addition, due to increasing concern regarding the environmental consequences of emissions from fossil fuels, renewable energy has become an important alternative. The existing literature shows that renewable energy can help mend the climate change problem (Paramati et al., 2017; Balsalobre-Lorente et al., 2018; Dong et al., 2018; Qiao et al., 2019).

However, few studies have examined the environmental effect of economic and non-economic factors together, with a focus on the G20 economies. In particular, G20 economies accounted for about 76.9% of the world's GDP and 78.4% of the world's CO_2 emissions in 2016, making them the largest economies and CO_2 emitters (see also Table 1). Given the importance of G20 economies to the world economy and quality of the environment, examining both economic and non-economic factors that contribute to CO_2 emissions reduction in the G20 is urgent.

Table 1. CO_2 Emissions, Economic Growth, Internet Users, Renewable Energy and Services Trade for Global and G20 Economies in 1995 and 2016 (Except the European Union).

Categories	1995			2016		
	G20	Global	share(%)	G20	Global	Share(%)
CO_2 emissions (million tonnes)	17646	22803	77.4%	26886	34291	78.4%
GDP (constant 2010 billion US$)	33027	42299	78.1%	59858	77797	76.9%
Internet users (100 thousands people)	338	447	75.6%	23156	34194	67.8%
Renewable energy (Mtoe)	755	1211	62.3%	1091	1881	58.0%
Services trade (current billion US$)	1571	2632	59.7%	5450	9764	55.8%
Energy consumption (Mtoe)	6765	9215	73.4%	10120	13812	73.3%

Data sources: Enerdata, 2018; World Bank, 2019; OECD,2019; GCP, 2019.

The purpose of this paper is to examine the impact of GDP per capita, services trade, internet use, and renewable energy on CO_2 emissions, based on the EKC framework. We compare the impact in advanced economies with developing ones of the G20, which, to our

best knowledge, is the first attempt to conduct such a comparative study.

This paper is organized as follows. Section 2 summarizes the existing related literature and presents the hypotheses. Section 3 describes the methodology and data, while section 4 discusses the empirical results. Finally, section 5 presents the conclusions and policy implications of this study.

2. Literature Review and Hypotheses

2.1. Economic Growth and CO_2 Emissions

The EKC hypothesis explains the existence of an inverted U-shape relation between income and pollutant emissions. In the early stages of economic growth, pollutant emissions increase until economic growth reaches a threshold level and then begin to decline (Grossman and Krueger, 1991; Shafik, 1994).

Numerous researchers have examined the validity of the EKC hypothesis; many of them support that the income-pollutant nexus presents an inverted U-shape (Farhani et al., 2014; Dong et al., 2018; Fujii et al., 2018; Omri et al., 2019).

Fujii et al. (2018), using data for 276 cities from 26 countries, explored the impact of economic growth on urban CO_2 emissions in the transport, residential and industrial, and energy sectors. The empirical results show that, for the transport and residential and industrial sectors, there is an inverted U-shape, which indicates the existence of the EKC. Omri et al. (2019) incorporated foreign direct investment (FDI), financial development, and trade openness into the EKC model. By using fully modified ordinary least squares (FMOLS), they confirmed that the EKC hypothesis is valid in Saudi Arabia.

For example, it is argued against the EKC studies that an economic growth can not always improve the environment as carbon emissions are monotonically increasing with income (Farhani and Ozturk, 2015; Fodha and Zaghdoud, 2010; Holtz-Eakin and Selden, 1995).

Adewuyi and Awodumi (2017) added that researches analyzing the tie between energy consumption and economic growth do not contribute much to the literature. In addition, given that energy consumption also has a direct impact on the level of carbon emissions to the air, examining these two strands of studies using an integrated framework is necessary.

However, Mikayilov et al. (2018) did not find any evidence of it. In their results, the effect of economic growth on CO_2 emissions was reported to be positive, and the coefficient was found to be 0.7–0.8.

This study uses panel data from G20 economies to re-examine this issue with the following hypothesis:

Hypothesis 1: An inverted U-shape relation exists between economic growth and CO_2 emissions in G20 economies. More specifically, CO_2 emissions are expected to increase with rising income levels; however, they are more likely to decline with higher income levels.

2.2. Internet Use and CO_2 Emissions

In recent decades, with the rapid penetration of ICT and internet use, arguments concerning the impact of technology on the environment seem to be increasing.

Some studies support that the diffusion of internet technology has a positive impact on CO_2 emissions (Lee and Brahmasrene, 2014; Salahuddin et al., 2016a).

Other studies argue that internet use has revolutionized economic growth and negatively affects CO_2 emissions because it has greatly changed modes of production and the ways we communicate and work (Williams, 2011). Such negative effects have been supported by the studies of Zhang and Liu (2015), Asongu (2018), Ozcan and Apergis (2018), and Zhang and Meng (2019).

Ozcan and Apergis (2018), in their study of 20 emerging economies, reported that an improvement in internet use reduces CO_2 emissions by 0.02–0.04%; the causality relationship is unidirectional, from internet use to CO_2 emissions.

Shabani and Shahnazi (2019), using data for Iran from 2002 to 2013, compared the impacts of ICT, GDP, and energy consumption on CO_2 emissions across economic sectors. Their results show that, in the industrial sector, the ICT variable increases CO_2 emissions, while for the transportation and services sector, the ICT impact lowers CO_2 emissions.

In particular, Zhang and Meng (2019), using data from 115 countries, investigated how internet use affects the link between income and emissions and compared the impact of internet use on CO_2 reduction in 1996–2005 to that of 2006–2014, revealing that by increasing internet penetration, the level of actual income beyond which pollution begins to decline can be reduced. Their comparative tests show that internet penetration has a growing negative impact on emissions reduction over time.

In addition to the linear relations, Higón et al. (2017) examined the non-linear association between these two variables. In their study, ICT is introduced as a part of the growth process in firms through scale, input, output, and technology effects, which produce an inverted U-shape relation between ICT and emissions. First, in term of the scale effect, it helps companies to expand, while such ICT may exist in large numbers in computers and software, which increases emissions. Once the basic ICT capital is placed, marginal ICT can be used to optimize the processes of production and to improve energy efficiency, which can reduce emission intensity through technology effects. By using panel data from 142 economies, they confirmed the inverted U-shape connection.

To examine the non-linear relationship between internet use and CO_2 emissions in G20 economies, we employed the following hypothesis:

Hypothesis 2: An inverted U-shape relationship exists between internet use and CO_2 emissions in G20 economies. More specifically, CO_2 emissions are expected to increase with rising internet use rate; however, they are more likely to decline with higher levels of internet use rate.

2.3. Renewable Energy and CO_2 Emissions

A growing number of studies have investigated the nexus of renewable energy-environment at the country level and region level. Most of them confirm the role that renewable energy plays in environmental sustainability (Paramati et al., 2017; Ito, 2017; Bekhet and Othman, 2018; Mohlin et al., 2018; Dong et al., 2018; Qiao et al., 2019).

At the country level, Mohlin et al. (2018), in their studies on the United States, employed the decomposition method and provided evidence in favor of renewable energy having an

equally significant effect on CO_2 reduction from 2007 to 2017 as natural gas; the reduction in CO_2 emissions by renewables was found to be 2.3–3.3%. In the case of the G20, Qiao et al. (2019) studied its impact on emissions using the EKC model; by using the FMOLS technique, they concluded that renewable energy has a beneficial environmental effect. Moreover, Bekhet and Othman (2018) added renewable energy to the base of the cubic polynomial functional form of EKC and confirmed its positive role in environmental sustainability.

At the regional level, Dong et al. (2018), using data for global samples across six regions, found that the growth of renewable energy use leads to the reduction of CO_2 emissions. They additionally reported that this negative impact is greater in South and Central America and Europe and Eurasia than in other regions.

In terms of causality, Cai et al. (2018) revealed that a bidirectional causality relationship exists in Germany between these two variables, while for the Unites States, the causality relationship is unidirectional, from renewable energy use to CO_2 emissions.

To explore the contribution of renewable energy to environmental quality, our hypothesis is developed as follows:

Hypothesis 3: The higher the renewable energy use, the lower the CO_2 emissions in G20 economies.

2.4. Services Trade and CO_2 Emissions

The trade openness-environment link has been widely examined, based on the EKC model; some studies have reported that trade openness positively affects CO_2 emissions (Lau et al., 2014; Li et al., 2017; Hasanov et al., 2018).

Li et al. (2017) used an input-output model and found that the increase in scale of China's steel export raises CO_2 emissions. Hasanov et al. (2018) used data from nine oil-exporting countries, and their long-run estimation results show that a 1% rise in imports leads to a 0.3–0.4% increase in CO_2 emissions, while a 1% rise in exports reduces CO_2 emissions by 0.6–0.8%.

However, other studies argue that trade openness improves environment quality (Shahbaz et al., 2017a; Frutos-Bencze et al., 2017). Specifically, Ling et al. (2015) decompose the trade effect into scale effect, technology effect, composition effect, and comparative advantage effect to explore the impact of trade on environment. They found that the scale effect has a positive effect on CO_2 emissions, while the technique effect on CO_2 emissions is negative after a threshold income level.

While a number of studies have examined the impact of trade on the environment, the linkage between services trade and the environment is relatively unexplored. Only a few researchers have begun to use the services trade as an explanatory variable to examine the trade-environment nexus. For example, Zhang and Zhang (2018), in their studies on China, examined the effect of services trade based on the EKC model. The empirical results show that the services trade mitigates CO_2 emissions. Thus, to check whether the services trade improves environmental quality in G20 economies, our hypothesis is presented as follows:

Hypothesis 4: The larger the volume of services trade, the lower the CO_2 emissions in G20 economies.

3. Empirical Analysis

3.1. Empirical Model

To test our hypotheses, we establish the following two empirical models.

First, to investigate the validity of the inverted U-shaped EKC hypothesis, model 1 was set up as CO_2 emissions (CO_2) is the dependent variable, while the independent variables are GDP per capita (*GDP*), internet use (*INTER*), renewable energy (*RE*), and services trade (*ST*). Moreover, based on the existing EKC model, a quadratic estimation term of *GDP* (GDP^2) is added as an independent variable.

Model 1:

$$CO_{2it} = \alpha_0 + \alpha_1 GDP_{it} + \alpha_2 GDP_{it}^2 + \alpha_3 INTER_{it} + \alpha_4 RE_{it} + \alpha_5 ST_{it} + \varepsilon_{it}$$

Under the EKC hypothesis, the parameters of α_1 and α_2 are expected to be $\alpha_1 > 0$ and $\alpha_2 < 0$, which indicate that with an increase in GDP per capita, CO_2 emissions first increase, and after reaching a threshold (turning point), CO_2 emissions decrease, showing an inverted U-shape relation between GDP per capita and CO_2 emissions. The subscript i refers to countries, and t represents the year.

By taking the derivative of model 1, the turning point of GDP per capita can be determined as follows:

$$\frac{\partial \mathrm{E}(CO_{2it})}{\partial GDP} = \alpha_1 + 2\alpha_2 GDP_{it} = 0$$

To examine whether an inverted U-shape relation exists between internet use and CO_2 emissions based on the EKC framework, model 2 takes the dependent variable of CO_2 emissions (CO_2) and independent variables of internet use (*INTER*), GDP per capita (*GDP*), renewable energy (*RE*), and services trade (*ST*). Additionally, the square term of *INTER* ($INTER^2$) is added to our model 2:

Model 2:

$$CO_{2it} = \beta_0 + \beta_1 INTER_{it} + \beta_2 INTER_{it}^2 + \beta_3 GDP_{it} + \beta_4 RE_{it} + \beta_5 ST_{it} + \varepsilon_{it}$$

According to the EKC concept, CO_2 emissions increase as internet use rate improves; however, as internet use rate reaches a higher level, CO_2 emissions may reduce. For hypothesis 2 to be valid, the parameters of β_1 and β_2 are expected to be $\beta_1 > 0$ and $\beta_2 < 0$.

Similarly, by taking the derivative of model 2, the turning point of internet use can be determined as follows:

$$\frac{\partial \mathrm{E}(CO_{2it})}{\partial INTER} = \beta_1 + 2\beta_2 INTER_{it} = 0$$

Moreover, hypothesis 3 and 4 can be tested with the above two models. For hypothesis 3 and 4 to be valid, the parameters of α_4, α_5, β_4, and β_5 are expected to be a negative value.

3.2. Data Sources

In this study, our full sample dataset includes the period of years from 1995 to 2016 in 19 individual economies of the G20. To fully address the concern that the impacts of GDP per capita, internet use, renewable energy, and services trade on CO_2 emissions may differ across various economic levels, these 19 economies in the G20 were classified into two groups based on the International Monetary Fund's (IMF) country classification: advanced economies and developing economies.

Accordingly, the advanced economies subpanel includes nine countries (i.e., Australia, Canada, France, Germany, Italy, Japan, Korea, United Kingdom, United States), while the developing economies consist of data for 10 countries (i.e., Argentina, Saudi Arabia, Indonesia, India, Brazil, China, Mexico, Russian Federation, Turkey, South Africa).

Appendix (1) presents the variables and data descriptions. The dependent variable of CO_2 emissions, measured in tonnes per capita, are taken from the Global Carbon Project (GCP). The independent variables consist of GDP per capita, services trade, internet use, and renewable energy. Data of GDP per capital, services trade, and internet use are derived from the World Development Indicators database, while data of renewable energy is collected from the Organization for Economic Co-operation and Development database.

We use real GDP per capita (constant 2010 US$) as a measure of economic growth. Services trade is measured as the ratio of the sum of service exports and imports to GDP. Following Zaghdoudi (2017) and Ozcan and Apergis (2018), the internet use variable is measured using individuals who had used the internet in the last three months (% of population). Renewable energy is measured in renewable energy use per capita GDP, and is calculated by renewable energy use (tonne of oil equivalent)/ GDP (constant 2010 US$) following the study of Dong et al. (2018). Table 2 reports the summary of statistics descriptive.

Table 2. Summary of Statistics Descriptive

Panel	Statistics	CO_2	*GDP*	*INTER*	*RE*	*ST*
Full sample	Mean	8.561840	22978.48	36.48024	0.028726	9.529164
	Maximum	21.28300	55777.35	94.62000	0.225040	21.01766
	Minimum	0.808000	677.0355	0.004955	1.01E-05	2.055087
	STd. Dev	5.776352	17388.71	30.41560	0.040444	4.014747
	Observations	418	418	418	418	418
Advanced economies	Mean	11.97944	39607.39	54.58307	0.008191	10.88191
	Maximum	21.28300	55777.35	94.62000	0.038096	21.01766
	Minimum	5.134000	12055.23	0.524413	0.000791	3.840829
	STd. Dev	4.749329	9141.977	28.86885	0.008502	4.095912
	Observations	198	198	198	198	198
Developing economies	Mean	5.486000	8012.463	20.18768	0.047208	8.311689
	Maximum	19.76800	21507.96	74.88000	0.225040	19.74858
	Minimum	0.808000	677.0355	0.004955	1.01E-05	2.055087
	STd. Dev	4.814436	5054.837	21.18661	0.048220	3.529328
	Observations	220	220	220	220	220

Note: STd. Dev. indicates standard deviation.

4. Results

4.1. Results of Panel Unit Root Tests

To check the stability and examine the integration level of selected variables, the panel unit root tests are conducted. All tests have the null hypothesis with a unit root (non-stationary); the results are presented in Table 3. Clearly, most variables are non-stationary at level. However, when the first difference is taken, all selected variables become stationary at 1% significant level, indicating that all variables are integrated on the order of one I (1). Accordingly, this result enables us to test whether a cointegration relation exists among the selected variables in the long run by developing the Johansen Fisher panel cointegration test.

Table 3. Unit Root Test

Categories	Full sample		Advanced economies		Developing economies	
	Level	1st Difference	Level	1st Difference	Level	1st Difference
CO_2						
ADF - Fisher Chi-square	51.2060	212.294***	26.3124	121.153***	24.8936	91.1407***
PP - Fisher Chi-square	49.7406	292.389***	29.2123**	171.384***	20.5283	121.005***
GDP						
ADF - Fisher Chi-square	48.5551	119.843***	21.3776	68.4933***	27.1775	51.3494***
PP - Fisher Chi-square	22.7715	148.034***	13.9300	91.0978***	8.84146	56.9361***
GDP^2						
ADF - Fisher Chi-square	27.8163	119.644***	20.2140	70.1411***	7.60222	49.5028***
PP - Fisher Chi-square	21.3094	162.281***	14.1845	98.7421***	7.12486	63.5389***
INTER						
ADF - Fisher Chi-square	21.9586	97.3773***	3.36285	57.6836***	18.5958	39.6937***
PP - Fisher Chi-square	13.6258	127.284***	1.94152	66.3416***	11.6842	60.9420***
$INTER^2$						
ADF - Fisher Chi-square	9.72896	113.884**	6.79254	66.8122***	2.93643	47.0719***
PP - Fisher Chi-square	8.03182	125.264***	7.57660	67.3440***	0.45522	57.9196***
RE						
ADF - Fisher Chi-square	49.1763	172.206***	11.8229	104.216***	37.3534**	67.9892***
PP - Fisher Chi-square	91.6952***	497.265***	6.65044	162.665***	85.0448***	334.600***
ST						
ADF - Fisher Chi-square	46.2570	167.007***	27.8308	65.3442***	18.4262	101.662***
PP - Fisher Chi-square	35.1460	194.455***	11.6223	71.0051***	23.5238	123.450***

Note: ***, **, * denote statistical significance at 1%, 5%, and 10% level, respectively.

4.2. Results of Cointegration Test

The Johansen Fisher panel cointegration test is applied to examine the long run cointegration relations among the variables. The results from both trace tests and max-eigen value tests show the existence of long-run equilibrium relationships at 1% significant level for each of the models, as well as for all three panels (Table 4).

Table 4. Johansen Fisher Panel Cointegration Test

Hypothesized No. of CE(s)	Full sample		Advanced economies		Developing economies	
	Trace test	Max-eigen test	Trace test	Max-eigen test	Trace test	Max-eigen test
Model 1: CO_2= f (GDP, GDP^2, INTER, RE, ST)						
None	2611***	4196***	1217***	1875. ***	1394. ***	2321***
At most 1	825.8***	469.4***	370.3***	185.5***	455.5***	283.9***
At most 2	444.7***	316.5***	215.9***	129.4***	228.7***	187.1***
At most 3	206.3***	134.3***	110.3***	72.64***	95.96***	61.63***
At most 4	103.9***	67.86***	53.91***	34.34**	50.02***	33.52**
At most 5	70.39***	70.39***	36.09***	36.09***	34.30**	34.30**
Model 2: CO_2= f (INTER, $INTER^2$, GDP, RE, ST)						
None	2235***	3735***	1133***	1845***	1102. ***	1889***
At most 1	714.6***	404.3***	352.8***	190.4***	361.8***	213.9***
At most 2	371.0***	211.0***	190.3***	112.5***	180.8***	98.48***
At most 3	193.5***	114.4***	94.63***	53.50***	98.90***	60.88***
At most 4	110.4***	73.09***	57.13***	35.15***	53.27***	37.94***
At most 5	73.11***	73.11***	40.07***	40.07***	33.04**	33.04**

Note: ***, **, * denote statistical significance at 1%, 5%, and 10% level, respectively.

4.3. Estimation Results for All G20 Economies

After employing the cointegration test, the long-run equilibrium relation among all variables is confirmed; it allows us to explore the long-term elasticity of our models. We adopt FMOLS technique, which is widely used in a EKC model for long run estimations (Farhani et al., 2014; Paramati et al., 2017; Omri et al., 2019; Qiao et al., 2019). Table 5 reports the long-run elasticities for all G20 economies as a whole.

The results of model 1 show that coefficients of *GDP* and GDP^2 on CO_2 are positive and negative respectively and are statistically significant at 1% level. This suggests the existence of an inverted U-shape relation between GDP per capita and CO_2 emissions in G20 economies, which supports our hypothesis 1. The turning point of GDP per capita can be calculated as follows by using the coefficients from Table 5:

$$GDP_{it}(\text{turing point}) = \frac{-\alpha_1}{2\alpha_2} = \frac{-0.000559}{2*(-7.29e-09)} = 38{,}340\text{US\$}$$

The result suggests that CO_2 emissions first show an upward trend, however, when reaching the per capita GDP level of US$ 38,340, CO_2 emissions begin to decline. Moreover, it is worth mentioning that the turning point estimated above are still above the mean value of per capita GDP for the full sample (US$ 22,978.48), which indicates that many G20 economies have not yet reached the level of per capita GDP at which CO_2 emissions will be reduced as per capita GDP increases.

In Model 2, CO_2 is affected positively by *INTER* and negatively by $INTER^2$, which supports an inverted U-shape relation between internet use and CO_2 emissions; these results support hypothesis 2. The turning point of internet use rate can be calculated as follows:

$$INTER_{it}(\text{turing point}) = \frac{-\beta_1}{2\beta_2} = \frac{-0.060565}{2*(-0.000687)} = 44\%$$

The result indicates that CO_2 emissions are likely to increase first as the internet use rate improves, however, when reaching an internet use rate of 44%, CO_2 emissions tend to decrease. The calculated turning point of internet use rate for the full sample is still above the mean value (36.48 %), meaning that many G20 countries have not yet reached the level of internet use rate at which CO_2 emissions decrease as internet use rate increases.

In both Model 1 and 2, renewable energy negatively affects CO_2 emissions at 5% significant level, which supports our hypotheses 3. An increase in one unit of renewable energy leads to a reduction in CO_2 emissions by 10–12 units in the long run. Services trade also show a negative impact on CO_2 emissions and is significant at 1% level. An increase in one unit of services trade volume causes CO_2 to decline by around 0.12–0.16 units in the long run. This support our hypotheses 4.

Table 5. Long-run Elasticities for all G20 Countries

Variables	Model 1	Model 2
GDP	0.00056***	0.00003
GDP^2	-7.29e-09***	
INTER	-0.00014	0.06057***
$INTER^2$		-0.00069***
REI	-10.79600**	-12.60804**
ST	-0.15806***	-0.12952***
Turning point	Turning point of GDP per capita	Turning point of internet use rate
	38,340US$	44%

Note: ***, **, * denote statistical significance at 1%, 5%, and 10% level, respectively.

4.4. Comparison Analysis for Advance and Developing Economies of G20

To investigate whether the impact varies with different economic levels, we divide G20 economies into two groups: advance and developing economies. Table 7 displays the long run estimates by economic levels.

For advance economies, *GDP* has a positive coefficient value on CO_2, while GDP^2 has a negative coefficient value, suggesting an inverted U-shape relationship between GDP per capita and CO_2 emissions. The turning point of GDP per capita is calculated as US$ 42,356. It means that CO_2 emissions increases first as the GDP per capita rises, however, after reaching the per capita GDP level of US$ 42,356, CO_2 emissions will decline. The coefficient value of *INTER* and $INTER^2$ are positive and negative, respectively, suggesting an inverted U-shape relation between internet use and CO_2 emissions. The turning point of internet use rate is estimated as 27%. It means that CO_2 emissions is likely to increase first with rising rates of internet use, however, when reaching an internet use rate of 27%, CO_2 emissions are likely to decline. Renewable energy has a negative impact on CO_2 emissions: an increase in one unit of renewable energy causes CO_2 emissions to decline by around 88–107 units in the long run. Service trade is negatively related to CO_2 emissions: an increase in one unit of services trade volume cause to a reduction in CO_2 emissions by around 0.26 unit.

For developing economies, *GDP* has a negative coefficient value on CO_2, while GDP^2 has a positive coefficient value. It indicates that a U-shape relationship exists between GDP per capita and CO_2 emissions. The turning point of GDP per capita is calculated as US$ 7,809. This suggests that CO_2 emissions initially decline until reaching a per capita GDP point of

US$ 7,809, where an increase in CO_2 emissions can be identified. *INTER* and *INTER*^{2} have no significant impacts on CO_2, indicating that there is no inverted U-shape relation between internet use and CO_2 emissions. In addition, renewable energy negatively affects CO_2 emissions: an increase in one unit of renewable energy reduces CO_2 emissions by around 11–28 units in the long run. Services trade also has a negative impact on CO_2 emissions: an increase in one unit of services trade volume leads to a reduction in CO_2 emissions by around 0.09–0.13 units in the long run.

The following observations emerge from a comparison of advanced and developing economies. First, there is an inverted U-shape relationship between GDP per capita and CO_2 emissions in advanced economies, but there is a U-shape relationship in developing economies. For advanced economies, the rising level of GDP per capita first increases CO_2 emissions, however, after reaching the GDP per capita level of US$ 42,356, the CO_2 emissions tends to decline as the GDP per capita rises. On the contrary, for developing economies, the increase of GDP per capita initially decrease CO_2 emissions, however, after reaching a GDP per capita level of US$ 7,809, CO_2 emissions is likely to increase as the GDP per capita rises.

Second, the existence of an inverted U-shape relationship is found between internet use and CO_2 emissions in advanced economies, while there is no impact of internet use on CO_2 emissions in developing economies. It suggests that, in advanced economies, an increase in internet use rate initially increases CO_2 emissions, but after attaining the internet use rate of 27%, the CO_2 emissions tend to decline as the internet use rate increases.

Third, renewable energy has a more negative impact on CO_2 emissions in advanced economies than in developing economies. It means that the rising level of renewable energy leads to a greater reduction in CO_2 emissions in advanced economies.

Finally, services trade has a greater negative impact on CO_2 emissions in advanced economies than in developing economies. The growth in services trade volume causes a higher decline in CO_2 emissions in advanced economies.

Table 7. Long-run Elasticities for Advance and Developing Economies

Variables	Model 1		Model 2	
	Advanced economies	**Developing economies**	**Advanced economies**	**Developing economies**
GDP	0.00088***	-0.00058***	0.00005	0.00007
GDP^2	-1.04e-08***	3.72e-08***		
INTER	-0.00514	0.01510*	0.02959*	0.03107
INTER^2			-0.00055***	-0.00007
REI	-88.61761*	-28.04699***	-106.7350*	-11.47752*
ST	-0.26241***	-0.13581***	0.04907	-0.09976*
Turning point	Turning point of GDP per capita		Turning point of internet use rate	
	42,356US$	7,809US$	27%	Na

Note: ***, **, * denote statistical significance at 1%, 5%, and 10% level, respectively.

5. Conclusions and Limitations

This paper analyzed the economic and non-economic factors affecting CO_2 emissions based on panel data of G20 economies during 1995–2016. We conducted a comparative analysis of advanced and developing economies of the G20. To examine the impact, the EKC

model was employed with additional explanatory variables such as internet use, renewable energy, and services trade.

The empirical findings for all G20 economies show the existence of an inverted U-shape relationship between GDP per capita and CO_2 emissions. The turning point of per capita GDP is US$38,340. In addition, the existence of an inverted U-shape relation was found between internet use and CO_2 emissions with turning points at 44% for the internet use rate in G20 economies. Renewable energy and services trade have negative impacts on CO_2 emissions. As renewable energy use and service trade volumes increase, CO_2 emissions is more likely to decrease.

The comparative results for advance and developing economies show that there is an inverted U-shape relationship between GDP per capita and CO_2 emissions with turning point at US$ 42,356 for GDP per capita in advanced economies. However, for developing countries, the inverted U-shape EKC phenomenon did not exist, because despite their eagerness to pursue economic growth instead of preserving the environment, they had not reached a certain level of income. Moreover, there is an inverted U-shape relation between internet use and CO_2 emissions with turning points at 27% for internet use rate in advanced economies. However, for developing economies, the inverted U-shape relation did not exist, because they had not installed sufficient network infrastructure to facilitate it. Renewable energy and service trade has a more negative impact on CO_2 emissions in advanced economies than in developing economies. The rising level of renewable energy and service trade volume lead to a greater reduction of CO_2 emissions in advanced economies.

Three policy implications are identified as follows. First, the results advocate for the development of adequate ICT infrastructure and improved internet use rate to enhance environmental sustainability, not only in advanced nations, but also in developing countries.

Second, the findings show that renewable energy plays a significant role in decreasing CO_2 emissions in G20 economies, especially in advanced economies. We suggest that G20 policy-makers optimize the mix of energy consumption and increase the share of renewable energy within the total number of energy components.

Finally, the results confirmed the potential role of the services trade in environmental sustainability. The international services trade can enhance environmental quality by encouraging the import of modern technologies for the services sector, thereby decreasing CO_2 emissions levels. Thus, we suggest that to reduce the CO_2 emissions of G20 economies, it is necessary to adjust the trade structure and improve the services trade volume.

6. Limitations and Future Research

This study mainly analyzed the non-economic determinants of environmental sustainability but not analyzed the recent developments of carbon neutrality. As of 2021, countries representing more than 60% of harmful greenhouse gasses and more than 70% of the world economy would have committed to achieve carbon neutrality by the end of 2050. Carbon neutrality is referred to achieving net-zero carbon dioxide emissions. This can be done by balancing producing carbon dioxide with its removal or by reducing emissions from country. Not only every country but also city, financial institution and company should setup plans for net zero, and prepare the right way to that goal, which means cutting global emissions by 45 per cent by 2030 compared with 2010 levels. Republic of Korea, USA, European Union, United Kingdom and more than 110 countries have committed to do so.

China has pledged to achieve the goal before 2060. European Union is going to establish a carbon border adjustment mechanism(CBAM). The CBAM would place a carbon tax on imports of certain goods from outside the EU, in an effort to reduce the risk of carbon emission in the process of manufacturing. Future research, therefore, could analyze the impact of CBAM through in-depth research with more specific and recent data on each country. In addition, it will be better to analyze the effect of CBAM on the carbon emission in a various perspective.

Appendix / Appendices

Appendix 1. Summary of Data Description and Source

Signs	Variables	Variable definitions	Sources
CO_2	CO_2 emissions	CO_2 emissions per capita (tonnes per capita)	Global Carbon Project (GCP)
GDP	GDP per capita	GDP per capita (constant 2010 US$)	World Bank (WDI)
INTER	Internet use	Individuals using the internet (% of population)	World Bank (WDI)
RE	Renewable energy	Renewable energy use per capita GDP (tonne of oil equivalent per constant 2010US$)	OECD data
ST	Services trade	Sum of service exports and imports (% of GDP)	World Bank (WDI)

Appendix 2. Summary of Studies

Authors	Data sample	Variables	Methodology	Shape of EKC	Main findings
Studies of EKC					
Farhani et al. (2014)	• 10 MENA countries • 1990–2010	CO_2, GDP, EC, TO, MAN	FMOLS, DOLS	∩	FMOLS estimates: • 1% ↗ EC, 1.828% ↗ CO_2 • 1% ↗ TO, 0.216% ↗ CO_2
Dong et al. (2018)	• China • 1993–2016	CO_2, GDP, FF, NU, RE	ARDL, VECM	∩	• 1% ↗ FF, 1.0747% ↗ CO_2 • 1% ↗ NU, 0.0021% ↘ CO_2 • 1% ↗ RE, 0.0192% ↘ CO_2
Fujii et al. (2018)	• 276 cities in 26 countries • 2000, 2005 and 2008	CO_2, GDP, POP	Partial linear regression	∩	• The EKC hypothesis is valid for transport and residential & industry sectors.
Mikayilov et al. (2018)	• Azerbaijan • 1992–2013	CO_2, GDP	DOLS, FMOLS, CCR		• GDP (+) CO_2
Omri et al. (2019)	• Saudi Arabia • 1990–2014	CO_2, GDP, FDI, TO, FD	FMOLS, DOLS	∩	• FDI, TO, and FD have inverted U-shape relationships with CO_2.

Appendix 2. (Continued)

Authors	Data sample	Variables	Methodology	Shape of EKC	Main findings
Studies of the nexus of internet use and CO_2 emissions					
Lee and Brahmasrene (2014)	• Nine ASEAN countries • 1991–2009	ICT, CO_2, GDP, HCD	DOLS, FMOLS, CCR		• 1% ↗ ICT, 0.660% ↗ CO_2
Zhang and Liu (2015)	• 29 provinces of China • 2000–2012	ICT, CO_2, INDU, UR, EI, GDP	FE		• Eastern regions: 1% ↗ ICT, 0.0286% ↘ CO_2 • Central regions: 1% ↗ ICT, 0.129% ↘ CO_2
Salahuddin et al. (2016a)	• OECD countries • 1991–2012	INTER,FD, TO, GDP, CO_2	PMG, FOLS,DOLS		• INTER (+) CO_2 (LR)
Salahuddin et al. (2016b)	• Australia • 1985–2012	INTER, FD, GDP, CO_2	ARDL		• No significant association between INTER and CO_2 emissions (LR)
Higón et al. (2017)	• 142 countries • 1995–2010	ICT, GDP, CO_2, INDU	POLS, FE	∩	• An inverted U-shaped relation exists between ICT and CO_2 emissions.
Ozcan and Apergis (2018)	• 20 emerging countries • 1990–2015	INTER, CO_2, GDP, FD, TO, EC	MG, AMG, GM-FMOLS		• 1% ↗ INTER, 0.02~0.04% ↘ CO_2 • INTER→ CO_2
Asongu et al. (2018)	• 44 countries of sub Saharan Africa • 2000–2012	ICT, CO_2, CO_2 from liquid fuel consumption	GMM		• ICT has a positive net impact on CO_2 • Mobile phone penetration alone has a net negative effect on CO_2 emissions from liquid fuel consumption
Yan et al. (2018)	• 50 countries • 1995–2013	ICT, FDI, INDU, TO, EP	OLS, FE		• ICT (+) EP
Zhou et al. (2018)	• China	ICT, EI	SDA		• 1% ↗ ICT, 4.54% ↗ energy intensity
Zhang and Meng (2019)	• 115 countries • 1996–2014	INTER, CO_2, GDP, UR, INDU	FE	∩	• INTER (-) CO_2 • Internet penetration has an increasing negative impact on the reduction of CO_2.
Shabani and Shahnazi (2019)	• Iran • 2002–2013	ICT, EC, GDP, CO_2	DOLS, panel causality test	∩	• Industrial sector: ICT (+) CO_2; transportation and services sectors: ICT (-) CO_2 • Industrial and transportation sectors: ICT ↔ CO_2(SR); services sector: ICT→CO_2 (SR), ICT, GDP, EC → CO_2 (LR)

Appendix 2. (Continued)

Authors	Data sample	Variables	Methodology	Shape of EKC	Main findings
Studies of the nexus of renewable energy and CO_2 emissions					
Shafiei and Salim (2014)	• OECD countries • 1980–2011	NRE, RE, INDU, POP, UR, GDP, CO_2	AMG		• 1 % ↗ RE, 0.004 % ↘ CO_2 • 1 % ↗ NRE, 1.038 % ↗ CO_2
Paramati et al. (2017)	• G20 countries • 1991–2012	FDI, EE, SMC, POP, RE, NRE, GDP, CO_2	FMOLS		• Full sample: 1% ↗ RE, 0.038% ↘ CO_2 • Advanced economies: 1 % ↗ RE, 0.024% ↘ CO_2 • Developing economies: 1 % ↗ RE, 0.062% ↘ CO_2
Ito (2017)	• 42 developing countries • 2002–2011	RE, NRE, GDP, CO_2	GMM, PMG		• 1 % ↗ RE, 0.11~0.25 % ↘ CO_2 • 1% ↗ NRE, 0.56~0.93 % ↗ CO_2
Bekhet and Othman (2018)	• Malaysia • 1971–2015	RE, GDP, CO_2	VECM Granger causality analysis, DOLS, FMOLS	N	• RE (-) CO_2 • GDP↔ CO_2, CO_2 →RE (SR); CO_2, GDP→ RE (LR)
Balsalobre-Lorente et al. (2018)	• Five European Union countries • 1985–2016	REC, TO, NAR, EIN, GDP, CO_2	PLS	N	• RE (-) CO2
Cai et al. (2018)	• G7 countries • 1965–2015	CEC, GDP, CO_2	ARDL cointegration test, Granger causality test		• Germany: CEC and CO_2 co-integrated with CO_2; Japan: CEC and GDP co-integrated with CO2. • CEC ↔ CO_2 in Germany; CEC→ CO_2 in United States.
Dong et al. (2018)	• 128 countries • 1990–2014	RE, POP, GDP, CO_2	FMOLS, CCEMG		• North America: 1% ↗ RE, 0.1603% ↘ CO_2; South and Central America: 1% ↗ RE, 0.3242% ↘ CO_2; Europe and Eurasia: 1% ↗ RE, 0.1917% ↘ CO_2; Middle East: 1% ↗ RE, 0.1107% ↘ CO_2; Africa: 1% ↗ RE, 0.1884% ↘ CO_2; Asia Pacific: 1% ↗ RE, 0.1018% ↘ CO_2; Global panel: 1% ↗ RE, 0.1184 %↘ CO_2.
Qiao et al. (2019)	• 19 G20 countries • 1990–2014	RE, AGI, GDP, CO_2	FMOLS	∩	• Full sample: 1% ↗ RE, 0.130% ↘ CO_2 • Advanced economies: 1 % ↗ RE, 0.156% ↘ CO_2 • Developing economies: 1 % ↗ RE, 0.036% ↘ CO_2

Appendix 2. (Continued)

Authors	Data sample	Variables	Methodology	Shape of EKC	Main findings
Studies of the nexus of trade and CO_2 emissions					
Lau et al. (2014)	• Malaysia • 1970–2008	TO, FDI, GDP, CO_2	Bounds test, VECM Granger causality analysis	∩	• TO (+) CO_2 • FDI (+) CO_2
Ren et al. (2014)	• Industrial sector of China • 2000–2010	TO, FDI, GDP, CO_2	GMM	∩	• TO (+) CO_2
Omri et al. (2015)	• 12 MENA countries	FD, TO, GDP, CO_2	GMM	∩	• TO → CO_2
Shahbaz et al. (2017a)	• Unites States • 1960–2016	RE, TO, OP, GDP, CO_2	Bounds test, VECM Granger causality analysis	N	• TO (-) CO_2
Shahbaz et al. (2017b)	• 105 countries	TO, GDP, CO_2	FMOLS, VECM Granger causality analysis		• TO (+) CO_2 • TO ↔ CO_2 for global level and middle-income countries • TO → CO_2 for high- and low-income countries
Frutos-Bencze et al. (2017)	• CAFTA-DR member countries	TO, FDI, CO_2	GMM	∩	• TO (-) CO_2
Hasanov et al. (2018)	• Nine oil-exporting countries • 1995–2013	Import, export, GDP, CO_2	FMOLS, DOLS, PMG		• 1% ↗ import, 0.3-0.4% ↗ CO_2 • 1% ↗ export, 0.6-0.8% ↗ CO2
Mutascu (2018)	• France	TO, CO_2,	Time frequency approach		• No co-movement between TO and CO_2 at high frequency • CO_2 (+) TO at medium frequency; TO (+) CO_2 at low frequency
Zhang and Zhang (2018)	• China • 1982–2016	ST, ER, FDI, GDP, CO_2	ARDL bound test, VAR Granger causality test	∩	• ST (-) CO_2 • ST ↔ CO_2

Note: ***1) Variables:*** EC=energy consumption, TO= trade openness, MAN= manufacture value added, FF= fossil fuels consumption, NU= nuclear energy consumption, RE= renewable energy consumption, POP = population, FD= financial development, HCD=human capital development, INDU= industrialization, UR= urbanization, EI=energy intensity, INTER= internet use (or internet penetration), EP= energy productivity, NRE= non-renewable energy consumption, EE= energy efficiency, SMC= stock market capitalization, REC= renewable electricity consumption, NAR=natural resource, EIN=energy innovation, CEC= clean energy consumption, ARI=agricultural value added, OP=oil price, ER=exchange rate, ST=services trade; ***2) Methods:*** ARDL=autoregressive distributed lag, VECM=vector error correction model, CCR=canonical cointegration regression, FE= fixed-effect analysis, PMG=pooled mean group, POLS= pooled ordinary least squares, MG= group estimator, AMG= augmented mean group estimator, GM-FMOLS=group-mean fully modified ordinary least squares, GMM= generalized method of moments, SDA= three-tier structural decomposition analysis, PLS=partial least squares, CCEMG=common correlated effects mean group, VAR=vector autoregression ***3)*** MENA countries denote Middle East and North African countries, CAFTA-DR denote Central American Free Trade Agreement-Dominican Republic ***4) Symbols:*** ↔ denotes bidirectional causality, → denotes unidirectional causality, ↗ denotes increase of variables, ↘ denotes decline of variables, (+) denotes positive impact, (-) denotes negative impact, SR denotes short-run term, LR denotes long-run term.

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A Stochastic Frontier Analysis of Trade Efficiency for the Sino-Korea Trade*

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Abstract

Purpose – This paper intends to make theoretical analysis and empirical test on the factors influencing China's export to South Korea, and draw conclusions about China's export efficiency and trade potential. Based on the conclusions, the reasons for China's trade deficit with South Korea are found, and a solution is put forward for solving the problem of China's trade deficit with South Korea.

Design/methodology – Based on the data of 2004-2017 years in China, this paper uses the stochastic frontier gravity model to analyze the influencing factors of China's export to South Korea, as well as the export efficiency of each province and the export potential that can be explored.

Findings – First, in terms of the factors affecting China's export trade to South Korea, the GDP of the provinces and cities in China, the FDI of South Korea to the provinces and cities in China, the GDP of South Korea, the population and education level of provinces and cities in China can significantly promote the export scale of Chinese provinces and cities to South Korea. The distance between Chinese provincial capitals and the South Korean capital significantly hinders Chinese exports to South Korea; Second, in terms of export trade efficiency, the trade exchange rate of the economically developed cities along the eastern coast of China and several provinces that are close to South Korea is higher than that of the cities in the central and western regions; Third, economic globalization makes trade more convenient, the average export trade efficiency of China's exports to South Korea showed an upward trend. However, under the influence of the 2008 global financial crisis, the export trade efficiency declined from 2008 to 2009, indicating that the impact of the financial crisis on the trade efficiency cannot be ignored.

Originality/value – This paper finds out the influencing factors of China's export to South Korea, analyzes the export efficiency of different provinces and cities, excavates the export potential, and puts forward some suggestions for the balanced development of China and South Korea trade in the next step.

Keywords: Sino-Korea Trade, Stochastic Frontier Analysis (SFA), Trade Efficiency, Trade Potentials
JEL Classifications: F18, F40

1. Introduction

China and Korea are geographically close to each other and share a similar history and culture. Since the establishment of diplomatic ties in August 1992, the economic and trade exchanges between the two countries have achieved rapid development, According to the

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statistics of the Ministry of Commerce of China in 2020, China is the largest trading partner, the largest export market, and the largest source of imports of South Korea, while South Korea is the third largest trading partner of China. The bilateral trade volume of the two countries has increased from US $5 billion at the time of establishing diplomatic relations to US $284.53 billion in 2019, an increase of more than 50 times. In 2019, China's exports to South Korea reached US $110.96 billion, and imports from South Korea reached US $173.57 billion. The trade deficit between China and South Korea reached US $62.61 billion. With the rapid expansion of bilateral trade scale, the trade imbalance between China and South Korea has become increasingly serious, and South Korea has become the largest source of trade deficit of China. The signing and implementation of the China-South Korea Free Trade Agreement will inject strong vitality into bilateral economic and trade activities, and the trade scale will further expand. At the same time, trade frictions between the two countries will further increase and the competition between the two sides will be more intense. With the increasing trade friction between China and the United States, China is bound to increase cooperation with Japan and South Korea, especially the latter, which is closer to China in distance and has similar cultures. Therefore, the bilateral trade situation and development potential between China and South Korea have become one of the hot issues for scholars at home and abroad.

Trade potential measures how much a country gains by moving from a market with trade resistance to one without. So the measure of trade potential can be the scale of trade as well as the revenue. Among them, the analysis based on trade scale is the main method used by scholars. Zhang Hong et al. (2009) investigated the current situation of intra-regional trade among China, Japan and South Korea, studied the factors influencing trade flow by using gravity model, and examined the trade potential of the three countries.

Zhang and Zhu (2014) used the expanded gravity model to study the development of trade flow and trade potential between China, Japan and South Korea. The research shows that China's export trade potential to both South Korea and Japan is “of huge potential”, Japan's export trade potential to China is “of reshaping potential”, and the trade potential between Japan and South Korea and South Korea's export trade potential to China and Japan is “of pioneering potential.” Kuang (2015) used the gravity model to analyze the trade potential of China, Japan and South Korea. The research shows that the income level and distance factors have a significant impact on the export trade volume, and there is a huge trade potential among the three countries. Jin and Yang (2015) made an empirical analysis on the current situation and trade potential of China-South Korea trade by using the bilateral trade data between China and South Korea from 2003 to 2013. The results show that the degree of trade integration and trade complementarity between China and South Korea are decreasing, and the potential of bilateral trade is increasing, with huge development space. Waugh and Ravikuma (2016) and Gozgor (2017) calculated the Trade Potential Index (TPI) from the perspective of income to measure the benefits of a country's transfer from a world with trade costs to a frictionless world, so as to evaluate its trade potential.

Gravity Model is the most commonly used research method in the literature of measuring trade potential by using trade scale (Tinbergen, 1962; Rauch, 1999; Sheng and Liao, 2004). The traditional gravity model and stochastic frontier gravity model are mainly used by scholars. Anderson and Wincoop (2003) and Armstrong (2007) show that the traditional gravity model is based on the assumption of frictionless trade and iceberg transport cost, and ignores the influence of multilateral resistance factors on trade when estimating trade potential, which may lead to deviations. Secondly, Kang and Fratianni (2006) found that

when using ordinary least squares (OLS) to estimate the traditional gravity model, the R2 value is generally small, because most of the trade is determined by some other factors besides economic size and distance. Furthermore, Ravishankar and Stack (2014) proposed that trade potential should be the maximum possible trade value under the minimum trade friction or the maximum degree of trade liberalization that may be achieved in the current environment, rather than the average value in the traditional gravity model. Therefore, Kalirajan (1999, 2007) and Armstrong (2007) introduced stochastic frontier method (SFA) into gravity model to analyze trade efficiency and potential. Compared with the traditional gravity model, stochastic frontier gravity model can analyze the impact of artificial trade inefficiency. However, in the early stochastic frontier gravity model, it is generally assumed that the trade inefficiency term is time invariant (TIM). Since then, Battese and Coelli (1992) proposed a time-varying model (TVDM) which is more consistent with the reality of trade. The main methods used to study trade inefficiency are two-step method and one-step method. Kumbhakar and Ghosh et al. (1991), R eifschneider and Stevenson (1991) proposed that the two-step method is logically inconsistent, and the one-step method proposed by Battese and Coelli (1992) is more rigorous.

In addition, the existing studies on the factors affecting the efficiency and potential of China's export trade to South Korea mostly focus on the foreign factors restricting China's commodity export. For example, the studies of Wang Lili and Yao Zhiyi all point out that the infrastructure conditions of export market, the level of investment facilitation, government efficiency, and technical barriers to trade can significantly affect China's export trade efficiency. Although a few scholars have analyzed the impact of domestic factors on the trade potential of China's provinces and cities, such as Wu(2003) and Zhang (2016) , no paper has paid attention to the trade potential of China's regions to South Korea from the perspective of domestic factors. Lu Xiaodong (2011) and others believe that export trade is a cross-border market behavior, which will be restricted by both domestic and foreign factors. Although the Chinese government has adopted a variety of policies to strengthen ties and cooperation with other countries, such as the construction of the Belt and Road, and although it provides a strong external demand support for the further release of China's trade potential with various countries, this external demand is often accompanied by a strong uncontrollability. In this context, how to further enhance the effective domestic supply level is more practical.

To sum up, the existing research on trade potential is relatively fruitful, which provides a strong foundation and support for this paper. This paper takes the export trade efficiency and trade potential of China's provinces and cities to South Korea as the research object, analyzes the impact of China's domestic factors on South Korea's export trade by constructing a stochastic frontier model, calculates its export efficiency and export potential, investigates its power sources, and puts forward some suggestions. Compared with previous studies, this paper has the following differences: in terms of research perspective, it is the first time to explore the export trade efficiency, export trade potential and its influencing factors from the perspective of provinces and cities in China; in terms of research content, the imbalance of economic development among provinces and cities in China is obvious. Ignoring the regional differences will not only produce certain evaluation deviations, but also fail to provide targeted suggestions for provinces and cities to improve trade efficiency and explore trade potential. Therefore, this paper attempts to analyze the impact of domestic factors on South Korea's export trade based on the stochastic frontier model.

Through the above analysis, Chinese provinces and cities should objectively evaluate their

own trade efficiency and trade potential, explore the endogenous driving force for their growth, improve innovation ability and supply level, tap the potential of export trade, improve the quality and efficiency of export, and realize high-quality development of export trade to South Korea. Such measures will help improve the situation of China's trade deficit with South Korea, and provide a solid theoretical basis for the government.

2. Methodology

Due to the unbalanced development of China's provinces and cities, there are great differences in their export trade status. Therefore, this paper chooses the stochastic frontier model to study the export trade status of China's provinces and cities to South Korea. With the help of the stochastic frontier gravity model proposed by Aigner et al. (1977), this paper constructs a model to study the export trade potential and trade efficiency of China's provinces and cities with South Korea.

$$export_{it}^{*} = f(x_{it}, \beta) \tag{1}$$

wherex_{it}refers to the endowment scale of various factors owned by i region, such as land, labor, capital, etc.; β is parameter vector to be estimated; $export_{it}^{*}$ is the largest export scale of region i in the t period. However, in the actual trade, affected by various inefficiency variables, the export trade level is difficult to reach the maximum possible export trade level $export_{it}^{*}$. Therefore, the actual export trade level can be expressed as:

$$export_{it} = f(x_{it}, \beta)\exp(-\mu_{it}) , \ -\mu_{it} \geqq 0 \tag{2}$$

here, $TE_{it} = \exp(-\mu_{it})$ is the specific export efficiency parameter of sample i. μ_{it} is the export inefficiency effect, which determines the export efficiency parameters. When $\mu_{it} = 0$, the export of i achieves the maximum efficiency; When $\mu_{it} > 0$, that is, $export_{it} \leq export_{it}^{*}$, there is trade low efficiency (inefficiency),Considering the random measurement error or random impact, the observed real trade level is determined by:

$$export_{it} = f(x_{it}, \beta)\exp(v_{it} - \mu_{it}) \tag{3}$$

By taking logarithm on both sides of formula (3), we can get that:

$$\ln export_{it} = f(x_{it}, \beta) + v_{it} - \mu_{it} \tag{4}$$

The expression is the basic form of stochastic frontier exit equation. Among them, v_{it} is the random measurement error or random factor, μ_{it} is the trade inefficiency term. Meanwhile, $v_{it} : N(0, \sigma_v^2)$, $\mu_{it} \geq 0$, . It is generally considered thatv_{it} and μ_{it} are independent of each other, which can be expressed as $Cov(v_{it} , \mu_{it}) = 0$. In general, it is assumed that the inefficiency term μ_{it} has the following distributions: Semi normal distribution, truncated semi normal distribution, logarithmic distribution and gamma distribution. This paper assumes that μ_{it} obeys a more flexible truncated semi normal distribution, that is, μ_{it}: N(ϖ,

σ_{it}^2):

$$\omega_{it}= \exp(b_0+ z_{it}^k\delta);\ \sigma_{it}^2 = \exp(b_1+ z_{it}^k\gamma) \quad (5)$$

Formulas (4) - (5) show the stochastic frontier model used in this paper. On this basis, we can not only analyze the impact of constraint variables z_{it}^k on the size of trade inefficiency (ω_{it}) and its volatility (σ_{it}^2), but also calculate the export trade efficiency of provinces and cities to South Korea in each period. Trade efficiency refers to the degree that the actual trade volume deviates from the maximum possible export trade level.

$$\text{Export trade efficiency: } TE_{it}=\frac{\exp(x_{it}\beta-\mu_{it})}{\exp(x_{it,}\beta)} = \exp(-\mu_{it}) \quad (6)$$

$$\text{Export trade potential : potential}_{it} = 1\text{-}\exp(-\mu_{it}) \quad (7)$$

Export trade efficiency TE_{it} is between 0-1 . When trade inefficiency exists ($\mu_{it}> 0$), the greater the TE_{it} value is, the higher the trade efficiency is, and the smaller the trade potential is. The smaller the TE_{it} value is, the lower the trade efficiency is and the greater the trade potential is. If there is no trade inefficiency ($TE_{it}= 0$), export trade efficiency is the highest $TE_{it}= 1$.

In the early stochastic frontier model, it is assumed that the trade inefficiency does not change with time, but when the time dimension of the data in the model is long enough, the original assumption of "constant technical efficiency" is no longer reasonable. Therefore, Battese and Coelli (1992) proposed the basic form of stochastic frontier time-varying model. In the time-varying model, the trade inefficiency term is expressed as:

$$\mu_{it} = \eta_t\mu_i=\{\exp[-\eta(t-T)]\}\ \mu_i$$

where μ_i,is assumed to be a non-negative truncation of : $N(\omega, \sigma_{it}^2)$:distribution, and the scalar parameter η, (which will be estimated) can be used to determine whether efficiency increases, decreases, or remains constant. The last period(t=T) for export from china's province i to korea contains the base level of efficiency, so $\mu_{it}= \mu_i$, Hence, the parameters u and σ_u^2 denote the statistical properties of the country effects related to the last period. If $\eta > 0$, the level of efficiency increases towards the base level, or the impact of country-specific man-made policy constraint on exports decreases over time; If $\eta = 0$ or is insignificant, the level of efficiency remains constant or the impact of country-specific man-made policy constraint on exports remains unchanged over time. The estimation also includes parameterization with$\sigma^2=\sigma_u^2+\sigma_\xi^2$ and $\gamma=\sigma_u^2/(\sigma_u^2+\sigma_\xi^2)$where γ must take a value between 0 and 1. We can test whether or not we should include the error term u in the form of the stochastic frontier function by testing the significance of parameter γ. If the null hypothesis, i.e. γ equals zero, is rejected, this would mean that σ_u^2 is non-zero and therefore the term u should be added into the model, leading to a specification with the parameter that should be consistently estimated using the stochastic frontier approach.

3. Model Setting and Data Description

3.1. Model Setting

According to the above analysis and the needs of this study, this paper sets the export trade model of China's provinces and cities to South Korea as follows:

$$\ln EXPORT_{it} = a_0 + a_1 \ln FDI_{it} + a_2 \ln CGDP_{it} + a_3 \ln KGDP_{it} + a_4 \ln POP_{it} + a_5 \ln DIS_{it} + a_6 \ln EDU_{it} + v_{it} - \mu_{it} \quad (8)$$

3.2. Data Source and Description

This paper selects the panel data of 30 provinces and cities in China except Hong Kong, Macao and Tibet from 2004 to 2017. The description and data sources of each variable are shown in Table 1.

Table 1. Variables and Data Sources

Abbreviation	Variable	Data source
EXPORT	Annual exports of China's provinces and cities to South Korea (Million US$)	Korea Trade Association www.kita.net
FDI	South Korea's annual direct investment in China's provinces and cities (Million US$)	The Export- Import Bank of Korea https://www.koreaexim.go.kr
CGDP	Annual GDP of provinces and cities in China (Million US$)	China Statistical Yearbook, the statistical yearbooks
KGDP	South Korea's annual GDP (Million US$)	Korean Statistical Information Service
DIS	The linear distance from Seoul, South Korea to every provincial capital city in China (km)	Goole Earth
POP	Populations of provinces and cities in China (10 million)	China Statistical Yearbook, the statistical yearbooks
EDU	Average education time of people in different provinces and cities in China (Years)	China Statistical Yearbook, the statistical yearbooks

Table 2. Summary Statistics

Variable	Mean	Std. Dev	Min	Max
LNEXPORT	6.5248	1.6919	2.4849	10.1512
LNFDI	2.6186	2.4363	-0.4933	7.6145
LNCGDP	11.1355	0.9845	8.0011	12.8751
LNKGDP	11.8873	0.1437	13.5844	14.0833
LNDIS	7.2683	0.4387	6.3323	8.1219
LNPOP	3.5654	0.7487	1.6845	4.7157
LNEDU	2.1603	0.1171	1.8528	2.5822

3.3. Analysis of the Results of Influencing Factors

In the time-varying stochastic frontier gravity model, η value is 0.0149, greater than 0, and it passes the t-test at the significance level of 1%, which indicates that the technical efficiency is affected by time change, and the time-varying stochastic frontier gravity model is more applicable than the time-invariant stochastic frontier gravity model. μ is significantly greater than 0, which confirms the existence of inefficiency factors in Chinese provinces and cities' export trade to South Korea. And the value of γ is close to 1, indicating that the variation of the error component factor of the model is mainly caused by the inefficiency factor. The trade inefficiency factor results in the gap between the actual and the potential level of trade, which indicates the applicability of the stochastic frontier gravity model. The hypothesis of LR test based on likelihood ratio is that the least square model is more suitable than the stochastic frontier model, but the result of LR is significant at 1% level. It is considered that rejecting the original hypothesis, that is, the stochastic frontier model is more suitable than the least square model. (Marie M Stack, Eric J Pentecost and Geetha Ravishankar, 2018)

In the time-varying stochastic frontier gravity model, the coefficient of FDI of South Korea to foreigners in China is 0.237 and is significant at 1%, which also proves that FDI is complementary to international trade (K. Kojima, 1987). The GDP coefficient of each province in China is 0.285 and is significant at the level of 1%, which indicates that the growth of GDP of each province has a positive effect on promoting China's export to South Korea. The coefficient of GDP of South Korea is 1.033 and is significant at the level of 1%, which indicates that the greater the market size of China's export to South Korea, the greater the impact on China's export to South Korea. The coefficient of DIS between capitals is -0.928 and is significant at 1%, which indicates that distance variables have negative effects on export trade. The greater the distance between capitals, the higher the cost of export trade transportation, so distance is an obstacle to export trade. The coefficient of population (POP) in China is 0.597, and it is significant at 1%. The increase of population increases the labor force, and thus increases output, and thus the number of exports. The coefficient of education (EDU) is 2.249, and it is significant at 1% level, which shows that China's education level has played a great role in promoting the export to Korea. In the past, China mainly exported basic products and energy. With the improvement of Chinese education level, the proportion of high-tech products in export trade has been increasing, which will play an important role in solving the trade deficit between China and South Korea.

Table 3. Estimates of the Stochastic Gravity Model

Independent Variables	Frontier Estimate	OLS Estimate
LNFDI	0.237***	0.053***
	(9.78)	(0.183)
LNCGDP	0.285***	0.005***
	(4.32)	(0.087)
LNKGDP	1.033***	1.403***
	(3.10)	(0.244)
LNDIS	-0.928***	-1.776***
	(-7.16)	(0.306)
LNPOP	0.597***	0.911***
	(7.71)	(0.177)

Table 3. (Continued)

Independent Variables	Frontier Estimate	OLS Estimate
LNEDU	2.249*** (4.49)	2.046*** (0.548)
Constant	-11.866*** (-2.85)	-7.927*** (3.294)
σ2	0.531*** (1.75)	
γ	1.038*** (5.63)	
μ	3.968*** (7.06)	
η	0.0149*** (3.78)	
LR	50.9***	
R2		0.731
Observations	420	420

N**ote**: The t value in brackets, *, ** and *** indicate that the statistical value is significant at 10%, 5% and 1%, respectively.

3.4. Estimated Trade Efficiency

After estimating the main factors affecting China's export to South Korea, combined with equation (5), we can further calculate the export trade efficiency of China's provinces and cities to South Korea. According to equation (6), the lower the trade efficiency, the higher the trade potential. In this paper, a total of 420 estimations about export trade efficiency have been measured and calculated, of which the mean value is 0.468, the standard deviation is 0.255, the maximum value is 0.702, and the minimum value is 0.019. The interval span is large, indicating that the export trade efficiency and potential of different provinces and cities in China vary greatly in different years. See Table 4 for details of the estimated value of export trade efficiency.

From Table 4, we can see that the average export trade efficiency of China's exports to South Korea is on the rise from 2004 to 2017. However, affected by the 2008 global financial crisis, the export trade efficiency is on the decline from 2008 to 2009. With the adjustment of national policies and the recovery of economy, it has resumed the upward trend from 2010. Although the efficiency of China's export trade to South Korea is on the rise, we can see from the data that the average efficiency of China's export trade to South Korea is only 0.557 in one year, so there is still great potential for China's export trade to South Korea.

From Fig. 1, we can see that the trade efficiencies of the eastern provinces is higher than that of the central and western regions. On the contrary, the export trade potential of the central and western regions to South Korea is greater than that of the eastern coastal provinces. Therefore, in order to reverse the huge trade deficit with South Korea, China should vigorously tap the trade potential of the central and western provinces on the basis of maintaining the trade efficiency of the eastern coastal cities.

Table 4. Estimated Efficiency

	2004	2006	2008	2010	2011	2012	2013	2014	2015	2016	2017
ShanghaiCY	0.58	0.616	0.591	0.603	0.564	0.604	0.62	0.618	0.638	0.615	0.632
GuangdongPE	0.545	0.604	0.534	0.548	0.523	0.595	0.543	0.537	0.62	0.611	0.651
Tianjin CY	0.523	0.623	0.595	0.623	0.606	0.617	0.632	0.63	0.65	0.639	0.639
Jiangsu PE	0.52	0.53	0.443	0.494	0.332	0.443	0.392	0.24	0.444	0.435	0.442
Zhejiang PE	0.519	0.59	0.596	0.608	0.617	0.632	0.633	0.617	0.642	0.647	0.637
Beijing CY	0.518	0.659	0.645	0.653	0.67	0.69	0.692	0.693	0.702	0.7	0.699
Shandong PE	0.497	0.572	0.568	0.599	0.599	0.631	0.635	0.566	0.6	0.607	0.581
Henan PE	0.496	0.558	0.575	0.593	0.578	0.599	0.598	0.598	0.626	0.614	0.625
Jiangxi PE	0.495	0.526	0.548	0.56	0.432	0.536	0.557	0.544	0.591	0.577	0.599
Anhui PE	0.495	0.533	0.537	0.612	0.569	0.574	0.587	0.593	0.638	0.642	0.637
Shaanxi PE	0.492	0.56	0.576	0.554	0.536	0.567	0.572	0.585	0.627	0.621	0.606
Jilin PE	0.49	0.579	0.597	0.605	0.612	0.617	0.621	0.617	0.635	0.633	0.635
Hubei PE	0.438	0.47	0.498	0.538	0.501	0.513	0.564	0.496	0.571	0.582	0.602
Liaoning PE	0.43	0.512	0.53	0.534	0.545	0.572	0.578	0.538	0.6	0.561	0.602
Guizhou PE	0.418	0.588	0.555	0.582	0.525	0.564	0.551	0.554	0.566	0.554	0.537
Hebei PE	0.415	0.442	0.437	0.505	0.458	0.541	0.48	0.5	0.558	0.576	0.574
ChongqingCY	0.349	0.446	0.456	0.527	0.515	0.427	0.562	0.519	0.557	0.548	0.578
Hainan PE	0.347	0.374	0.512	0.501	0.394	0.389	0.526	0.427	0.555	0.552	0.556
Fujian PE	0.324	0.388	0.434	0.495	0.503	0.477	0.58	0.462	0.519	0.502	0.541
Gansu PE	0.305	0.347	0.381	0.405	0.363	0.412	0.452	0.479	0.558	0.548	0.58
Guangxi AR	0.295	0.369	0.278	0.284	0.355	0.467	0.382	0.354	0.484	0.474	0.459
Hunan PE	0.291	0.467	0.293	0.364	0.326	0.195	0.524	0.467	0.552	0.55	0.567
Yunnan PE	0.278	0.597	0.142	0.153	0.278	0.108	0.582	0.452	0.44	0.515	0.592
Inner Mongolia AR	0.27	0.25	0.087	0.187	0.131	0.333	0.358	0.366	0.491	0.485	0.49
Qinghai PE	0.257	0.465	0.41	0.413	0.387	0.333	0.333	0.232	0.403	0.448	0.385
Xinjiang AR	0.245	0.396	0.379	0.438	0.382	0.388	0.385	0.399	0.475	0.483	0.463
Heilongjiang PE	0.237	0.149	0.188	0.061	0.038	0.185	0.237	0.07	0.371	0.195	0.266
Ningxia AR	0.229	0.098	0.104	0.053	0.044	0.05	0.234	0.262	0.412	0.443	0.462
Sichuan PE	0.191	0.474	0.186	0.527	0.434	0.095	0.35	0.43	0.518	0.546	0.559
Shanxi PE	0.171	0.267	0.132	0.348	0.346	0.367	0.354	0.273	0.536	0.516	0.514
mean efficiency	0.389	0.468	0.427	0.466	0.439	0.451	0.504	0.471	0.553	0.547	0.557

Fig. 1. The efficiency of China's export trade to South Kore

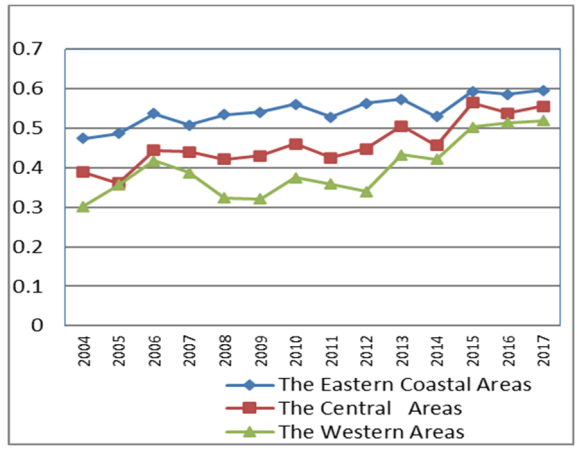
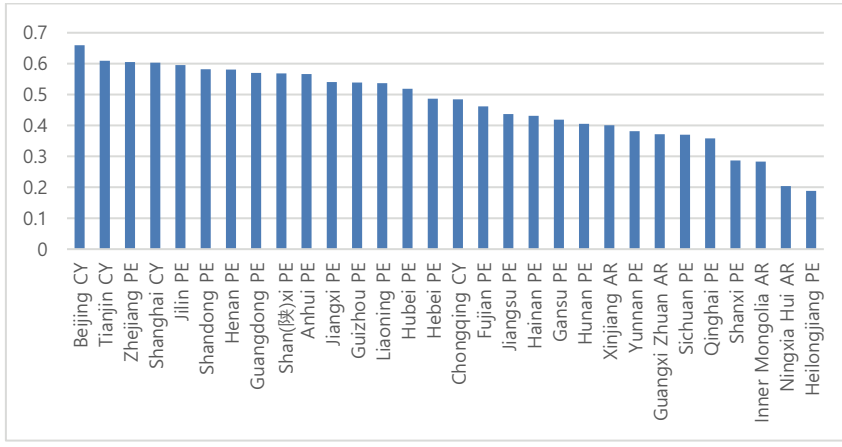


Fig. 2. Export trade efficiencies of Chinese provinces and cities to South Korea



According to Table 4 and Fig. 2, the provinces and cities with the highest export trade efficiencies are Shanghai, Guangdong, Tianjin, Jiangsu, Zhejiang, Shandong and other eastern coastal provinces and cities. The reason may be that these provinces and cities are relatively well developed in China's economy and foreign trade, and all have convenient port facilities. Shandong, Tianjin and other cities are geographically close to South Korea. At the same time, Shanghai has the first Pilot Free Trade Zone established in China, with a high degree of trade liberalization, which can effectively promote the development of its export trade.

4. Conclusions and Suggestions

To sum up, this study uses the panel data of China's export trade volume to South Korea and the factors affecting China's export trade volume to South Korea during the 14 years from 2004 to 2017 to construct a stochastic frontier gravity model to estimate the factors influencing China's export trade to South Korea, and thereby obtain the efficiency and trade potential of China's export trade to South Korea. The main conclusions are as follows:

First, in terms of the factors affecting China's export trade to South Korea, the GDP of China's provinces and cities, the FDI of South Korea to China's provinces and cities, the GDP of South Korea, the population and education level of China's provinces and cities can significantly promote the export scale of China's provinces and cities to South Korea. However, the distances between the capitals of China's provinces and cities and the capital of South Korea has significantly hindered China's export trade to South Korea.

Second, in terms of export trade efficiency, the trade efficiency of China's eastern coastal economically developed cities and several provinces close to South Korea is relatively high compared with those of the central and western cities, but the highest level is only 0.7, most of which remain at about 0.5. In particular, the trade efficiency level of the central and western cities is maintained at about 0.3. This shows that China's export trade to South Korea has great potential.

Third, with economic globalization and convenience of trade, the average export trade efficiency of China's exports to South Korea is on the rise. However, affected by the 2008 global financial crisis, the export trade efficiency declined from 2008 to 2009, which shows that the impact of the financial crisis on trade efficiency cannot be ignored.

Based on the above results, we propose the following suggestions:

First, improve trade facilitation.

Although the geographical distances between countries will not change, improving the convenience of trade will promote the development of bilateral trade. At present, we can consider establishing an open trading platform between the neighboring cities of the two countries to realize the sharing of information resources and shorten the time of customs clearance. We should also strengthen the cooperation between the two countries' customs, and promote the coordination, transparency and non-discrimination of tariff policies, coordinate the customs clearance system, and promote the development of E-customs.

Second, vigorously support the development of China's technology intensive industries.

The proportion of China's capital intensive or technology intensive products exported to South Korea is becoming close to that of China's imports from South Korea year by year. However, China's exports of such products are at the low end, and are mainly processing trade. Therefore, China should strengthen further cooperation with South Korea on technology intensive or capital intensive products, and promote China's related industries and enterprises to enhance their independent R&D and innovation capabilities through the introduction of technology. At the same time, the government should increase its support for technology intensive industries, formulate relevant industrial development plans and export support strategies. Enterprises should take the initiative to learn from the technology and experience of the high-tech enterprises of South Korea, narrow the gap with Korean enterprises in technology intensive industries, and enhance the international competitiveness of China's technology intensive products.

Third, enhance political mutual trust.

Due to historical and political factors, trade between China and South Korea is often affected by policy fluctuations. Therefore, we should enhance political mutual trust, strengthen dialogue at the government level, reduce the impact of political factors on China-ROK economy and trade, and take the establishment of China-ROK Free Trade Zone as an opportunity to improve the level of economic and trade cooperation between China and South Korea.

Fourth, most of China's exports to South Korea are inefficient and have great export potential.

In terms of tapping export potential, the less developed areas in the central and western regions and the developed coastal provinces in the east of Jiangsu, Zhejiang and Shanghai have different emphases. The developed coastal provinces should give full play to their own advantages while consolidating their own export capacity, and focus on the development of characteristic industries. Inland provinces need to rely on industrial policies, talent introduction policies, and to obtain scale effect by introducing foreign capital to establish advantageous industries, and then improve market efficiency and export efficiency.

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FTAs for Global Free Trade: Through Trade Liberalization Game

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Abstract

Purpose – This paper explains how free trade agreements (FTAs) work as a building block to achieve global free trade and be better than other trade regimes.

Design/methodology – This paper utilizes a trade liberalization game setup. Three countries choose a trade agreement strategy based on a given trade regime. Trade agreement is made only when all member countries agree. The paper evaluates each trade regime concerning FTAs and customs union (CU) by area size of global free trade equilibrium on the technology or demand gap between countries.

Findings – FTAs make global free trade easier. In this game, there are two main reasons for failure to reach global free trade. First, a trade regime with FTAs makes non-member face difficulties in refusing trade agreements in the existence of a technology gap than a trade regime without FTAs. Also, a trade regime with FTAs causes it harder to exclude non-members in the existence of a demand gap than a trade regime with only CUs. Therefore, a trade regime with FTAs can work better in reaching global free trade.

Originality/value – The concept of "implicit coordination" was used, which assumes that FTA members keep external tariffs for non-members the same as before an FTA. Without this consideration, FTA members lower their tariffs to non-members, and it makes non-member refuse free trade easier. FTA can prevent it sufficiently only with implicit coordination. This makes the trade regime with FTAs more effective to reach global free trade.

Keywords: Customs Union, Free Trade Agreement, Trade Liberalization Game
JEL Classifications: F12, F13, F15

1. Introduction

An issue of concern to countries undergoing economic integration is whether preferential trade agreements (PTAs), such as FTAs or CUs, will help world trade organization (WTO) countries reach global free trade. Bhagwati (1993) raised a famous question; will these arrangements be "building blocks" or "stumbling blocks" for global free trade? Some argue that PTAs work as building blocks by making overall tariffs lower, and then more trade agreements will make tariffs approach zero. However, when "imperfect" global trade based on PTAs improve the welfare of member countries or non-member countries, and that gain is higher than what can be achieved under global free trade, those countries will reject free trade. This is how PTAs become stumbling blocks.

This paper addresses how free trade agreements (FTAs) work well to achieve global tariff-free trade and support the building block hypothesis. To answer this question, a trade liberalization game setup is utilized with a three-country oligopoly goods market. Each country determines its trade agreement strategy to maximize its total surplus. The strategy and equilibrium results depend upon whether PTAs are possible or banned. FTA and CU

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members have zero internal tariffs between members. CU members must have the same external tariffs for goods from a non-member country, but FTA members can decide external tariffs independently.

How external tariffs for non-member country are determined is essential. When external tariffs are low, a non-member country can export more goods to member countries without opening their domestic market. If the gains from exports are high enough, a non-member refuses to be a member of trade agreements, and global free trade becomes unachievable. This refusal is called "free-riding" because this non-member country can gain from more exports without increased competition with imports on the domestic market.[1]

In contrast, when an external tariff is high enough, sometimes member countries can gain more by trading among themselves and not accepting another country as a new member than from accepting other countries and reaching global free trade. An "exclusive trade bloc" is established when PTA members do not accept non-members and reject free trade. Free-riding and exclusive trade blocs are the two main routes outside global free trade.

This paper compares the equilibrium results of different trade regimes[2] when each of two kinds of asymmetry (technology and demand) between countries exists, and as a result, each member country has different optimal external tariffs. First, permitting FTAs reduce the free riding of non-member countries effectively in the case of a technology gap. When FTAs and CUs are banned, countries can make a trade agreement and agree to a tariff decrease, but it must be applied to all countries under the most favored nation (MFN) rule. Under this trade regime, the free riding of non-members becomes prevalent. However, permitting FTAs are better to reduce free riding than prohibiting FTAs.

Second, permitting FTAs reduce the exclusive trade bloc possibility of member countries in the case of a demand gap. When FTAs are banned and only CUs are permitted, two countries make a CU, exclude non-members, and complete an exclusive bloc, failing to reach global free trade. This is because to add additional members to a trade agreement, both members must agree in a CU. In contrast, one FTA member can make another FTA with a non-member country, regardless of the opinion of other FTA members. Therefore, an FTA is less likely to be an exclusive bloc, and a trade regime with an FTA makes global free trade easier to reach.

Also, this paper considers an "implicit coordination" assumption for FTAs, which assumes that FTA members keep external tariffs for non-members the same as before an FTA. This assumption is deeply related to the tariff complementarity effect.[3] The model of this paper assumes tariff complementarity; the optimal external tariffs of FTA members are lower than external tariffs before reaching an FTA. However, member countries can keep an external tariff even with tariff complementarity, not lowering external tariffs for implicit coordination. If implicit coordination is considered, a trade regime permitting FTAs becomes more effective in reducing free riding. Implicit coordination cannot be considered in CUs because CU members must have identical external tariffs.[4]

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[1] The expression of free-riding is popular for papers on the most favored nation (MFN) rule, such as Ludema and Mayda (2009). Also, Maggi (2014) used the term to explain how non-members of trade agreement refuse to be a member.

[2] Trade regime includes all kinds of trade agreements and trade rules on those agreements. This paper analyzes the MFN regime, trade regimes with FTAs, and trade regimes with CU. Other trade regimes are not covered in this paper.

[3] For more details on tariff complementarity, check Bagwell and Staiger (1999) and Bond et al. (2004).

[4] CU members set external tariffs together. Therefore, it can be considered "explicit coordination"

How trade agreements work on the path to global free trade is an essential question for international trade economics, as mentioned by Maggi (2014). Trade creation and the trade diversion effect are important to explain the effects of PTAs, as mentioned in Baldwin and Venables (1995). Grossman and Helpman (1995) found that trade-diverting FTAs are more prevalent due to enhanced protection incentive. In contrast, Krugman (1991) insisted that FTAs formed among natural trade partners were more likely to increase welfare through trade creation. Also, McLaren (2002) focused on the rule of irreversible investments for the achievement of trade agreements. Goyal and Joshi (2006) and Furusawa and Konishi (2007) utilized a network-formation approach.

This paper uses a simple three-country oligopoly model and combines it with a trade liberalization game, which is similar Ornelas (2007) and Saggi and Yildiz (2010). This model is simple but useful in analyzing how countries make or refuse trade agreements and equilibrium changes in various environments. Saggi and Yildiz (2010) support the building block hypothesis of FTA regimes to reduce free riding with asymmetry in endowments for each country. Saggi et al. (2013) supported the stumbling block hypothesis of CUs using similar framework.

However, these papers do not consider implicit coordination. The basic setup of this paper is same as Nahm (2019). However, the main goal of Nahm (2019) was different. Nahm (2019) showed the popularity of FTAs through the concept of implicit coordination. In contrast, the main goal of this paper is a comparison of trade regime by comparing the equilibrium results of each trade liberalization game, which were not considered in Nahm (2019). Also, this paper shows how equilibrium results change with technology and demand asymmetry. The main route for the results of this model is setting external tariffs. High external tariffs decrease the likelihood of free riding, and low external tariffs decrease the likelihood of an exclusive trade bloc. Saggi and Yildiz (2010) used endowments asymmetry, but in this paper, optimal external tariffs are a function of the technology and demand parameters. These asymmetries make optimal external tariffs different between countries.

In this study, it is assumed that international transfers are impossible.[5] Then, each FTA or CU can make non-members lose welfare, which is harmful in the short-run, but this loss of welfare is helpful for the world to reach global, tariff-free trade in the long-run. It can prevent free-riding and cause non-members try to jointly reduce tariff levels by establishing another trade agreement. In this sense, this paper supports the "domino theory" or "contagion" of trade agreements. Riezman (1999) approached this problem similarly. Trade agreements can create trade diversion or a loss to non-member countries, and it makes global free trade more accessible. This was also empirically shown in Baldwin and Jaimovich (2012)[6].

Debates on tariff complementarity are not related to the main goal of this paper, but are heavily related to implicit coordination assumption. This assumption fits with the conflicting empirical work of Limão (2006) and Estevadeordal et al. (2008) on tariff complementarity for external tariffs after a trade agreement is made.[7] In addition, implicit coordination is optimal

compared to FTAs.

[5] Therefore, failure to reach global free trade may not achieve the maximization of total welfare, but can achieve Pareto-efficiency. To focus on the main objective, this paper assumes that the maximization of total welfare is the most desirable goal of the global economy.

[6] However, this paper uses only three countries and has only limited implications on domino theory.

[7] Their empirical works support the opinion that developing countries are more likely to lower external tariffs after making trade agreements than developed countries. Freund and Ornelas (2010) and Maggi (2014) asserted that when external tariffs were high enough, as in most developing countries, strong

for both FTA members in a specific parameter range, as shown in Nahm (2019).

This paper is organized as follows. In Chapter 2, model setup is explained. This details how market equilibrium is created for given tariffs, how each country chooses optimal tariffs for each trade agreement structure, and how the trade liberalization game is made. Chapter 3 analyzes the case of free riding. Trade agreement negotiations and equilibrium results for different trade regimes are compared with or without FTAs based on the trade liberalization game setup, and equilibrium results with exogenous technology differences are described and establish a parameter range to reach global free trade. Chapter 4 concerns exclusive blocs. It applied a similar tool to compare trade regimes with FTAs and trade regimes with CUs, and compare equilibrium results with a demand gap. Conclusions are presented in Chapter 5.

2. Model

The model has three stages.[8] Stage 1 is a cooperation game. In Stage 1, countries can negotiate trade agreements. Before Stage 1, the kinds of trade agreements are determined. This paper assumes that the social planner (or international organization) decides the trade regime, which permits or bans an FTA or CU. Then, each country can establish a trade agreement to maximize national welfare as the total surplus, which contains consumer surplus, producer surplus, and tariff revenue. Producer surplus consists of firm profits from domestic and foreign markets.

There are three countries, 1,2, and 3, and they establish trade agreements in this game. Trade agreements are assumed to be made only when all countries agree. This assumption is based on the character of agreements. There are four possible types of equilibrium results: (1) no agreement (trade war); (2) one agreement between two countries and another country becomes a non-member; (3) two agreements are made, and one country becomes a 'hub' of two agreements (possible only for FTAs); and (4) global tariff-free trade.

Stage 2 is the tariff decision of each country. Each country decides its tariff to maximize total welfare, but it must follow the equilibrium result made as the form of trade agreement in Stage 1. When global free trade is achieved, every tariff becomes zero and nothing can change. When free trade is not perfect, FTA and CU members set the internal tariff to zero and need to decide optimal external tariffs. FTA members set external tariffs independently, but CU members set the same external tariff for both members. If both FTAs and CUs are banned before Stage 1, two of three countries can make a trade agreement which sets identical internal and external tariffs under the MFN rule.

Stage 3 is the production decision of firms. They determine production to maximize profits based on production cost, demand, and tariff conditions in Stage 2. It is assumed there are two firms for each good, and the competition is a Cournot equilibrium.

The tariff decision of each country in Stage 2 reflects its own information about firm production and Cournot equilibrium in Stage 3. Similarly, the negotiation strategy of each country in Stage 1 rests on information about decisions in Stages 2 and 3. In this chapter, the model is explained starting with Stage 3 and goes backward. The full derivation of the model is in an Appendix available upon request.

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tariff complementarity appears. Implicit coordination assumption fits with this empirical research and supports this assertion.

[8] The model setup of this paper is same as Nahm (2019). A detailed solution is available upon request.

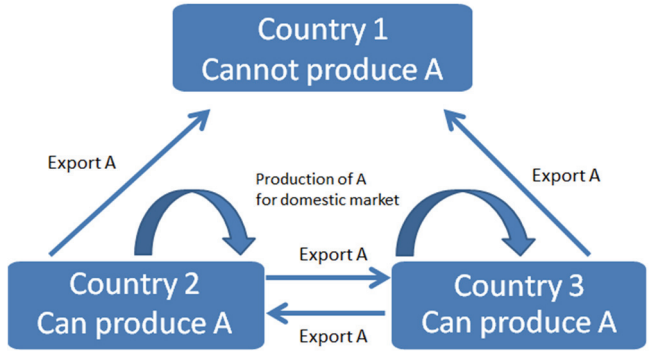
2.1. Market Equilibrium

There are three non-numeraire goods: A, B, and C. Consumers in three countries have the same preference for the three goods.

$$U_i = \alpha_{iA}x_{iA} - \frac{1}{2}x_{iA}^2 + \alpha_{iB}x_{iB} - \frac{1}{2}x_{iB}^2 + \alpha_{iC}x_{iC} - \frac{1}{2}x_{iC}^2 + \psi_i \quad (1)$$

for each country i =1, 2, and 3. ψ_i is the consumption of a numeraire good. Then, demand is derived from the utility function of $d(p_{ix}) = \alpha_{ix} - p_{ix}$ in each country i = 1,2, and 3, where X = A, B, and C. Demand is linear, and its slope is fixed to 1. Intercept α_{ix} represents the market size of each good X in country i.

Fig. 1. Trade Flows for Good A between the Three Countries



Each country can produce two of three non-numeraire goods.[9] Country 1 cannot produce Good A, Country 2 cannot produce Good B, and Country 3 cannot produce Good C. Each country has only one domestic firm for each product, and therefore 6 firms exist in this model: 2 firms for each good. All firms sell their goods domestically and export to foreign markets. Trade flows for Good A are described in Figure 1. Two firms for each good compete in three countries. From the viewpoint of the countries, each country produces and exports two kinds of goods, and imports all three goods. Also, two foreign firms compete in Country 1, but one domestic firm and one foreign firm compete in Countries 2 and 3.

Next, each country levies a tariff on imported goods. Then, the profit of each firm in this model is revenue minus production and tariff costs. π_{ijX} is the profit of the firm that produces good X in country j and sells those in country i. The profit is

$$\pi_{ijX} = p_{iX}q_{ijX} - q_{ijX}(c_{jX} + \tau_{ijX}) \quad (2)$$

for i, j = 1, 2, and 3 and X=A, B, and C. p_{iX} is the price of good X in country i. q_{ijX} is the sale

[9] When each country can produce all three non-numeraire goods and their productivity differs enough, the conclusion of the model is similar to the original. This model assumes that the production cost does not change with scale. This model setup focuses on how each member has different optimal external tariffs.

of good *X* in country *i*, which is produced in country *j*. c_{jX} is the unit production cost of the firm in country *j* that produces good *X*. c_{jX} represents the production technology of firms, and its difference represents the technology gap between firms. τ_{ijX} is the tariff determined in Stage 2 that country *i* levies on good *X* from country *j*. τ_{iiX} is assumed to be zero, and it means that positive tariff rates are only applied to the imported and subsidy as a negative tariff is banned.

Now, there are nine independent markets, and three goods for three countries. During Stage 3, firms compete in each market from optimal production decisions. The decisions constitute a Cournot equilibrium, and results depend on tariffs determined in Stage 2. When two firms from country *j* and country *k* produce good *X* and sell their goods in country *i*, the Cournot equilibrium productions are

$$q_{ijX} = \frac{1}{3}\left(\alpha_{iX} - 2c_{jX} + c_{kX} - 2\tau_{ijX} + \tau_{ikX}\right) \tag{3}$$

for each country *i*, *j*, and *k* = 1, 2, and 3, and each good X = A, B, and C, except combinations where a country cannot produce a specific good (*jX* and *kX* ≠ 1A, 2B, and 3C). These are function of the three set of parameters. First, α_{iX} represents the market size of each country and the difference between countries represents the demand gap. Second, c_{jX} represents the cost of each firm and its difference between firms represents the technology gap. τ_{ijX} represents tariffs, and these will be determined from the optimal decision of countries in Stage 2.

Consumer surplus and tariff revenue are identified as a function of the above parameters as well. Firm profits are the square of equilibrium production.

$$\pi_{ijX} = \left(p_{iX} - c_{jX} - \tau_{ijX}\right)q_{ijX} = \frac{1}{9}\left(\alpha_{iX} - 2c_{jX} + c_{kX} - 2\tau_{ijX} + \tau_{ikX}\right)^2 \tag{4}$$

As the production cost and tariff of a firm are low, that firm earn more profit. In contrast, as a competing firm has lower production costs and pays lower tariffs, the firm has less profit because consumers choose goods from the competing firm. If this market is the domestic market, the firm pays no tariff and earns more profit.

Next is identifying the total surplus. Total surplus is the sum of consumer surplus, tariff revenue, and firm profits. This paper categorizes total surplus into domestic surplus and profits from exports. The total surplus is described as

$$TS_1 = \sum_{X=A,B,C}\left(CS_{1X} + TR_{1X} + \pi_{11X}\right) + \sum_{Y=B,C}\left(\pi_{21Y} + \pi_{31Y}\right) = \sum_{X=A,B,C} DS_{1X} + \sum_{Y=B,C} EX_{1Y} \tag{5}$$

for Country 1. Domestic surplus is the sum of consumer surplus, tariff revenue, and firm profit from the domestic market for each good. Export profit is the sum of exports to Countries 2 and 3. Domestic surplus is from three goods, but exports are from only two goods because Country 1 cannot produce Good A. Also, considering equation (4), domestic surplus depends on the tariff decision of the home country, but exports depend on the tariff decision of foreign countries. This surplus structure is crucial in understanding the trade agreement strategy in Stage 1.

2.2. Stage 2: Optimal Tariff Choices in Trade Agreements

This section identifies the optimal tariff decisions. They try to maximize total surplus by setting optimal tariffs. The decision must follow the trade agreements made in Stage 1. For example, internal tariffs between FTA members must be zero, and members need to decide optimal external tariffs for non-members. Each country decides optimal tariffs under the constraints given in Stage 1. However, exports are part of total surplus, but do not depend on the home tariff decision. Therefore, each country maximizes domestic surplus DS_{iX} under the trade agreement structure given in Stage 1. Before calculating optimal tariffs, one assumption is added to makes results non-negative.

Assumption 1: $\alpha_{iX} + 4c_{jX} - 5c_{kX} \geq 0$ for all goods X = A, B, C and countries i, j, k = 1, 2, 3

This assumption confirms all production and optimal tariffs under all types of trade agreements are non-negative. When all countries agree with global tariff-free trade, all tariffs must be zero, and there is no decision in Stage 2. When any trade agreement is not made in Stage 1 (trade war), each country maximizes domestic surplus without constraint.

However, optimal tariffs are different for each good. At first, this is due to parameter differences such as the demand and technology gaps. Trade flow structure is different for each good. See Fig. 1 again and consider the case of Good A. Countries 2 and 3 produce good A, but also import Good A. Hence, they maximize the sum of consumer surplus, profit of domestic firms, and tariff revenue from trade. In contrast, Country 1 cannot produce Good A, and hence does not need to care about the profit of domestic firms. Also, Country 1 imports Good A from two countries and needs to set two optimal tariffs. Identified optimal tariffs in a trade war state are as below:

- $\tau_{ijX}(\Phi) = \frac{1}{8}(2\alpha_{iX} - 3c_{jX} + c_{kX})$ for each (i, X) = (1, A), (2, B), (3, C)
- $\tau_{ijX}(\Phi) = \frac{1}{3}(\alpha_{iX} - c_{jX})$ otherwise

Φ denotes a trade war, wherein any kind of trade agreement is not made. Four total tariffs need to be determined for each country. First optimal tariffs occur when the home country cannot produce a good and are applied to one good from two countries. Second optimal tariffs are an import that competes with domestic goods and is applied to two types of good. For example, Country 2 need to set two tariffs for Good B, which they cannot produce, and import from Countries 1 and 3 and need to set two tariffs for Good A from Country 3 and Good C from Country 1. All tariffs are positive under assumption 1.

This paper explained four types of equilibrium and showed optimal tariffs for two cases, the trade war and global free trade. Optimal tariffs for the 'hub of two FTAs' case are in the next chapter. Below are the optimal tariffs when equilibrium is one member and another non-member country, with different types of trade agreement. In these cases, the non-member country puts the same tariffs as a trade war state, but the optimal tariff structure of member countries heavily depend on the type of trade agreement.

First is the FTA case. When country *i* and country *j* reach an FTA, their internal tariffs become zero. Country *i* sets two tariffs with country *j* to zero and needs to choose two external

tariffs for Country k to maximize domestic surplus. Assume that Countries 1 and 2 make an FTA. Now, Country 1 sets tariffs to zero with Country 2 for Goods A and C which Country 2 produces. Consider τ_{13B}. Country 2 cannot produce Good B, and hence any condition for an optimization decision on τ_{13B} does not change. Therefore, τ_{13B} with an FTA for Countries 1 and 2 is the same as $\tau_{13B}(\Phi)$. This is applied to τ_{23A} and it is also same for $\tau_{23A}(\Phi)$. The optimization condition is changed only for τ_{13A} and τ_{23B}. Country 1 can decide τ_{13A}, and Country 2 can decide τ_{23B} for their own domestic surplus.

This paper proposes "implicit coordination". FTA members do not cooperate explicitly by deciding optimal tariffs to help exporting foreign firms. However, they can coordinate tariffs implicitly by keeping external tariffs the same as before an FTA. This strategy stipulates the status-quo as the focal point for coordination. When country *i* and country *j* establish an FTA *each other*, *I denote* (ij|FTA-in) denotes the strategy with independent optimal external tariff decision and (ij|FTA-co) is the strategy with implicit coordination on external tariffs.

- $\tau_{ikX}(ij|FTA-in) = \frac{1}{11}(\alpha_{iX} + 4c_{jX} - 5c_{kX})$ if country *i* cannot produce good *X*
- $\tau_{ikX}(ij|FTA-co) = \tau_{ikX}(\Phi) = \frac{1}{8}(2\alpha_{iX} + c_{jX} - 3c_{kX})$ if country *i* cannot produce good *X*
- $\tau_{ikX}(ij|FTA-in) = \tau_{ikX}(ij|FTA-co) = \frac{1}{3}(\alpha_{iX} - c_{kX})$ otherwise

$\tau_{ikX}(ij|FTA-in)$ is lower than $\tau_{ikX}(\Phi)$ under Assumption 1. Hence, exports from a non-member country to members decrease under implicit tariff coordination than a case without coordination. The non-member country loses from this tariff coordination. In comparison to a case without coordination, member countries lose some domestic surplus, but gain exports between members. When parameters are similar between countries, gains from exports are higher than the domestic surplus loss.

This structure is the famous prisoner's dilemma. Setting a lower external tariff is better for the domestic surplus, but these strategies hurt members with decreased trade volume. However, with coordination, they can gain more. Both members must satisfy conditions because this works only when both countries keep their tariff strategies. This paper calculated parametric conditions for both countries that prefer implicit coordination in Nahm (2019), and it is satisfied for most of the numerical analysis.

Establishing a CU is "explicit" coordination. CU members must have identical external tariffs for a non-member country, and hence they choose an identical optimal tariff to maximize the member surplus. In this process, they internalize trade between members, which are not considered in an optimal external tariff decision in an FTA. (ij|CU) denotes a case with a CU of country *i* and *j*. Optimal tariff decision is defined below, and optimal tariffs are identified when country *k* cannot produce *Z*.

- $\tau_{\cdot kX}(ij|CU) \equiv \text{argmax}(DS_{iX} + DS_{jX} + \pi_{ijX})$ with $\tau_{ijX} = 0$
- $\tau_{\cdot kY}(ij|CU) \equiv \text{argmax}(DS_{iY} + DS_{jY} + \pi_{jiY})$ with $\tau_{jiY} = 0$
- $\tau_{\cdot kX}(ij|CU) = \frac{1}{6}(\alpha_{iX} + \alpha_{jX} - 2c_{kX})$

When FTAs and CUs are banned, two countries can reach another kind of trade agreement

to increase surplus. FTA and CU are categorized as a PTA (Preferential Trade Agreement), with lower tariffs for members and higher tariffs for non-members. Under the MFN rule, PTAs are banned, and a new trade agreement under strict multilateralism is possible option. Now members must apply lower tariffs for all countries, regardless of whether they are members. This is denoted (ij|multi). The optimization and identified tariffs are below when country *k* cannot produce *Z*.

- $\tau_{\cdot X}(ij|multi) \equiv argmax(DS_{iX} + DS_{jX} + \pi_{ijX})$ with $\tau_{\cdot X}(ij|multi) = \tau_{ijX} = \tau_{ikX} = \tau_{jkX}$
- $\tau_{\cdot Y}(ij|multi) \equiv argmax(DS_{iY} + DS_{jY} + \pi_{jiY})$ with $\tau_{\cdot Y}(ij|multi) = \tau_{jiX} = \tau_{ikX} = \tau_{jkX}$
- $\tau_{\cdot X}(ij|multi) = \frac{1}{5}(\alpha_{jX} + c_{jX} - 2c_{kX})$ and $\tau_{\cdot Y}(ij|multi) = \frac{1}{5}(\alpha_{iY} + c_{iY} - 2c_{kY})$

This trade agreement also considers trade flows between members. This is the same as the optimization of CU members. However, constraints that low tariffs must be applied to non-members are strong. Optimal tariffs are consequently changed.

Now all conditional tariffs are identified. As a result, all total surpluses are identified as a function of the technology $\{c_{iX}\}$ and demand parameters $\{\alpha_{iX}\}$ for all types and equilibriums. With this information about Stages 2 and 3, countries in Stage 1 choose trade agreement strategies to maximize total welfare.

2.3. Stage 1: Trade Liberalization Game

At Stage 1, countries become players in a trade liberalization game. They know what the equilibrium result will be in Stages 2 and 3 under each trade agreement relationship. There are four possible types of equilibrium results in Stage 1: trade war (Φ), one agreement and a non-member (ij), two agreements and one hub country (i-hub), and global free trade (G). Also, this game must follow a given trade regime which determines permission or bans a type of trade agreements. There are three types of trade regime: (1) both FTA and CU are not possible (no PTA: strict multilateralism), (2) only the FTA is possible, (3) only the CU is possible.[10]

Each player can decide whether to propose a trade agreement with the two other countries with the goal of maximizing total surplus. It is assumed that international transfer is impossible, and that each country arrives at its decision by comparing the surpluses produced under each game result, considering Stages 2 and 3. When only one type of trade agreement is possible, there are four possible strategies in Stage 1: (1) do not propose a trade agreement (∅), (2 and 3) propose a trade agreement with only one country (ρ_j and ρ_k), and (4) propose a trade agreement with both countries (ρ_G). For example, the strategy set of Country 1 is $\{\emptyset, \rho_2, \rho_3, \rho_G\}$.

The countries undertake strategies simultaneously, and a trade agreement is established only when two countries propose an agreement . For example, when only FTA is possible, assume that Countries 1, 2, and 3 choose strategies $\{\rho_2\}$, $\{\rho_G\}$, and $\{\rho_1\}$, respectively. Then, an FTA between Countries 1 and 2 is made because both countries want it. Countries 1 and 3 do not reach agreement because Country 3 wants it, but Country 1 does not. Countries 2 and 3 cannot arrange an FTA because Country 3 does not want it. Global tariff-free trade

[10] Trade regime which permit both of FTA and CU are possible option. But that result is not much different from the one of trade regime which permit only FTAs.

between these countries is possible only when all three players choose $\{\rho_G\}$.

It is assumed that global tariff-free trade is desirable and conditions to reach global free trade as equilibrium under each trade regime will be indentified. There are three kinds of potential deviations from free trade.

- Free Riding: occurs when one non-member country refuses a trade agreement with other countries.
- Exclusive Bloc: occurs when two member countries refuse participation of a non-member country.
- Hub-and-Spoke: occurs when one country refuses a trade agreement with another country, and the remaining country becomes a hub of two trade agreements.

These deviations occur from the optimization decisions of countries. That is, a certain deviation is beneficial for one country over global free trade, and that country chose that deviation naturally, which causes free riding or a hub-and-spoke structure as equilibrium. However, making an exclusive bloc is different. It is not possible from the decision of one country. A trade agreement becomes an exclusive bloc only when both members deviate and cut ties with another non-member country. For example, to make trade agreements of 1 and 2 exclusive blocs, both countries must cut ties with Country 3, and both get a higher total surplus than the total surplus under global free trade. In short, deviation from global free trade can proceed from a coalition of Countries 1 and 2.

This cooperative deviation is not considered in the simple Nash equilibrium, which needs to block all deviations of each player, but does not consider coalition deviation. Hence, in this game, the concept of the "Coalition-proof" Nash equilibrium (CPNE) is employed, which Bernheim et al. (1987) defined.

This paper concentrates on how free riding and exclusive blocs are harder under a trade regime in which FTAs are possible. These two deviations may become prevalent when more than three countries exist and work as a stumbling block in reaching global free trade. Free riding is analyzed first and compares a trade regime with FTAs and trade regime with no PTAs in the next chapter. This paper analyzes the exclusive bloc, gives more detail on CPNE, a hub-and-spoke, and CUs later.

3. Free Riding and FTAs

Each country can refuse any trade agreement and becomes a free rider of a trade agreement with other countries based on a comparison of welfare. It is assumed that Country 3 chooses whether to become a free rider. When choosing to be a free rider, the domestic gain of Country 3 is from an increase of tariff revenue and firm profit for the domestic market. Instead, Country 3 loses some of the consumer surplus. What about exports? Current GATT/WTO Article XXIV regulates trade agreement members to not raise external tariffs. Therefore, Country 3 can export more to the member countries as a free rider.

To identify how decision by Country 3 changes with a different trade regime, we need to find how the welfare of Country 3 changes by trade agreement. At first, when Countries 1 and 2 establish a trade agreement, the type of trade agreement does not have any effect on the domestic welfare of Country 3. Therefore, when choosing to be a free rider, Country 3 levies

the same tariffs as the trade war state, regardless of the type agreement. Hence, the free riding decision of each case depends on the domestic welfare difference, but the free riding welfare difference between different trade agreements with Countries 1 and 2 does not depend on the domestic welfare difference. As a result, we can identify which trade regime makes free riding easier by comparison of the exports of Country 3.

When external tariffs of member countries are low, Country 3 can see higher exports and higher welfare, and more easily choose to be a free rider. Country 3 is a free rider because they can enjoy increased exports without opening domestic markets. Opening to trade is overall beneficial for many real-world cases, but there are many incentives to raise tariffs. This model is based on oligopoly, and each country can earn more welfare by shifting the profit from foreign firms to domestic firms or as tariff revenue. Considering increased exports from global free trade, the gain of global free trade becomes larger. However, when other countries make a trade agreement, incentives for a unilateral tariff decrease for Country 3 may not be high.

When Country 3 chooses not to be a member of trade agreement, it is a unilateral deviation from global free trade, and global free trade cannot be a Nash equilibrium. In this chapter, how trade regimes with FTAs are better to reduce free riding over trade regimes without FTAs is evaluated.

3.1. Theoretical Analysis on Free Riding

Within an FTA between two countries, two external tariff policy options are possible: the separate decision of each country, or an implicit coordination that both countries keep the status-quo. Country 3 chooses free riding based on total surplus, and therefore we need to compare the total surpluses for two different tariff policies.

Proposition 1. (Implicit Coordination and Free Riding) If countries *i* and *j* established an FTA, $TS_k(ij|FTA-in) > TS_k(ij|FTA-co)$.

Detailed proof is in the Appendix. To explain it briefly, domestic surplus areas are same for two cases, and the decision on free riding depends on the external tariff decisions of member countries. External tariffs are lower when they decide external tariffs independently than under implicit coordination. Therefore, the non-member country exports less when members choose implicit coordination.

The proposition indicates that when countries in an FTA coordinate implicitly, they can prevent free riding and push outside countries to negotiate another FTA to come close to free trade, in comparison to separate external tariff decisions. Then, will they choose implicit coordination? Nahm (2019) offered these conditions and indicated that two countries will coordinate implicitly when it provides a better result than a separate decision for both countries. (ij|FTA*) is denoted an endogenous decision of the external tariff policy in an FTA. Then, each country considers the endogenous external tariff policy decisions of all members before deviation.

- (ij | FTA*) denotes (ij|FTA-co) if $TS_x(ij|FTA-in) > TS_x(ij|FTA-co)$ for each x = i, j

- (ij | FTA*) denotes (ij|FTA-in) otherwise.

Next, the study identifies the case of trade regimes without PTAs. The conditions of free riding are similar. Each country can compare surpluses with free trade and surpluses from cutting ties. Free riding decision depends on exports to member countries. For proposition 1, a comparison of the external tariffs of member countries for each case is enough proof. However, optimal external tariffs under strict multilateralism contain the demand of each country that produces a good. When FTA members decide optimal tariffs, they only consider their own demand. In contrast, under multilateralism, members decide the same optimal tariffs for all external and internal tariffs, and they need to consider the demand of both member countries. Therefore, the next proposition works under additional conditions.

Proposition 2. (Free Riding under an FTA and Multilateralism) If countries *i* and *j* make a trade agreement and their market sizes are the same, $\mathrm{TS_k(ij|multi)} > \mathrm{TS_k(ij|FTA-co)}$.

The proof is in the Appendix. For each good, country *k* exports to the country which can produce the good and the country which cannot produce the good. When market sizes are same, both exports are lower under a trade regime with an FTA than under strict multilateralism. Therefore, free riding becomes easier under strict multilateralism.

In respect to free riding, a trade regime with an FTA with implicit coordination is better than strict multilateralism. However, a hub-and-spoke deviation is possible under an FTA, and this deviation is not possible under strict multilateralism. How a hub-and-spoke type deviation is made is identified in the next section.

3.2. Hub-and-Spoke Structure of an FTA

When countries i and *j* make an FTA and countries *i* and *k* made another FTA, country *i* becomes a hub of two FTAs. This state is denoted the 'i-hub'. When at least one of *j* and *k* refuse a trade agreement between *j* and *k*, the (i-hub) becomes the equilibrium state. The hub country sets all tariffs to zero and exports goods to spoke countries without tariffs. Only two spoke countries maintain a positive tariff with each other.

This hub-and-spoke structure is possible only under a trade regime with FTAs. Under the CU, members must have the same external tariffs. When countries *i* and *j* made the CU, the negotiation of the trade agreement between *j* and non-member *k* conflict with the external tariff rule of the CU without including country *k* as a member and reaching global free trade. Under strict multilateralism, external and internal tariffs are the same. In this case, when countries *i* and *j* made the trade agreement, only the external tariffs of country *k* were different. Under the i-hub structure, all tariffs become the same, and the three countries can lower tariffs to zero. As a result, the i-hub structure does not exist under strict multilateralism.

Implicit coordination does not work with a hub-and-spoke structure. Implicit coordination strategy works only when all FTA members keep external tariffs with the status-quo. Hence, when one country becomes a hub, it means the collapse of coordination. Therefore, under the hub-and-spoke structure, spoke countries set external tariffs independently. Optimal tariffs between spoke countries are same as the tariffs under an FTA without coordination because country *i* has zero tariffs for all imports, and it cannot coordinate with any country.

- $\tau_{jkX}(i-\text{hub}) = \frac{1}{11}(1\alpha_{jX} + 4c_{iX} - 5c_{kX})$ for each (i, X) = (1, A), (2, B), (3, C)
- $\tau_{jkX}(i-\text{hub}) = \frac{1}{3}(\alpha_{jX} - c_{kX})$ otherwise

Being a hub country is very attractive because it can get the same domestic surplus as under global free trade and have higher exports due to non-zero tariffs between two spoke countries.

Proposition 3. (Superiority of the Hub Country) $TS_i(i-\text{hub}) > TS_i(G)$.

The proof is in the Appendix. With two spoke countries, imports from the hub country and the other spoke country compete, but the tariff is only on the other spoke country. As a result, the hub country can export more of the good that the spoke country cannot produce than under global free trade. The total surplus gained in a hub of two FTAs is always larger than the surplus gained as a member of global free trade.

What about spoke countries? Assume that Countries 1 and 2 make an FTA, and Country 1 becomes a hub by making another FTA with Country 3. Country 3 can gain from an FTA with Country 1, but this does not provide exclusive advantages because Country 1 has an FTA with Country 2. Hence, gains from this FTA are limited in this sense. Country 2 loses some of its ability to export to Countries 1 and 3 from the FTA of Countries 1 and 3. Implicit coordination is not possible here. Country 2 lowers its tariff on Country 3, and its domestic surplus can increase as a result.

In comparison to free trade, spoke countries have zero tariffs with a hub country, and only low tariffs with the other spoke country. A spoke country exports less to other countries and gains domestic surplus from external tariffs on the other spoke country. If this gain is higher than the loss, the spoke country will not negotiate a trade agreement with the other spoke country, and a hub and spoke state become the equilibrium. That is, when an FTA is possible, each country can choose to be not only a free rider by nullifying FTAs with both countries, but also a spoke country by cutting only one FTA with one country.

3.3. Numerical Application for Free Riding: Technology Gap

This section describes the equilibrium result of the trade liberalization game above with a technology gap. When three countries have similar unit costs and market size, it become easier to reach global free trade. However, asymmetry between countries makes global free trade harder to achieve. In this section, how equilibrium result changes in some parametric regions under different trade regimes is identified. The focus is on the technology gap and cost difference here. Equilibrium change from the demand gap will be identified in the next chapter.

It is hard to visualize the change of all parameters in one graph. Below is the assumption to focus on the relative technology difference between firms in different countries and skip other factors.

Assumption 2-1.
(i) $\alpha_i \equiv \alpha_{iA} = \alpha_{iB} = \alpha_{iC}$ and $c_j \equiv c_{jA} = c_{jB} = c_{jC}$ for i and j = 1, 2, and 3.
(ii) $e \equiv \alpha_1 - c_1$ and $\alpha = \alpha_1 = \alpha_2 = \alpha_3$

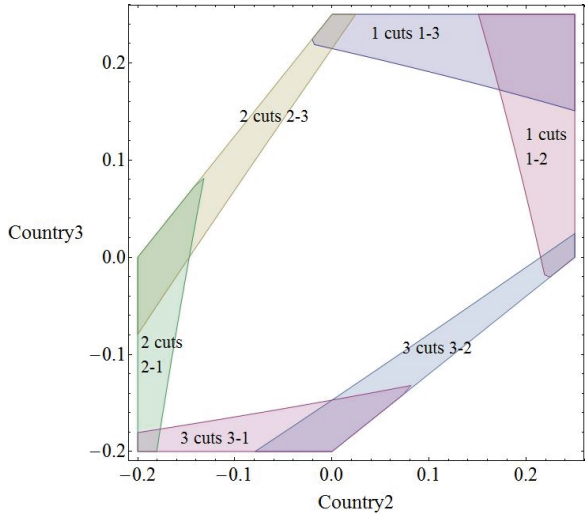
(iii) $t_k = \frac{(\alpha_1 - c_k) - (\alpha_1 - c_1)}{\alpha_1 - c_1}$

(iv) $-0.2 < t_2, t_3 < 0.25, 4t_2 - 5t_3 < 1, -5t_2 + 4t_3 < 1.$

All demand and cost difference between three goods were left out through assumption (i). Each country has same demand size and same unit cost for all three goods. Under assumption (ii), the demand sizes of all countries are the same for all three goods. Absolute cost parameters were exchanged $\{c_i\}$ into the relative technology parameter $\{t_i\}$ for i=2,3. If c_2 is higher than c_1, t_2 is less than zero. If the cost of firms in Country 2 is higher than cost of firms in Country 1, the relative technology of Country 2 become negative. t_1 is always set to zero. Now, we can check the change of equilibrium results in the (t_2, t_3) plane. An assumption is added for the parameter range in (iv), and this is technology version of Assumption 1. Also, the condition of implicit coordination[11] is satisfied under the range in (iv). That is, when two countries make an FTA at any point of given parametric space, they choose implicit coordination.

Global, tariff-free trade is desirable in the sense that the joint surplus of the three countries in a free trade state is higher than in any other state among the results of trade liberalization games in all parametric ranges. When $t_2 = t_3 = 0$, the three have the same cost and demand size, and they reach global free trade in any case. However, when asymmetry is assumed, the region in which free trade is achievable depends on the possible type of trade agreement. As that region is wide, that type of trade regime is better for reaching global free trade.

Fig. 2. Hub-and-Spoke Deviation: Technology Gap



At first, Fig. 2 describes hub-and-spoke type deviations. This type of deviation is not dependent on implicit coordination, and only appears in an FTA trade regime. Six shaded

[11] $\sqrt{\frac{77}{206}}(2 + 3t_2) < 2 + 3t_3 < \sqrt{\frac{206}{77}}(2 + 3t_2)$

areas appear, and each area stands for the deviation if one country nullifies one FTA and makes the other country a hub. If Country 1 cuts an FTA with Country 3, Country 2 becomes a hub of two FTAs.

Fig. 3. Equilibrium Result for the FTA Trade Regime (Without Coordination): Technology Gap

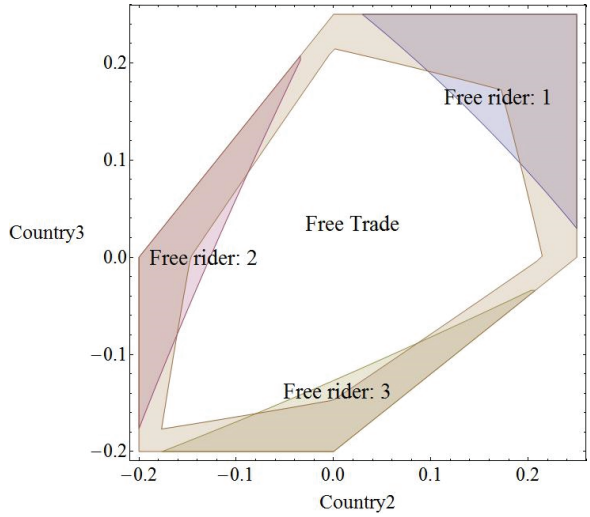


Fig. 3 describes free riding under the FTA trade regime where implicit coordination is not considered. Under the parametric range in Assumption 2-4, all FTA members choose implicit coordination, but this graph was chosen to compare the difference with the results under implicit coordination. There are three shaded areas which describe the free riding of each country. In contrast, when implicit coordination is considered, additional shaded areas disappear, and more free-riding beyond the hub-and-spoke type deviation does not happen. This is the same result as Proposition 1 predicts.

When each FTA member does not coordinate, they choose their own optimal external tariff. If this is low enough, non-members choose not to join the trade agreement and enjoy export increases with no cost in their domestic markets. In contrast, when two countries can choose coordination and keep the status quo, there is no free riding. Each country must lose export profit if they choose to be a non-member, and then deviation becomes more costly.

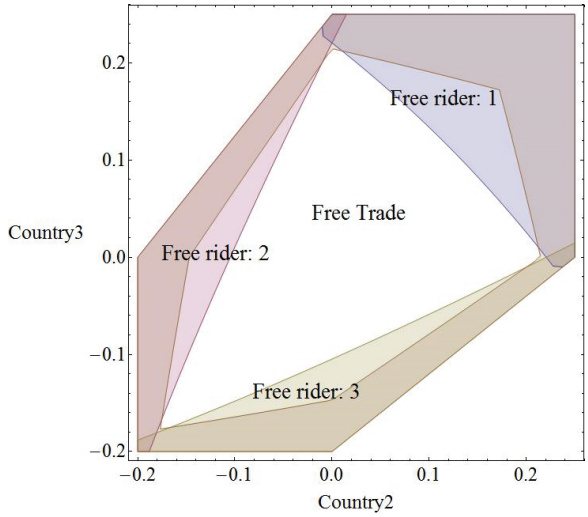
Fig. 4. Equilibrium Result for Strict Multilateralism: Technology Gap

Fig. 4 shows that the free riding of a non-member country becomes prevalent under strict multilateralism. In this case, a hub-and-spoke type deviation is impossible, but free riding areas are larger than the shaded area in Figure 2 (10). This is in line with Proposition 2. Under strict multilateralism, tariffs should be the same for members and non-members. Therefore, free riding becomes easier because members cannot reduce imports from non-member. This regime is dominated by an FTA regime in respect to global free trade.

Fig. 2 shows that a country with less developed technology tends to nullify an FTA with a country that has the most developed technology and become a spoke. Similarly, Figures 3 and

4 show that a country with less developed technology tries more to be a free rider. As a country has a higher production cost, the loss of exports from tariffs are smaller. They become free riders because gains from tariff revenue and the consumer surplus increase. Other developed countries see more gains from export profits, and becoming a free rider is costly. A less developed country becomes unfavorable to free trade, and the trade regime with an FTA can make these countries more accepting of global free trade, especially under consideration of the implicit coordination of FTA members.

In the above cases, an exclusive bloc does not appear. How this exclusive bloc decreases in the FTA trade regime from demand gap is shown in next chapter.[12]



4. Exclusive Bloc and FTA

When two countries made a trade agreement and exclude the other country, then that trade agreement becomes an exclusive trade bloc and reaching global free trade fails. Assume Country 1 and Country 2 make a trade agreement. They can set external tariffs to maximize their own welfare based on the type of trade agreement, and it may be higher than welfare from global free trade. Making an exclusive bloc offers gains such as more profits from evading competition in domestic markets, markets in member countries, and more tariff revenue. This may be higher than the reduced consumer surplus and reduced exports to the non-member country.

This gain and loss depends on the level of external tariffs and the type of trade agreement. In contrast with the free riding case, the type of exclusive bloc changes all domestic welfare of a country and has a different effect on exports to members and non-members. Therefore, the welfare difference of an exclusive bloc between different types of trade agreement is more

[12] When the technology gap is applied to a trade regime with a CU, an exclusive bloc appears, but free riding disapperas. As a result, the size of the region to achieve free trade is hard to compare with the case of an FTA. It was added to the online Appendix.

complex than the free riding decision.

Also, this deviation from global free trade is a joint strategic move. An exclusive bloc is made from the decision of both countries. If Country 1 breaks the FTA with Country 3, but Country 2 does not, this FTA structure makes Country 2 a hub, not an exclusive bloc. To identify the equilibrium with consideration to joint deviation, the concept of CPNE is applied here. The paper will identify the condition of deviation from global free trade with CPNE first, compare the conditions of the FTA and a CU, and perform a numerical application with a demand gap.

4.1. CPNE and Exclusive Bloc on FTA

When two countries jointly deviate from global free trade, is that bloc is stable? This paper identified the joint deviation above, but did not identify the stability of the bloc. Under the trade regime in which an FTA is possible, a hub-and-spoke structure is possible. Becoming a hub allows more welfare than free trade does for any country, as shown in Proposition 3. When the current state is one FTA and one non-member, such as when an exclusive bloc is made, each FTA member can become a hub of two FTAs by making another FTA with a non-member. That is, an exclusive bloc becomes fragile when an FTA is possible.

When the current state is global free trade, a country can be a hub only when two others break FTAs. Each country cannot become a hub from its own choice when free trade is already made. In contrast, when the current state is one bloc and another non-member, a country can be a hub with negotiation with another non-member. Making themselves a hub country is possible only when the country is the member of one bloc and another non-member exists. Also, a hub-and-spoke state can be moved to global tariff-free trade when two spoke countries reach an FTA, regardless of the opinion of a hub country.

In short, there are three states and deviations {G} → {12 | FTA*} → {1-hub} → {G} in which circling deviation is possible. Below, the conditions for each deviation are summarized.

- {G} → {12 | FTA*} : $\mathrm{TS}_1(\mathrm{G}) < \mathrm{TS}_1(12|\mathrm{FTA}*)$ and $\mathrm{TS}_2(\mathrm{G}) < \mathrm{TS}_2(12|\mathrm{FTA}*)$
- {12 | FTA*} → {1-hub} : $\mathrm{TS}_1(12|\mathrm{FTA}*) < \mathrm{TS}_1(1-\mathrm{hub})$ and $\mathrm{TS}_3(12|\mathrm{FTA}*) < \mathrm{TS}_3(1-\mathrm{hub})$
- {1-hub} → {G}: $\mathrm{TS}_2(1-\mathrm{hub}) < \mathrm{TS}_2(\mathrm{G})$ and $\mathrm{TS}_3(1-\mathrm{hub}) < \mathrm{TS}_3(\mathrm{G})$

Condition 1 prevents global free trade from being a stable equilibrium. Condition 2 prevents the exclusive bloc from becoming a stable equilibrium, and Condition 3 prevents the hub-and-spoke state from being a stable equilibrium. Therefore, any state looks unstable if the three conditions are satisfied. All three conditions can be satisfied together. Consider the case of $\mathrm{TS}_1(\mathrm{G}) < \mathrm{TS}_1(12|\mathrm{FTA}*) < \mathrm{TS}_1(1-\mathrm{hub})$. $\mathrm{TS}_1(\mathrm{G}) < \mathrm{TS}_1(12|\mathrm{FTA}*)$ is always satisfied by Proposition 3. When the value of $\mathrm{TS}_1(12|\mathrm{FTA}*)$ is in the middle of other two, all inequalities are satisfied.

The coalition-proof Nash equilibrium (CPNE) concept is employed to solve this kind of problem. A deviation within a coalition of two or three countries is considered only when it is "self-enforcing". The deviation strategy of the coalition is defined as self-enforcing when the coalition strategy creates Nash equilibrium for all coalition members under a given strategy of a player outside of the coalition. When a self-enforcing deviation by one coalition from one

state is possible, that state cannot be a CPNE. A CPNE must be proof to all self-enforcing coalitions.[13]

Assume all three conditions are satisfied, with the establishment of an exclusive bloc against Country 3 from global free trade. For this deviation to occur, both Countries 1 and 2 must cut their FTAs with Country 3. However, for Country 1, a better option is to maintain its connection with Country 3 and let only Country 2 break its connection with Country 3. Then, only the relationship between Countries 2 and 3 will be broken, and Country 1 can become a hub of two FTAs. A deviation strategy is "self-enforcing" when that joint strategy is a Nash equilibrium strategy for a given strategy choice by other countries. When $TS_1(G) < TS_1(12|FTA*) < TS_1(1-hub)$, deviation {G} → {12 | FTA*} is attractive, but {1-hub} is a better state for Country 1, and then Country 1 will betray Country 2. This betrayal does not need cooperation with Country 3. As Country 1 pretends to cut the FTA with Country 3 but does not when Country 2 does, {G} → {1-hub}, deviation is made.

This possibility indicates that deviation {G} → {12 | FTA*} is not self-enforcing when $TS_1(G) < TS_1(12|FTA*) < TS_1(1-hub)$. Only when the total surplus of exclusive the FTA is higher than the total surplus of becoming a hub for both countries, and deviation from global free trade to an exclusive bloc is self-enforcing, global free trade becomes unstable. When this condition is not satisfied for Country 1, joint deviation is not possible because Country 1 will not break the FTA with Country 3 to become a hub, and Country 2 already can predict that and will not believe Country 1. As a result, global free trade becomes stable in this case.

In contrast, {12 | FTA*} → {1-hub} deviation is joint between Countries 1 and 3, but {1-hub} → {G} is another joint move of Countries 2 and 3. Deviation of Countries 1 and 3 is not self-enforcing only when additional deviation of Country 1 or 3 is possible under a given strategy choice of a player outside of the coalition, Country 2. If additional deviation is possible only with the strategy change of Country 2, the initial deviation of Countries 1 and 3 is self-enforcing. Also, {1-hub} → {G} deviation is joint between Countries 2 and 3, but {G} → 'any FTA' also needs move Country 1. This means that this deviation is self-enforcing. Also, {1-hub} → {G} always happen as countries do not choose hub-and-spoke type deviations, which is sorted as another type of deviation.

In conclusion, the below three cases are possible deviations when only an FTA is possible. For any *i*, *j*, and *k* = 1, 2, and 3, but differ from each other;

1. $TS_k(ij|FTA*) > TS_k(G)$: *k* becomes a free rider.
2. $TS_j(i-hub) > TS_j(G)$: *j* deviates and *i* becomes a hub of two FTAs.
3. $TS_i(ij|FTA*) > TS_i(i-hub)$, $TS_j(ij|FTA*) > TS_j(j-hub)$: *i* and *j* make an exclusive bloc.

Otherwise, {G} becomes a unique CPNE.

When countries *i* and *j* do not coordinate, free-riding increases, the second condition does not change, and the exclusive bloc decreases as a result. Therefore, overall equilibrium results considering coordination can only be compared through numerical application in the next

[13] The correct definition of CPNE needs mathematical induction on the number of players. See Bernheim et al.(1987) or Moreno and Wooders(1996) for details.

section.

4.2. Exclusive Bloc with a CU

In a CU, a hub-and-spoke trade agreement structure is impossible. Therefore, {G} → {12 | CU} joint deviation is self-enforcing because betrayal of the hub-and-spoke state is not possible. The two cases below are possible types of deviations when only a CU is possible. For any *i*, *j*, and *k* = 1, 2, and 3, but are different from each other,

1. $TS_k(ij|CU) > TS_k(G)$: *k* becomes a free rider.
2. $TS_i(ij|CU) > TS_i(G)$, $TS_j(ij|CU) > TS_j(G)$: *i* and *j* make an exclusive bloc.

Otherwise, {G} becomes a unique CPNE. In this case, one country cannot deviate to a hub-and-spoke state. Also, free riding is not a severe problem because external tariffs of CU members are relatively high. Comparison of the exclusive bloc is crucial for the evaluation of the two trade regimes. When two countries make a trade agreement, are their total surpluses greater than the total surplus under global free trade? There are three differences between an FTA and CU.

First is the internalization of externality under the CU. When each country set optimal external tariffs, they maximize domestic surplus under the FTA, and exports between members are not considered. However, under the CU, countries set optimal external tariffs together, and exports between members come into the optimization. In this perspective, a CU is easier to become an exclusive bloc than an FTA. Instead, FTA members can help each other through implicit coordination to some extent.

Second is the additional constraint of CU optimization. CU members must have the same external tariffs. If they consider trade between members and each country can set different optimal external tariffs, they can maximize the total surplus of members more efficiently, but the external tariff becomes an additional constraint on optimization. In addition, GATT/WTO Article XXIV does not allow member countries to raise external tariffs as an additional constraint. This makes it harder for a CU to become an exclusive bloc.

Third is the flexibility of the FTA, explained in the previous chapter. The hub-and-spoke structure possibility of the FTA makes an FTA exclusive bloc easier to collapse than a CU. As a result, to become an exclusive bloc, FTA members must have a higher trade surplus than the surplus of the hub of two FTAs. In contrast, CU members can have higher trade surpluses than the free trade state to become an exclusive bloc. As proposition 3 notes, conditions for a CU are easier to satisfy. This makes it harder for an FTA to become an exclusive bloc.

It is hard to propose solutions in this comparison because of the differences. This paper suggests a numerical approach instead in following section.

4.3. Numerical Application for the Exclusive Bloc: Demand Gap

This section identifies how an exclusive bloc is made under different trade regimes from an equilibrium result of the trade liberalization game with a demand gap. As in the technology gap case, three countries reach free trade easier when market sizes are similar. As the demand gap increases, it becomes harder to achieve free trade, and the study compares the parametric region that allows global free trade under different trade regimes, with an FTA or CU.

Below is the assumption applied in this section to focus on the relative demand difference between countries and skip other elements, such as demand and cost differences between the three goods.

Assumption 2-2.
(i) $\alpha_i \equiv \alpha_{iA} = \alpha_{iB} = \alpha_{iC}$ and $c_j \equiv c_{jA} = c_{jB} = c_{jC}$ for i and j = 1, 2, and 3.
(ii) $e \equiv \alpha_1 - c_1$ and $c = c_1 = c_2 = c_3$
(iii) $d_k = \frac{(\alpha_k - c_1) - (\alpha_1 - c_1)}{\alpha_1 - c_1}$
(iv) $-0.5 < d_2, d_3 < 1, d_2 - 2d_3 < 1, -2d_2 + d_3 < 1.$

Assumptions are similar to Assumption 2-1. Every firm has the same production cost for all goods, and each country has the same market size for all three goods. Only a demand size difference between countries remains. Absolute demand parameter α_I was changed into relative demand parameter d_I for Countries 2 and 3. When Country 2 has more market demand than Country 1, d_1, relative market size, becomes positive. We can identify how equilibrium results changes in the (d_2, d_3) plane. The fourth assumption set the parameter range in this setup. Assumption 1 is satisfied, and other tariffs and production are positive under this assumption. Global tariff free trade is desirable in this area in the sense that the total surpluses of the countries in the free trade state are higher than any other state, as in the previous section.

Fig. 5. Hub-and-Spoke Deviation: Demand Gap

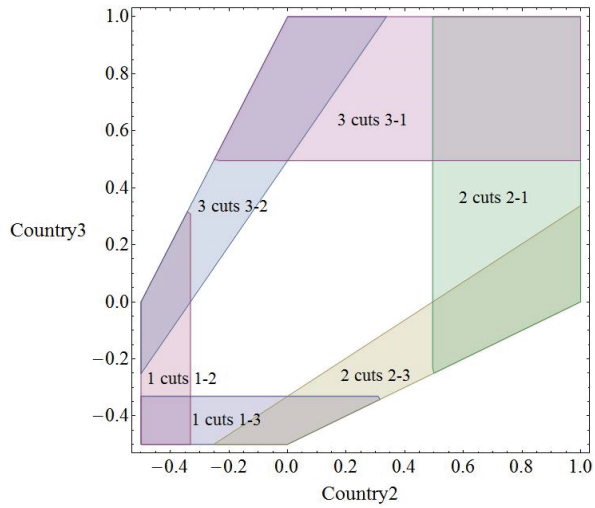


Fig. 5 illustrates hub-and-spoke deviation under an FTA trade regime. As in Fig. 2, six shaded areas appear, and at least one country cuts an FTA with one country in each area. In the central area near $d_2 = d_3 = 0$, equilibrium results are global free trade, but it becomes harder to achieve as each parameter is farther from zero. In the figures below, there is a focus on the central area $(-0.4 < d_2, d_3 < 0.6)$ to compare trade regimes. Also, FTA members

choose implicit coordination in most of this area.[14]

Fig. 6. Equilibrium Result for an FTA Trade Regime (With Coordination): Demand Gap

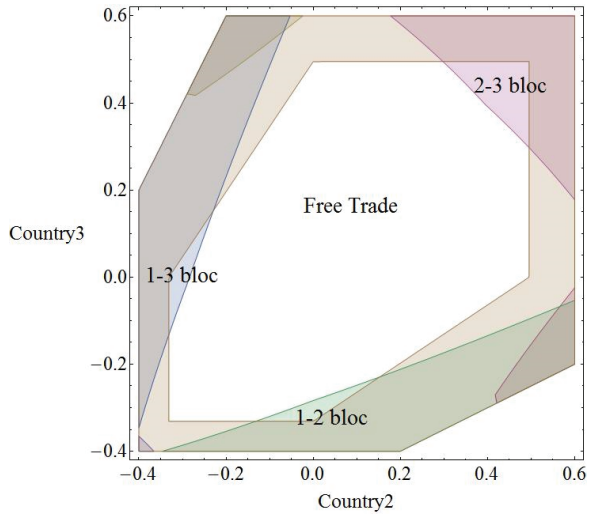


Fig. 7. Equilibrium Result for an FTA Trade Regime (Without Coordination): Demand Gap

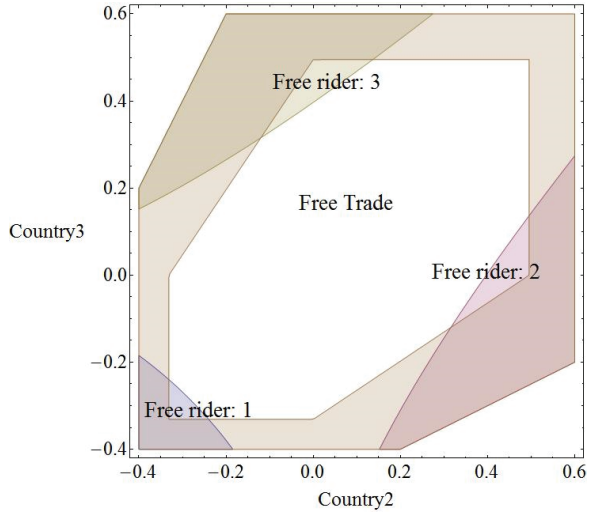


Fig. 6 describes the exclusive bloc under an FTA trade regime where implicit coordination is considered. An exclusive bloc based on an FTA does not appear in the technology gap case,

[14] $\sqrt{\frac{77}{206}} - 1 < d_2, d_3 < \sqrt{\frac{206}{77}} - 1, \sqrt{\frac{77}{206}}(1 + d_2) < 1 + d_3 < \sqrt{\frac{206}{77}}(1 + d_2)$.

but an exclusive bloc is possible in this demand gap case. Fig. 7 shows the case of an FTA trade regime without implicit coordination. An exclusive bloc is not possible, but free riding appears. When implicit coordination is considered, free riding become harder, but making an exclusive bloc is possible when a demand gap exists. This result is in accordance with the propositions in this paper. However, implicit coordination cannot improve the results of global free trade, in contrast to the improvement in the technology gap case.[15]

Fig. 8. Equilibrium Result for a CU Trade Regime: Demand Gap

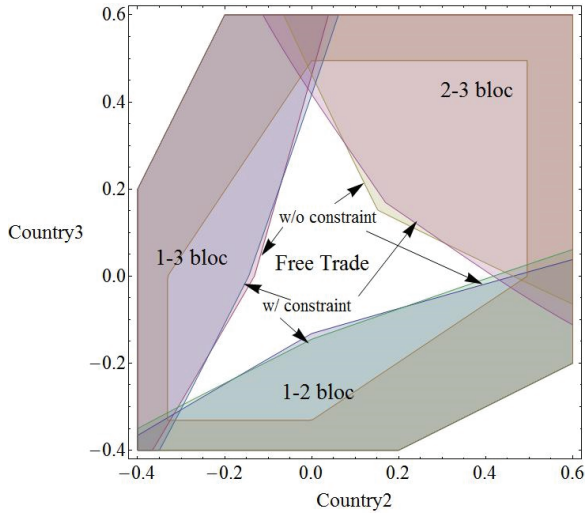


Fig. 8 shows an exclusive bloc under a CU trade regime. An exclusive bloc is prevalent when it can make a CU trade agreement. The region where global free trade is the equilibrium is much wider under an FTA trade regime than a CU trade regime. The fact that a hub-and-spoke is impossible cannot help, and a bloc based on a CU is stable. Similar work was done with additional constraints for GATT/WTO Article XXIV, and this is expressed as "w/constraint" in Fig. 8. It does not make much difference, as Fig. 8 illustrates. In conclusion, an FTA is much better to achieve global free trade than a CU in a demand gap case. [16]

Fig. 5 shows that a country with large demand wants to nullify an FTA with a small country. Through an FTA, each country loses its domestic market share, but increases profits from exports. The large country loses more from opening its domestic market and becomes passive in making agreements. Then the large country wants to deviate. Similarly, in Figures 6 and 8, large countries refuse free trade by creating a bloc because of the higher cost of opening markets.

A trade regime which permits an FTA and CU does not make much difference compared to a trade regime with only FTAs. In consideration of implicit coordination, an FTA offers

[15] Under strict multilateralism, free-riding becomes prevalent, as Fig. 4 predicts. However, a hub-and-spoke deviation does not exist under strict multilateralism, and it makes harder to compare with an FTA trade regime.

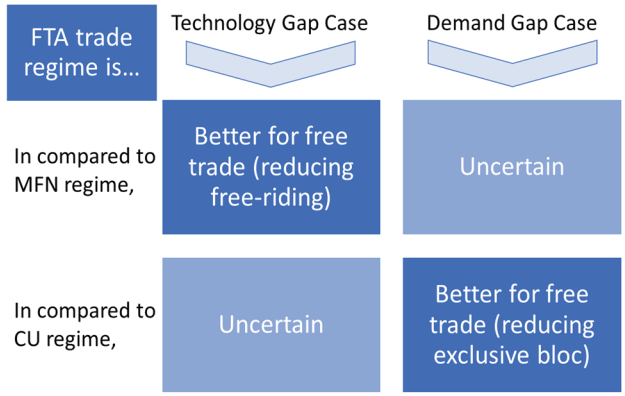
[16] I did similar work for a CU in the technology gap case, but there is not much difference for the region to reach free trade with an FTA trade regime.

more welfare for members, and it becomes harder to agree to reach a CU for both members. As a result, they choose FTAs over CUs, and therefore the numerical application result for the trade regime contains FTAs and CUs, similar to the result of the trade regime with only FTAs. Those results are in the online Appendix.

5. Conclusion

This paper compares different trade regimes for different types of trade agreements via a trade liberalization game with numerical applications. In conclusion, a trade regime with FTAs is best for achieving global free trade. It is better to reduce free riding than strict multilateralism for the technology gap between countries, and better to prevent an exclusive bloc than a trade regime with CUs for the demand gap between countries. In addition, this result is reinforced with consideration of the implicit coordination of FTA members. Results are summarized in Fig. 9.

Fig. 9. Summary



The main objective of this paper was finding optimal rules for trade negotiations. This paper concludes that a trade regime with FTAs, which is the current trade regime under the WTO, is the optimal rule to achieve global free trade. This paper shows that the current trade regime which permits FTAs cannot eradicate the likelihood of an exclusive trade bloc but maximizes the likelihood of reaching global free trade. As a result, this paper supports thee building block hypothesis of FTAs.

This paper does not check additional strategic moves for countries. In the real world, two countries choose not to reach an FTA before persuading a potential free rider to join. Transfer between countries can be possible, but this paper does not consider this option. Also, this paper supports the domino theory of trade agreements, but has only limited implications because the model in this paper has only three countries. These will be follow-up research topics.

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The Effects of Logistics Technology Acceptance in the Fourth Industrial Revolution on Logistics Safety Performance: The Moderated Mediating Effect of Logistics Safety Behavior through Safety Culture*

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Abstract

Purpose – This study aims to examine the relationships between the acceptance of the 4th industrial revolution logistics technology, logistics safety behavior, and logistics safety performance, as well as the moderated mediating effects of logistics safety behavior through safety culture in Korea.

Design/methodology – Research models and hypotheses were established based on prior research related to the 4th industrial revolution logistics technology, logistics safety, and logistics performance. The survey was conducted on the employees of logistics companies, and reliability analysis, confirmatory factor analysis, discriminant validity analysis, structural equation model analysis, and mediating effect analysis were performed. In addition, the moderated mediating effect analysis applying SPSS Process Model No. 7 was conducted.

Findings – Usefulness and sociality of the acceptance of the 4th industrial revolution logistics technology had a significant effect on logistics safety behavior. Ease of use, sociality, and efficiency had meaningful effect on logistics safety performance. And in the relationships between the acceptance of logistics technology and logistics safety performance, logistics safety behavior had a significant mediating effect. But the moderated mediating effect of safety behavior through safety culture was not significant. Logistics companies can improve logistics safety performance through the utilization of new logistics technologies such as intelligent logistics robots, autonomous driving technology, and artificial intelligence, etc.

Originality/value – This is the first study to analyze the relationships between the acceptance of logistics technology in the 4th industrial revolution and logistics safety. In addition, previous studies analyzed mediating effects or moderating effects, but this is the first study to identify the moderated mediating effects of safety behavior through safety culture. In other words, it has originality in terms of research methodology.

Keywords: Logistics Safety, Logistics Safety Behavior, Logistics Safety Performance, Logistics Technology, Safety Culture, The Fourth Industrial Revolution

JEL Classifications: C12, J28, L87, L91, M15

1. Introduction

According to an announcement by the Korea Occupational Safety and Health Agency (2020), there were a total of 6,173 people injured in 2019 (a 16.7% increase compared to 2018)

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and 4,219 accidents filed in the field related to transportation, warehouse, and communications including the logistics industry. The deaths that resulted from disasters were 153 people, and the logistics industry was ranked fourth after construction, manufacturing, and mining industries for frequency of safety accidents. Traffic accidents are the most common types of accidents, and also includes falls, bumps, and jams.

Logistics is an industrial field where it is not possible to be free from safety accidents. Whenever accidents such as freight car traffic accidents, fires in logistics centers, or casualty accidents are covered by the media, the public's perception of the logistics industry becomes more negative. Although the logistics industry plays an important role in the Korean economy, safety accidents have negatively affected logistics as an industry or occupation. In the logistics sector, the safety accidents such as personal and material damages due to traffic accidents during transportation, fires in logistics centers, disasters of workers, and forklift overturn accidents occur continuously. Until recently, fire accidents and traffic accidents have continued, which cannot be determined to occur only at certain companies. These are safety issues that most logistics companies face, and it can be said to be a potential problem that may occur at any time.

With the spread of the 4th industrial revolution, the demand for smart logistics technology in the logistics field is increasing. The new logistics technology is the application of the 4th industrial revolution technology, and IoT, blockchain, AI, intelligent robots, autonomous vehicles, and big data are first required in the logistics field. Logistics technology of the 4th industrial revolution can have a positive effect on the safety of logistics processes, and the use of smart logistics technology can contribute to improving logistics companies' performance by reducing logistics safety accidents and minimizing human and material losses.

Despite the widespread awareness of the importance and need for logistics safety, logistics safety activities at the logistics sites have not yet been actively carried out. Because additional costs are required to practice or prevent logistics safety, logistics companies are very passive in implementing safety activities while recognizing the necessity. To minimize safety accidents occurring in the logistics process, interest and support for safety, and active practice are required. Thus, it is necessary to take into account that even if human and material inputs for logistics safety are made, the benefits may appear in the long term without being linked to the reduction of logistics safety accidents in the short term.

Safety research is continuously conducted on construction and steel industries, which have frequent industrial accidents and large damage, and is conducted with a psychological approach rather than business administration. Active studies are conducted in areas such as safety motivation, safety knowledge, and safety activities based on analysis of precedents of safety motivation (Zohar, 1980), and safety climate and safety behavior models (Griffin and Neal, 2000). Moreover, because a company's safety culture affects the frequency of occurrence of safety accidents, many companies are making great efforts to establish a safety culture. But, regardless of these efforts, studies that are related to logistics safety are still in the early stages, and safety is only emphasized from a CSR perspective. Recently, empirical researches on logistics safety and performance, logistics safety climate, and logistics safety performance in the transportation sector have begun.

Logistics safety is no longer an option in terms of corporate image or operational performance, but is becoming a necessity for corporate management, and the government is also emphasizing safety priorities. As the 4th industrial revolution technology has been

developed and applied in all industries, it is necessary to improve logistics performance by actively utilizing smart logistics technology as well as interest and support for safety in the logistics industry. In other industries, safety research is being actively conducted, but studies on safety in the field of logistics are only in the preliminary levels, so it is necessary actively to research in this area. Moreover, when new technology was developed, studies applied the technology acceptance model or integrated technology acceptance model have been conducted to identify the acceptance or use intentions.

New logistics technologies such as Internet of Things, self-driving trucks, intelligent logistics robots, big data, and artificial intelligence are being used in various logistics processes, and these logistics technologies are very helpful in preventing safety accidents. In case of using self-driving trucks, it is possible to prevent traffic accidents caused by drowsy driving or speeding. And by using IoT technology, collision accidents between logistics facilities and workers can be prevented, and also, by using intelligent logistics robots, damage to cargo or injuries to workers can be significantly reduced in the process of cargo storage and loading/unloading. As such, logistics technology of the 4th industrial revolution can prevent risks that may arise from logistics activities, so it can be said to be an essential factor for logistics safety. Despite recognizing the importance and necessity of logistics technology in the 4th industrial revolution, research on this has not been actively conducted.

International trade and logistics are directly related. Logistics efficiency directly affects export expansion (Park Hyun-Hee and Cho Sung-Je, 2021), and logistics infrastructure is closely related to international trade (Wang Chao, Kim Yul-Seong and Kim Chi-Yeol, 2021; Wang Chao, Chu Weilong and Kim Chi-Yeol, 2020). It is also confirmed that the logistics performance index has a close relationship with international trade (La Kong-Woo and Song Jin-Gu, 2019). As such, logistics is very important in international trade, and in the end, it can be said that the safety of the logistics process is very important for international trade. Accidents of import/export container transport vehicles, accidents during port loading/unloading, and accidents during storage of import/export cargo can lead not only to direct damage to the cargo subject to the trade contract, but also to breach of contract such as delay in delivery. In other words, if logistics safety is not guaranteed, it can become a potential risk factor for international trade, which has a negative impact on export expansion, so it can be said that efforts for logistics safety in international trade are necessary. Since the improvement of logistics performance through logistics safety provides export and import opportunities to shippers, this study can be said to be very important not only in logistics but also in international trade. Nevertheless, research on logistics safety linking the 4th industrial revolution and logistics technology is also at the beginning stage. This study is essential to improve logistics safety and logistics performance that directly affect the development of international trade.

Therefore, this study aims to analyze the relationship between the acceptance of the logistics technology of the 4th industrial revolution, logistics safety behavior, and logistics performance, and to analyze the moderated mediating effect of logistics safety behavior through safety culture. Additionally, based on the results of the empirical analysis, this study will present strategic implications for logistics companies to improve logistics safety performance by utilizing logistics technology of the 4th industrial revolution.

2. Literature Review

2.1. Logistics Safety

Research on logistics safety was mainly conducted from the perspectives of logistics general, transportation, storage and loading/unloading, and CSR. First, in studies related to the safety of overall logistics, Kim Young-Min (2021a) analyzed the effect of the logistics safety climate on logistics safety behavior and safety performance, and the mediating effect of logistics safety knowledge and safety motivation applying Griffin and Neal's model (2000). It was observed that logistics safety climate had a significant effect on logistics safety knowledge, motivation, and behavior and that logistics safety knowledge and motivation had a positive effect on logistics safety behavior. Additionally, between logistics safety climate and safety performance, it was seen that there were no significant mediating effects for logistics safety knowledge or motivations but had a positive mediating effect on logistics safety behavior. Kim Young-Min and Kim Jin-Hwan (2019) analyzed the relationship between logistics safety culture, safety compliance, and logistics performance, and its mediating effect on corporate image. The results showed that not only did logistics safety culture and safety compliance have a significant effect on the corporate image and logistics performance, but also the corporate image had a partial mediating effect between the logistics safety culture and logistics performance.

Second, in studies related to transportation for logistics safety, Kim Young-Min (2017) investigated the effects of transportation safety activities such as safe transportation practice, transportation safety management, and safe transportation prevention management on corporate image and logistics performance. As a result, it was seen that safe transport practice and safe transport preventive management had a significant effect on corporate image, but did not have a direct significant effect on logistics performance. However, it was confirmed that safe transport practice and safe transport preventive management had a mediating effect on logistics performance through the corporate image. Zohar, Huang, Lee and Robertson (2015) analyzed the relationship between safety climate and safety performance, and the mediating effects of intrinsic and extrinsic motivation for long-distance truckers. It was confirmed that the perception of safety climate had a significant effect on safety behavior. Kim Young-Min (2014) conducted a survey by classifying the perceptions of logistics safety among workers in logistics companies into safe transport practice, driver management, transport vehicle management, and safe transport prevention. The results of the analysis revealed that workers in logistics companies recognized safe transportation practice as the most important safety factor and that logistics safety was important in the order of driver management, safe transportation prevention, and transport vehicle management. Bruning (1989) confirmed that there was a significant relationship between traffic accidents and financial performance on freight car transport companies in the United States.

Third, in a study on logistics safety related to storage and loading/unloading, Shang, Yang and Lu (2011) analyzed the relationship between safety management and the perceived safety performance for container unloading operations. The results revealed that interest in safety and safety motivation had a significant influence on the safety performance and that the supervisor's safety management had a mediating effect on safety performance. Kim Ki-Hong and Chung Byung-Hyun (2020) pointed out that forklift-related accidents in distribution centers frequently occur due to poor visibility and operation mistakes, which in turn negatively affect the image of the company. While emphasizing the importance of safety

education for accident prevention, this study also mentioned that education in these safety matters will be able to raise awareness about accidents and possible prevention for the future. In the study by Lee Jae-Gun and Kang Kyung-Sik (2016), the safety accident prevention and countermeasures, and safety education status analysis were conducted in clothing distribution centers. Choi Hyun-Joon, Moon Sang-Young and Ok Seung-Yong (2015) conducted a comparative study of factor analysis and group-to-group perceptions on safety awareness for distribution center workers. It was verified that safety perception factors such as work environment, safety behavior, work risk, safety knowledge and effort, risk justification, and compromise differ by their own disaster experience, colleague's disaster experience, position, and logistics center size. Concerning other storage and loading/unloading, other researches for fire prevention and safety in distribution warehouses were conducted.

Fourth, in studies related to safety for logistics CSR, Carter and Jennings (2002/2004) analyzed the relationship between CSR in the purchasing, transportation, and storage sectors and job satisfaction, trust, shareholder relations, and financial performance and concluded on the importance of safety. In addition, the study emphasized the need for safety of transportation that requires the safe activity of purchased materials as well as ensuring that suppliers are operating safely in logistics activities related to the purchases. Carter (2005) empirically analyzed the relationship between PSR, supplier performance, organizational learning, and cost reduction in the purchasing sector, and emphasized the importance of safe transportation in the purchasing process to measure PSR, including environmental and human rights as well as safety factors. Moreover, Ciliberti, Pontrandolfo and Scozzi (2008) studied the relationship between organizational work practices, managerial work practices, PSR practices, and sustainable transport practices in logistics CSR. In this study, the assertion on the importance of transportation safety was made, and the causal relationships were empirically analyzed using the indicators of Carter and Jennings (2002).

2.2. The 4th Industrial Revolution and Logistics

Progress on the research of the 4th industrial revolution related to logistics has been quite limited. Kim Young-Min (2020) analyzed the need for logistics 4.0 technology for logistics companies and presented the results that big data, logistics robots, smart packaging, and artificial intelligence are needed first. The results showed that the use of logistics robots had a significant effect on logistics performance (Kim Young-Min, 2021b), and that the need for logistics 4.0 technology had a positive effect on the improvement of logistics management performance (Kim Young-Min and Lee Wong-Dong, 2021).

Bag, Gupta and Luo (2020) analyzed the effects of technical capability, organizational capability, and environmental capability on logistics 4.0 capability and logistics 4.0 capability on firm performance. Also, logistics 4.0 capability had a significant effect on firm performance. The analysis found that technical, organizational, and environmental capabilities had a significant impact on logistics 4.0 capabilities, and those logistics 4.0 capabilities also had a significant impact on firm performance.

Son Jeong-Soo (2019) analyzed the development process of the logistics platform and its performance on corporate competitiveness and also showed that the easy accessibility and trustworthiness of the logistics solutions contributed to the firm's competitiveness. It also emphasized the need to present the future of logistics suitable for the 4th industrial revolution, establish development strategies, expand logistics R&D investment, enhance logistics infrastructure, and actively ease regulations.

Lee Choong-Bae, Noh Jin-Ho and Kim Jeong-Hwan (2017) investigated the perceptions of shippers and logistics companies on the effects of the technologies of the 4th industrial revolution on the efficiency and effectiveness of logistics management. It was revealed that the 4th industrial revolution would have a large impact on transportation, warehouse management, supply chain management, and information and that it would have a higher impact on effectiveness than logistics efficiency. Additionally, in terms of individual technologies, it was observed that technologies such as big data, artificial intelligence, IoT, and robots affected logistics.

Additionally, research related to logistics technology of the 4th industrial revolution includes the trends in the use of logistics technologies based on the 4th industrial revolution (Shin Hyun-Joo, 2020), the impact of blockchain technology on the logistics industry (Seon Hwa and Kim Huyn-Deck, 2019), the competitiveness of the Korean logistics industry in preparation for the 4th industrial revolution (Jung Ha-Eun and Kim Young-Jae, 2017), etc.

2.3. Safety Culture, Safety Behavior and Safety Performance

Although not studied in the context of the logistics industry, major prior studies related to safety culture, safety behavior, and safety performance can be summarized as follows. First, as a prior study related to safety culture, Lim Sung-Jun, Ahn Ji-Yeun, Park Sang-Ah, Moon Ki-Seop and Oah She-Zeen (2017) conducted an exploratory factor analysis on the components of safety culture. It suggested that the safety culture was formed in a bi-factor model structure, and revealed that there were common factors in safety. Juen Kyung-Il, Lee Wang-Gi and Son Ki-Sang (2015) explored the factors that hinder the establishment of a safety culture in the applicability of safety culture practice. It was suggested that various efforts should be made to interact with each other among factors of safety culture, such as the overall approach to society and the revitalization of research on individual safety culture beyond the limitations of companies on safety culture. Oh Young-Min and Jang Keun-Tak (2014) conducted a comparative study on the safety culture evaluation indicators by industry. In high-risk industries, the common elements of six safety cultures such as communication, employee participation, education and training, reward and punishment system, management's interest, and feedback system were presented. It was emphasized that this must be included when measuring safety culture in most organizations and industries. In addition, it was performed such as a literature study of safety culture (Guldenmund, 2000), a measurement of a safety culture based on social cognitive theory and behavior-based theory (Cooper, 2000), the relationship between safety culture and risk management (Pidgeon, 1991), and the relationship between safety management systems and safety culture (McDonald, Corrigan, Daly and Cromiee, 2000), etc.

Second, as a prior study related to safety behavior, the effect of safety consciousness level on safety behavior and the mediating effect of organizational trust, with a focus on the logistics center, were examined (Park Jin-Woong, Lee Jae-Gun, Hwang Dae-Seong, Kim Han-Seong, Kim Young-Gug and Kang Kyung-Sik, 2016). It was shown that the level of safety consciousness had a significant effect on organizational trust and safety behavior, and that organizational trust also had a meaningful effect on the level of safety awareness. Oah She-Zeen, Lee Jae-Hee, Lee Kye-Hoon and Moon Kwang-Su, (2012) analyzed the effect of the behavioral-based safety management program on safety climate and safety behavior. As a result of the analysis, the safety management program was found to have a significant effect on safety behavior and climate, and the effect was confirmed to be especially true in the

transportation industry (Olson and Austin, 2001).

Third, in prior studies related to safety, Lee Suk-Won, Ahn Kwan-Young and Choi Eung-Soon (2017) analyzed the moderating effect of the safety climate in the relationship between transformational leadership and safety performance. Transformative leadership was shown to have a significant impact on safety-related performance, and the safety climate had a partial moderating effect in the relationship. To improve safety-related performance, efforts are needed to spread the safety climate among employees along with transformational leadership education for seniors. Wu, Chen and Li (2008) analyzed the correlation between safety leadership, safety climate, and safety performance. The safety climate between safety leadership and safety performance was revealed to play a partial mediating role, and safety control such as safety commitment of top management and managers, use of safety facilities, and accident investigations was found to have an important influence in safety leadership.

2.4. Technology Acceptance

Research on the acceptance or use of new technologies is being conducted by applying the technology acceptance model, the integrated technology acceptance model, and the extended integrated technology acceptance model. Technology acceptance model (TAM) was developed by Davis (1989) and presented perceived usefulness and perceived ease of use as antecedents to technology acceptance. Integrated technology acceptance model (UTAUT1) was developed to enhance the explanation of technology acceptance by Venkatesh, Morris, Davis and Davis (2003), and performance expectancy, effort expectancy, social influence, and promotion conditions are suggested as antecedents to technology acceptance. Venkatesh, Thong and Xu (2012) developed extended integrated technology acceptance model (UTAUT2) to overcome the limitations that UTAUT1 can explain organizational acceptance, but not accurately explain technology acceptance of general users. In this model, in addition to performance expectancy, effort expectancy, social influence, and promotion conditions as antecedents for general consumer's acceptance of technology, pleasure motivation, price effectiveness, and habits were added. Since then, many studies have been conducted on the intention to accept or use a new technology applying these models, and additionally, new preceding factors have been added to the basic model and analyzed as well.

Although there are many prior studies related to technology acceptance, studies based on logistics technology can be said to be in their early stages. The major prior studies related to this are summarized as follows. Kim Young-Min (2021b) analyzed the relationship between the intention to use a logistics robot and the logistics performance of a logistics company by applying the integrated technology acceptance model. Performance expectancy, social influence, and innovation had a significant effect on the intention to use a logistics robot, and the use of logistics robot affected positively on the logistics performance. Kim Ki-Bong and Jeon In-Oh (2018) analyzed the factors affecting the intentions to use drone technology by applying the expanded integrated technology acceptance model. As a result, it was observed that performance expectancy, social influence, promotion conditions, and pleasure motivation had a significant effect on user intention, but did not significantly impact effort expectancy, price effectiveness, and perceived risk. Kim Sung-Young and Ahn Seung-Bum (2018) analyzed factors affecting the intentions to accept the blockchain system, focusing on logistics companies. Availability, diversity, and economy were found to have a significant influence on acceptance intention through perceived usefulness, but there was no significant mediating effect of perceived ease of use.

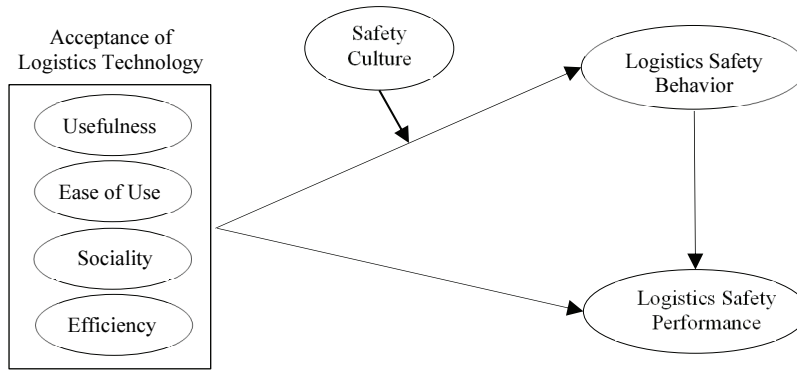
Most of the existing studies are on logistics safety based on transportation, storage and loading/unloading, logistics safety in CSR, and safety behavior models used in psychology. Many logistics companies are expected to help improve the logistics process by utilizing new logistics technologies related to the 4th industrial revolution. It is bringing a lot of convenience in handling logistics tasks while utilizing new logistics technologies that can bring about logistics efficiency. And new logistics technology is expected to contribute to the safety of logistics activities, but verification has not been made. This study differs in research content and methodology in that it empirically verifies the effects of the determinants of the use of new logistics technology that have not been identified in previous studies, on logistics safety behaviors and safety performance, and the mediating effects of safety behaviors moderated by safety culture.

3. Research Model and Hypothesis

3.1. Research Model

As the 4th industrial revolution had a significant impact on the entire industry, related technologies have already begun to be applied to logistics. This study attempted to empirically analyze the relationship between the acceptance of the 4th industrial revolution logistics technology (usefulness, ease of use, sociality, and efficiency), logistics safety culture, logistics safety behavior, and logistics safety performance. However, no research has been conducted to verify this relationship for logistics. There were only partial studies conducted on the relationship between the effectiveness and efficiency of the 4th industrial revolution technology and logistics management (Kim Young-Min, 2020/2021b; Lee Choong-Bae et al., 2017), the relationship between the capabilities of logistics 4.0 and corporate performance (Bag et al., 2020), the adaptation of blockchain (Kim Sung-Young and Ahn Seung-Bum, 2018), industrial and logistics safety and the relationship between performances (Griffin and Neal, 2000; Kim Young-Min, 2020; Kim Young-Min and Kim Jin-Hwan, 2019; Wu et al., 2008; Zohar et al., 2015), and the acceptance or use of new technology (Davis, 1989; Venkatesh et al., 2003/2012). Therefore, by applying extensive prior research related to the 4th industrial revolution logistics technology, logistics safety, safety culture and safety behavior, and technology acceptance, the following research model was established.

Fig. 1. Research Model



3.2. Research Hypothesis

In general, the intention to accept or use the logistics technology and new technology of the 4th industrial revolution can be explained through the technology acceptance model (perceived usefulness and perceived ease of use, self-efficiency) and the integrated technology acceptance model (performance expectancy, effort expectancy, social influence, and innovation) (Davis, 1989; Venkatesh et al., 2003/2012). In addition, safety behavior is affected by the safety climate, safety culture, safety motivation, safety knowledge, and safety leadership (Griffin and Neal, 2000; Kim Young-Min, 2020; Wu et al., 2008; Zohar et al., 2015). There are no prior studies that directly identified the relationship between the acceptance of logistics technology of the 4th industrial revolution and logistics safety behavior. But based on previous studies related, the following hypotheses were established to examine usefulness, ease of use, sociality and efficiency of new logistics technology on logistics safety behavior.

H1: Acceptance of the 4th industrial revolution logistics technology will have a positive effect on logistics safety behavior.
H1-1: Usefulness of acceptance of the 4th industrial revolution logistics technology will have a positive effect on logistics safety behavior.
H1-2: Ease of acceptance of the 4th Industrial Revolution logistics technology will have a positive effect on logistics safety behavior.
H1-3: Sociality of acceptance of the 4th industrial revolution logistics technology will have a positive effect on logistics safety behavior.
H1-4: Efficiency of accepting the 4th industrial revolution logistics technology will have a positive effect on logistics safety behavior.

Safety performance is directly affected by the safety climate, safety leadership, safety behavior, and safety culture (Griffin and Neal, 2000; Wu et al., 2008; Zohar et al., 2015). And the logistics safety performance is impacted by logistics safety behavior, the practice of safe transportation and preventive management (Kim Young-Min, 2017/2020; Zohar et al., 2015). If the use of new logistics technology has a positive effect on logistics safety performance, to confirm the effect of usefulness, ease of use, sociality, and efficiency of logistics technology on logistics safety performance as well as the relationship between logistics safety behavior and logistics safety performance, the following hypotheses were established.

H2: Acceptance of the 4th industrial revolution logistics technology will have a positive effect on the logistics safety performance.
H2-1: Usefulness of the acceptance of the 4th industrial revolution logistics technology will have a positive effect on the logistics safety performance.
H2-2: Ease of acceptance of the 4th industrial revolution logistics technology will have a positive effect on the logistics safety performance.
H2-3: Sociality of acceptance of the 4th industrial revolution logistics technology will have a positive effect on the logistics safety performance.
H2-4: Efficiency of accepting the 4th industrial revolution logistics technology will have a positive effect on the logistics safety performance.

H3: Logistics safety behavior will have a positive effect on logistics safety performance.

Safety performance is directly affected by the safety climate, safety culture, and safety behavior, but it is also indirectly influenced by safety behavior and corporate image, etc. Based on the mediating effect of logistics safety behavior (Kim Young-Min, 2020; Zohar et al., 2015) and the mediating effect of corporate image (Kim Young-Min and Kim Jin-Hwan, 2019), the following hypotheses were established to examine the mediating effects of logistics safety behavior concerning usefulness, ease of use, sociality, and efficiency of logistics technology and logistics safety performance.

H4: Acceptance of the 4th industrial revolution logistics technology will have a positive effect on the logistics safety performance through logistics safety behavior.
H4-1: Usefulness of the acceptance of the 4th industrial revolution logistics technology will have a positive effect on the logistics safety performance through logistics safety behavior.
H4-2: Ease of acceptance of the 4th industrial revolution logistics technology will have a positive effect on the logistics safety performance through logistics safety behavior.
H4-3: Sociality of acceptance of the 4th industrial revolution logistics technology will have a positive effect on the logistics safety performance through logistics safety behavior.
H4-4: Efficiency of acceptance of the 4th industrial revolution logistics technology will have a positive effect on the logistics safety performance through logistics safety behavior.

As described above, it has been confirmed that safety culture influences safety behavior and safety performance. Additionally, logistics safety climate or safety culture directly affects logistics safety performance and indirectly affects through corporate images. Although safety culture has a significant impact on safety behavior or safety performance, the impact on safety performance through safety culture has not been confirmed. The moderated mediating effect of safety culture has not been verified in the logistics field as well as other industries, so it is necessary to confirm these. Therefore, to verify the moderated mediating effect of safety culture in the relationship between the acceptance of the 4th industrial revolution logistics technology and logistics safety performance, the following hypotheses were established.

H5: Acceptance of the 4th industrial revolution logistics technology will have a positive effect on the logistics safety performance by the moderated mediation of logistics safety behavior through safety culture.
H5-1: Usefulness of the acceptance of the 4th industrial revolution logistics technology will have a positive effect on the logistics safety performance by the moderated mediation of logistics safety behavior through safety culture.
H5-2: Ease of acceptance of the 4th industrial revolution logistics technology will have a positive effect on the logistics safety performance by the moderated mediation of logistics safety behavior through safety culture.
H5-3: Sociality of acceptance of the 4th industrial revolution logistics technology will have a positive effect on the logistics safety performance by the moderated mediation of logistics safety behavior through safety culture.
H5-4: Efficiency of acceptance of the 4th industrial revolution logistics technology will have a positive effect on the logistics safety performance by the moderated mediation of logistics safety behavior through safety culture.

3.3. Composition of the Questionnaire

The questionnaire was developed based on previous studies related to logistics safety and technology acceptance theory to analyze the relationship between the acceptance of the 4th industrial revolution logistics technology, safety culture, logistics safety behavior and logistics safety performance, and the mediating effects of logistics safety behavior and the moderated mediating effects of logistics safety behavior through safety culture.

The acceptance of the 4th industrial revolution logistics technology was subdivided into the categories of usefulness, ease of use, sociality, and efficiency. Questionnaires to measure these factors were developed based on the model related to the acceptance or usage intention of new technology (Davis, 1989; Venkatesh et al., 2003/2012). The safety culture and safety behavior were based on the studies of Griffin and Neal (2000) and Wu et al. (2008), and logistics safety behavior and safety performance were based on the studies by Kim Young-Min (2017/2020), Kim Young-Min and Kim Jin-Hwan (2019).

Logistics technology of the 4th industrial revolution refers to logistics 4.0 technologies such as artificial intelligence, blockchain, Internet of Things, self-driving trucks, intelligent robots, drones, and big data that can be used in logistics processes (Kim Young-Min, 2020).

Usefulness referred to the degree to which logistics work was usefully handled using logistics technology of the 4th industrial revolution, was measured by 5 items including the effective implementation of logistics work through the 4th industrial revolution technology. Ease of use meant the degree to which logistics work was easily handled using logistics technology of the 4th industrial revolution, consisted of 5 measurements including convenient handling of logistics tasks by applying the 4th industrial revolution technology. Sociality was the degree to which colleagues or trading partners around them believed that they should use logistics technology for the 4th industrial revolution, included 5 items such as the use of 4th industrial revolution logistics technology by other colleagues in the company. And efficiency referred to the degree of confidence in handling logistics using logistics technology of the 4th industrial revolution, and category was measured by 5 questions such as confidence in effective work processing using the 4th industrial revolution logistics technology. The safety culture meant the degree of climate of a company that emphasized logistics safety, was measured with 4 items including emphasis on company's logistics safety regulations. Logistics safety behavior was the degree to which logistics work was executed (processed) in a safe way, 5 questions were included conducting out safely logistics tasks. Logistics performance referred to the degree of improvement in efficiency and productivity of logistics companies, and consisted of four questions including improvement in logistics services.

The questionnaire was surveyed on a 5-point Likert scale, with 1 being “no effect”, 3 being “somewhat have an effect”, and 5 being “strongly affected”, meaning that the higher the score, the more impact it had.

3.4. Research and Analysis Method

A survey was conducted to confirm the relationship between logistics companies' acceptance of logistics technology of the 4th industrial revolution, safety culture, logistics safety behavior, and logistics safety performance. It was conducted for workers in logistics companies from June 25 to August 20, 2020. A total of 495 responses were collected, and 456 responses were used for the survey analysis, excluding 39 responses be unreliable. The subjects of the survey were logistics companies that signed a consignment education

agreement with the Korea Integrated Logistics Association, and most of the logistics companies were included here. And they were selected by a random sampling method. The survey was sent to the employees of those logistics companies by e-mail and was collected by e-mail.

The collected questionnaires were analyzed using SPSS 26.0 and AMOS 26.0 statistical programs. Descriptive statistical analysis, reliability analysis, confirmatory factor analysis, discriminant validity analysis, and structural equation model analysis were performed. SPSS Process Macro program was used to analyze the mediating effect and the moderated mediating effect (Hayes, 2018).

4. Results of Empirical Analysis

4.1. Demographic Characteristics of Respondents

The demographic characteristics of respondents are shown in Table 1. First, in terms of gender, there were a total of 271 men (59.4%) and 185 women (40.6%). By age range, 30-40 years old had the most participants, with 248 (54.5%), and those under 30 and around 41-50 years old had a total of 95 people (20.8%). When the position titles of the participants were considered, the number of assistant managers was 158 (34.6%), with 119 managers (26.1%),

Table 1. Demographics Characteristics of Respondents

		Frequency	Rate(%)			Frequency	Rate(%)
Gender	Men	271	59.4	Sales Scale	Less than 10 Billion Won	48	10.5
	Women	185	40.6		11~50 Billion Won	66	14.5
Age	30 and younger	95	20.8		51~100 Billion Won	47	10.3
	31~40 years	248	54.5		101~500 Billion Won	111	24.3
	41~50 years	95	20.8		501~1,000 Billion Won	51	11.2
	51 and older	18	3.9		1,001 Billion Won More than	133	29.2
Rank	General Employee	92	20.2	Career	3 years and less	88	19.3
	Assistant Manager/Chief	158	34.6		4~5 years	78	17.1
	Manager/ Team Leader	119	26.1		6~10 years	163	35.8
	General Manager	80	17.5		11 years and more	127	27.8
	Executives	7	1.5				
Number of Employees	300 or fewer	167	36.6				
	301~1,000	102	22.4				
	1,001 More than	187	41.0		Total	456	100.0

92 general employee (20.2%), 80 general manager (17.5%), and 7 executives (1.5%). In terms of the number of employees in the companies, those working in companies with more than 1,001 employees included 187 people (41.0%), and those with less than 300 people in the company were 167 people (36.6%), and those with around 301~1,000 people in the company were 102 people (22.4%). In terms of sales volume, those in companies with over KRW 1,001 billion were the most, with 133 people (29.2%), 111 people (24.3%) working in companies that made under KRW 101~500 billion won, 66 people (14.5%) under KRW 11~50 billion won, 51 people in companies making under 501~1,000 billion won (11.2%), 48 people (10.5%) less than 10 billion won, and 47 people (10.3%) in companies making less than 51~100 billion won. By work experience, there were 163 (35.8%) people with 6~10 years of work experience, 127 people that had worked over 11 years (27.8%), 88 people that had worked under 3 years (19.3%), and 78 people (17.1%) that had worked around 4~5 years.

4.2. Results of Reliability Analysis

There are various methods to confirm the reliability of constructs, but the most commonly used is to verify the reliability through the coefficient of Cronbach's alpha (Nunnally and Bernstein, 1994). As a result of verifying the reliability in this study, it was found that the Cronbach alpha value was between .739 ~ .912 in all factors, exceeding the general standard of 0.7. Accordingly, it was confirmed that the reliability was achieved at a high level.

Table 2. General Statistics and Reliability of Independent Variables

	Constructs mean and standard deviation	**Cronbach's Alpha**
	Usefulness / Mean= 4.323, Std= .481	
USF 1	Perform effectively logistics work	
USF 2	Increase effectiveness of logistics work process	
USF 3	Achieve logistics business goals	.803
USF 4	Provide convenience in performing logistics tasks	
USF 5	Help with logistics operations	
	Ease of use / Mean= 3.896, Std= .721	
EOU 1	Conveniently handling of logistics works	
EOU 2	Conveniently learning how to handle logistics tasks	
EOU 3	Easily learn the contents of logistics business	.784
EOU 4	Easily to apply to logistics without difficulty	
EOU 5	No special effort needed when utilizing logistics work	
	Sociality / Mean= 3.600, Std= .643	
SOC 1	Use of logistics technology by other colleagues in the company	
SOC 2	Use of logistics technology by other partners	
SOC 3	Recommend other companies to use logistics technology	.813
SOC 4	Pride in using new logistics technology	
SOC 5	Discuss the use of logistics technology with colleagues around you	
	Efficiency / Mean= 3.811, Std= .667	
EFC 1	Confidence in handling logistics tasks using logistics technology	
EFC 2	Confidence in improving logistics processing skill	
EFC 3	Confidence in understanding logistics operations	.912
EFC 4	Confidence in participating in logistics activities	
EFC 5	Confidence in efficient process of logistics tasks	

The independent variable was subdivided into usefulness, ease of use, sociality, and efficiency. The average values were 4.323, 3.896, 3.600, and 3.811, respectively, and the Cronbach alpha value was identified as usefulness .803, ease of use .784, sociality .813, and efficiency .912. The mean and Cronbach's alpha values of logistics safety culture were 4.451 and .739, logistics safety behavior 4.519 and .811, and logistics safety performance 3.520 and .853, respectively.

Table 3. General Statistics and Reliability of Dependent Variables

	Constructs mean and standard deviation	Cronbach's Alpha
	Logistics safety culture (LSC) / Mean= 4.451, Std= .482	
LSC 1	Emphasis on logistics safety regulations	.739
LSC 2	Discuss safety issues with employees	
LSC 3	Avoid unreasonable work instructions	
LSC 4	Emphasis on safety practice in the logistics site	
	Logistics safety behavior (LSB) / Mean= 4.519, Std= .453	
LSB 1	Work in a safe way	.811
LSB 2	Perform the work according to correct safety procedures	
LSB 3	Use the necessary safety devices	
LSB 4	Work in the safest conditions	
LSB 5	Interested in safety issues	
	Logistics safety performance (LSP) / Mean= 3.520, Std= .793	
LSP 1	Improvement of logistics service	.853
LSP 2	Reduction of logistics cost	
LSP 3	Increasing logistics operating profit	
LSP 4	Expansion of logistics market	

4.3. Results of Confirmatory Factor Analysis

A confirmatory factor analysis was conducted to verify the goodness-of-fit of the model. As a result of analyzing the goodness-of-fit of the initial model, it was confirmed that χ^2 = 1179.853 (p=.000), df = 474, GFI = .862, CFI = .895, TLI = .883, and RMSEA = .057. The test result of χ^2 was not satisfactory, and the other goodness-of-fit indexes were also not good, so the model was re-estimated. The re-estimation of the model was estimated considering the significance of the modification indices and factor loading.

In that process, two constructs such as EOU 1 and EOU 5 were removed for ease of use as they were judged to impair the fit. Thereafter, as a result of re-estimating the model, the goodness-of-fit index was calculated such as χ^2=750.928(p=.000), df=410, GFI=.905, CFI=.946, TLI=.939, RMSEA=.043 in the final model. Since the complementary fitness index was at a very good level, this study model could be considered to be appropriate. Accordingly, the convergent validity and discriminant validity of the construct was verified using this model.

Convergent validity was determined based on the significance of the factor loading of each construct. In other words, if the factor loading of each construct is 0.5 or more and significant, it can be considered that convergent validity is established. However, as complementary, the construct reliability (C.R) and average variance extracted (AVE) were considered together (Anderson and Gerbing, 1988). When the factor loading for a specific factor is significant

(t>1.96), the loading is higher than 0.5, and the C.R value is 0.7 or higher, and the AVE value is 0.5 or higher, the convergent validity of the constructs is significant. As a result of the analysis, the loading of the constructs in all was 0.5 or more, and all were found to be significant at a significance level of 1%, confirming that convergent validity is well established. All of the C.R is also above the standard 0.7. However, there are constructs where AVE is not more than 0.5, but all are approximating to 0.5, and all individual items have a value of 0.5 or more so they are significant, and C.R value is also above the standard, confirming the establishment of the convergent validity of this construct.

Table 4. Results of Confirmatory Factor Analysis

Constructs		Non-standardized estimates	Standardized estimates	t-value	C. R	AVE
Usefulness	USF 1	1.000	.754	-	.792	.437
	USF 2	.987***	.771	14.045		
	USF 3	1.012***	.656	12.441		
	USF 4	.722***	.535	10.203		
	USF 5	.790***	.554	10.570		
Ease of use	EOU 2	1.000	.895	-	.849	.658
	EOU 3	1.028***	.898	20.412		
	EOU 4	.684***	.605	13.798		
Sociality	SOC 1	1.000	.714	-	.811	.472
	SOC 2	1.127***	.806	15.085		
	SOC 3	1.169***	.809	15.117		
	SOC 4	.853***	.531	10.310		
	SOC 5	.718***	.512	9.935		
Efficiency	EFC 1	1.000	.833	-	.912	.675
	EFC 2	.972***	.845	21.547		
	EFC 3	1.000***	.807	20.151		
	EFC 4	.966***	.806	20.089		
	EFC 5	.998***	.817	20.515		
Logistics safety culture	LSC 1	1.000	.607	-	.741	.418
	LSC 2	1.008***	.633	9.946		
	LSC 3	1.033***	.619	9.807		
	LSC 4	1.178***	.721	10.689		
Logistics safety behavior	LSB 1	1.000	.822	-	.810	.469
	LSB 2	1.051***	.823	17.672		
	LSB 3	.742***	.661	14.145		
	LSB 4	.798***	.547	11.388		
	LSB 5	.665***	.506	10.433		
Logistics safety performance	LSP 1	1.000	.642	-	.854	.598
	LSP 2	1.491***	.822	14.187		
	LSP 3	1.563***	.891	14.694		
	LSP 4	1.199***	.713	12.777		

4.4. Results of Discriminant Validity Analysis

As the convergent validity was identified, the discriminant validity was then verified. This study examined whether or not the discriminant validity of the constructs is confirmed by the method proposed by Fornell and Lacker (1981). This is the most stringent way to verify discriminant validity, and the square of the AVE of a variable should be above the correlation coefficient of that variable.

Correlation analysis shows that sociality and efficiency have the highest level of correlation among independent variables. The correlation coefficient of sociality and efficiency is .486, and the square of AVE, sociality, and efficiency, is .687 and .821, respectively. Therefore, both values are considered to have discriminant validity because that exceeds the values of the correlation coefficient of sociality and efficiency. This study analyzed for discriminant validity as mentioned above, and it was confirmed that discriminant validity was significant between all constructs. Therefore, it was confirmed that the reliability, convergent validity, and discriminant validity of this model were all significant.

Table 5. Results of Discriminant Validity Analysis

Constructs	1	2	3	4	5	6	7
Usefulness	.661						
Ease of use	.304**	.811					
Sociality	.380**	.363**	.687				
Efficiency	.325**	.295**	.486**	.821			
LSC	.235**	.167**	.179**	.216**	.646		
LSB	.253**	.104*	.228**	.204**	.496**	.685	
LSP	.076	.199**	.254**	.237**	.191**	.194**	.773

Note: 1. **p< .01, *p< .05
2. The diagonal shaded area represents the value of each construct.

4.5. Verification of Research Hypothesis

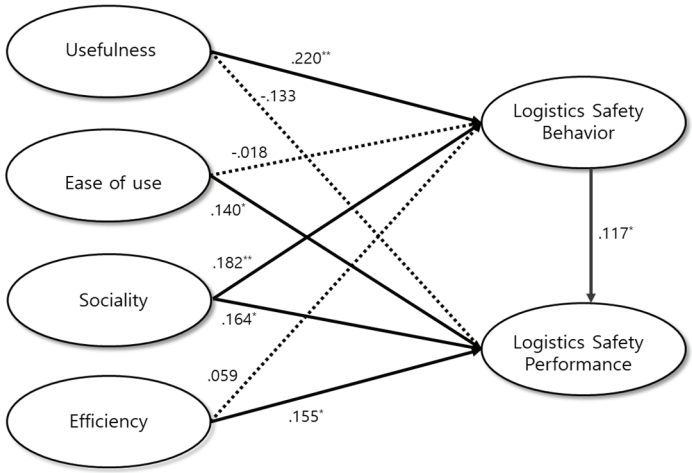
4.5.1. The relationship between acceptance of the logistics technology, logistics safety behavior, and performance

This study tried to verify the effect of the 4th industrial revolution logistics technology acceptance (usefulness, ease of use, sociality, and efficiency) on logistics safety behavior and logistics safety performance, and the moderated effect of safety culture as well as the mediating effect of logistics safety behavior. Structural equation model analysis was conducted, the model fit for path analysis was shown to be χ^2=5936.553 (p=.000), df=306, GFI=.913, CFI=.950, TLI=.943, RMSEA=.045.

As a result of confirming the relationship between the acceptance of the 4th industrial revolution logistics technology (usefulness, ease of use, sociality and efficiency) and logistics safety behavior, usefulness (standardized coefficients β= .220, t=3.413, p<.01) and sociality (standardized coefficients β=.182, t=2.689, p<.01) had a significantly positive (+) effect on logistics safety behavior. But ease of use (standardized coefficients β= -.018, t= -.316, p>. 1) and efficiency (standardized coefficients β=.059, t=.957, p>.1) did not have a meaningful effect. Therefore, Hypothesis 1-1 and Hypothesis 1-3 were supported, but Hypothesis 1-2 and Hypothesis 1-4 were not. No research has been conducted to empirically identify the

relationship between acceptance of logistics technology and logistics safety behavior. Similar studies have shown that usefulness, sociability (social impact), and efficiency have a significant effect on the acceptance or use of new technologies (Kim Seung-Young and Ahn Seung-Bum, 2018; Pak Ki-Hun and Kim Young-Min, 2013; Venkatesh et al., 2003/2012; Davis, 1989). The result that ease of use has a significant impact on logistics safety behavior is the same as Pak Ki-Hun and Kim Young-Min (2013), but contrary to Kim Sung-young and Ahn Seung-Beom (2018). For logistics companies to use the 4th industrial revolution logistics technology to improve the level of logistics safety behavior, they must actively consider the usefulness, ease of use, sociality, and efficiency of logistics technologies.

Fig. 2. Results of Path Analysis



And the relationship between the acceptance of the 4th industrial revolution logistics technology (usefulness, ease of use, sociality, and efficiency) and logistics safety performance showed that ease of use (standardized coefficients β=.140, t=2.447, p<.05), sociality (standardized coefficients β=.164, t=2.419, p<.05) and efficiency (standardized coefficients β= .155, t=2.516, p<.05) had a significantly positive (+) effect on logistics safety performance. Usefulness (standardized coefficients β= -.133, t=-2.059, p<.05) was shown to be statistically significant but had a negative (-) effect. Therefore, Hypothesis 2-2, Hypothesis 2-3, and Hypothesis 2-4 were supported, but Hypothesis 2-1 was not. Although prior studies have not been empirically identified the relationship between the acceptance of new logistics technology and logistics safety performance, the results shown are similar in that logistics 4.0 capability had a significant effect on corporate performance (Bag et al., 2020) and the 4th industrial revolution logistics technologies such as big data, robots, and artificial intelligence can increase the effectiveness and efficiency of logistics management (Lee et al., 2017). When the logistics company introduces the 4th industrial revolution logistics technology, it should be able to have a positive effect on the improvement of logistics safety performance in consideration of ease of use, sociality, and efficiency.

Also, as a result of confirming the relationship between logistics safety behavior and logistics safety performance, it was found that logistics safety behavior had a significant

positive effect on logistics safety performance (standardized coefficients β= .117, t= 2.056), p<.05). In other words, it could be observed that the higher the logistics safety behavior, the higher the logistics safety performance, so hypothesis 3 was supported. It was seen that safety culture, safety compliance, safety leadership, and safety climate affect safety performance (Alwahaishi and Snasel, 2013; Wu et al., 2008; Griffin and Neal, 2000), and safety behavior, safety compliance, safety practice, and prevention in the field of logistics have a significant effect on the logistics safety performance (Kim Young-Min, 2017/2020; Kim Young-Min and Kim Jin-Hwan, 2019; Zohar et al., 2015), which were same to the results in previous studies. In the end, the logistics companies will be able to secure logistics safety behavior by introducing the 4th industrial revolution logistics technology, and ultimately, they will be able to bring about logistics safety performance such as reduction of logistics costs and improvement of logistics services.

4.5.2. Mediating effect of logistics safety behavior

The other purpose of this study was to confirm whether logistics safety behavior plays a mediating role between the acceptance of the 4th industrial revolution logistics technology (usefulness, ease of use, sociality, and efficacy) and logistics safety performance. Generally, Sobel Test is used to estimate mediated effects, but bootstrapping is widely used for more accurate analysis. Thus, the mediating effect of logistics safety behavior was also estimated using the bootstrapping method, as presented in the SPSS Process program.

Because logistics safety behavior does not contain '0' in the confidence interval in all mediating paths, it can be said that the mediating effect is significant. In other words, the logistics safety behavior plays a mediating role in the influence all paths of the acceptance of the 4th industrial revolution logistics technology (usefulness, ease of use, sociality, and efficiency) on the logistics safety performance. The acceptance of logistics technology of the 4th industrial revolution is confirmed to play a meaningful mediated role by increasing the level of logistics safety behavior and improving logistics safety performance through this. Therefore, hypothesis 4-1, hypothesis 4-2, hypothesis 4-3, and hypothesis 4-4 that the acceptance of the 4th industrial revolution of logistics technology has a significant positive mediating effect on logistics safety performance through logistics safety behavior were all supported. Although usefulness had no direct effect on logistics safety performance, it was found that it had an indirect effect through logistics safety behavior. This was found to be in line with a previous study that showed a significant effect on the improvement of safety performance and reduction of safety accidents through logistics safety behavior (Kim Young-Min, 2021b; Zohar et al, 2015). Therefore, to improve logistics safety performance, logistics companies need to actively induce logistics safety behavior through usefulness, ease of use, sociality, and efficiency of new logistics technologies.

Table 6. Results of Mediating Effect Analysis

Hypothesis	Mediating effect path	Indirect effect	S.E	LLCI	ULCI
H 4-1	Usefulness → LSB → LSP	.0711	.0232	.0099	.0548
H 4-2	Ease of use → LSB → LSP	.0298	.0115	.0099	.0548
H 4-3	Sociality → LSB → LSP	.0332	.0133	.0113	.0625
H 4-4	Efficiency → LSB → LSP	.0369	.0140	.0128	.0670

4.5.3. Moderated Mediating effect of safety culture

Now, it was intended to verify that the acceptance of logistics technology (usefulness, ease of use, sociality, and efficiency) was significantly affected by the moderated variables of safety culture. Hayes' SPSS Process Model No. 7 was applied to analyze the moderated mediating effects of safety culture.

Usefulness does not contain a value of '0' within the confidence interval (Boot LLCI~Boot ULCI), so the moderated mediating effect of logistics safety behavior through safety culture is significant but has a negative (-) effect. Therefore, hypothesis 5-1 was not supported. In addition, the moderated mediating effects of logistics safety behavior through safety culture were analyzed for ease of use, sociality, and efficiency. As a result, it was found that there was no moderated mediating effect because all contained a value of '0' within the confidence interval (Boot LLCI~Boot ULCI). Therefore, hypotheses 5-2, 5-3, 5-4 were not supported. The relationship between the acceptance of the 4th industrial revolution logistics technology, logistics safety behavior, and logistics safety performance, all showed that the moderated mediating effect of safety culture was not significant. Prior studies have not verified the moderated mediating effects of safety culture. In this study, the effects were intended to be verified, but the results were found to be insignificant. These results demonstrate that the safety culture, directly and indirectly, has a significant effect on the safety performance, but does not have the moderated mediating effect. In other words, a logistics company's safety culture can be a prerequisite for logistics safety behavior or logistics safety performance, but it does not have a meaningful effect as a moderated variable. It is necessary to establish a logistics safety culture that can have a direct effect.

Table 7. Result of the Moderated Mediating Effect (Usefulness)

	Logistics safety behavior (M)			**Logistics safety performance (Y)**		
	Coeff.	**p-value**	**95% CI**	**Coeff.**	**p-value**	**95% CI**
Usefulness (X)	1.276	p<.001	.622, 1.931	.046	p> .1	-.107, .200
LSB (M)				.326	p<.001	.162, .490
LSC (W)	1.541	p<.001	.906, 2.177			
X*W	-.258	p<.001	-.405, -.111			
Constant	-2.879	p<.05	-5.689, -.069	1.844	p<.001	.980, 2.708
	R^2=.285			R^2=.038		
	F(3, 452)=60.04, p<.001			F(2, 453)=9.03, p<.001		
Mediator	**Index**		**SE(Boot)**	**Boot LLCI**		**Boot ULCI**
LSC	-.0843		.0296	-.1475		-.0324

Table 8. Result of the Moderated Mediating Effect (Ease of Use)

	Logistics safety behavior (M)			**Logistics safety performance (Y)**		
	Coeff.	**p-value**	**95% CI**	**Coeff.**	**p-value**	**95% CI**
Ease of use(X)	-.254	p>.1	.622, 1.931	.199	p<.001	.100, .297
LSB (M)				.306	p<.001	.149, .462
LSC (W)	.239	p>.1	-.166, .644			
X*W	.059	p>.1	-.405, -.111			
Constant	3.406	p<.01	-.046, .165	1.362	p<.001	.589, 2.133
	R^2=.248			R^2=.070		
	F(3, 452)=49.89, p<.001			F(2, 453)=17.05, p<.001		
Mediator	**Index**		**SE(Boot)**	**Boot LLCI**		**Boot ULCI**
LSC	.0183		.0188	-.0156		.0591

Table 9. Result of the Moderated Mediating Effect (Sociality)

	Logistics safety behavior (M)			Logistics safety performance (Y)		
	Coeff.	**p-value**	**95% CI**	**Coeff.**	**p-value**	**95% CI**
Sociability (X)	.131	p> 0.1	-.419, .681	.272	p<.001	.160, .384
LSB (M)				.250	p<.01	.092, .409
LSC (W)	.466	p<.05	.030, .901			
X*W	-.006	p> 0.1	-.128, .115			
Constant	2.079	p<.05	.122, 4.035	1.405	p<.001	.663, 2.146
	R^2=.266			R^2=.084		
	F(3, 452)=54.66, p<.001			F(2, 453)=20.77, p<.001		
Mediator	**Index**		**SE (Boot)**	**Boot LLCI**		**Boot ULCI**
LSC	-.002		.0170	-.0361		.0333

Table 10. Result of the Moderated Mediating Effect (Efficiency)

	Logistics safety behavior (M)			Logistics safety performance (Y)		
	Coeff.	**p-value**	**95% CI**	**Coeff.**	**p-value**	**95% CI**
Efficacy (X)	-.035	p> 0.1	-.556, .485	.244	p<.001	.136, .352
LSB (M)				.265	p<.01	.107, .423
LSC (W)	.361	p> 0.1	-.062, .786			
X*W	.023	p> 0.1	-.062, .786			
Constant	2.648	p<.01	.737, 4.558	1.389	p<.001	.638, 2.141
	R^2=.256			R^2=.078		
	F(3, 452)=51.95, p<.001			F(2, 453)=19.20, p<.001		
Mediator	**Index**		**SE(Boot)**	**Boot LLCI**		**Boot ULCI**
LSC	.0062		.0228	-.0363		.0587

5. Conclusion

The 4th industrial revolution has had a great impact on all industries, and many companies are introducing various technologies. Even in the field of logistics, various technologies such as artificial intelligence, intelligent robots, autonomous vehicles, and blockchain have been developed and are starting to be applied. Adopting these technologies into the logistics process, it has a positive impact on safety activities, and eventually contributes to improving logistics performance. The purpose of this study was to empirically analyze the relationship between the acceptance of logistics technology of the 4th industrial revolution, safety culture, logistics safety behavior, and logistics safety performance, the mediating effect of logistics safety behavior, and the moderated mediating effect of safety culture.

As a result, it was shown that the usefulness and sociality of the 4th industrial revolution logistics technology had a significant effect on logistics safety behavior. Ease of use, sociality, and efficiency had a significant effect on the logistics safety performance, and the logistics safety behavior had a significant effect on logistics safety performance. Additionally, it was found that the mediating effects of logistics safety behavior were all significant in the relationship between the acceptance of logistics technology (usefulness, ease of use, sociality, and efficiency) and logistics safety performance. However, it was observed that all of the moderated mediating effects of safety culture were not significant.

Based on the results of the empirical analysis, the following implications for logistics

companies to improve logistics safety performance by utilizing new logistics technologies can be proposed. First, logistics companies need to induce logistics safety behavior by utilizing the new logistics technologies. When intelligent logistics robots, packaging collaboration robots, automatic picking robots, and unmanned forklifts are utilized in the logistics procedure, not only can safety accidents be reduced, but also the safety of workers can be improved, which can have a positive effect on logistics safety behavior.

Second, logistics companies need to improve logistics safety performances by utilizing the new logistics technologies. Although a certain investment is required to introduce the new technology, it will be able to bring about results such as reduction of logistics cost and improvement of logistics service in the long term.

Third, logistics companies need to improve logistics safety performance by inducing logistics safety behavior. Not only can the logistics performance be improved directly by utilizing the new logistics technologies, but it can also bring an indirect effect of improving logistics performance by ensuring safety behavior. In particular, as the direct and indirect effects of safety behaviors have been confirmed in the relationship between acceptance of logistics technology and logistics safety performance, new logistics technologies can be actively utilized to improve logistics performance, which is the ultimate goal of logistics companies.

Fourth, logistics companies need to improve logistics safety behavior and logistics safety performance through the establishment of a safety culture. Although the effect of safety culture was not identified in this study, it is clear that it plays an important role in improving safety performance. Therefore, it is necessary to establish a safety culture at the company-wide level of logistics companies. In particular, if the level of safety culture is improved through the introduction of the new logistics technologies, it will bring more results in the future.

Fifth, logistics companies should ensure logistics safety by introducing new logistics technology to promote active trade expansion of exporters. In the event of a logistics safety accident, collapse of the supply chain leads to a breach of contract, which can hinder international trade. Considering the close relationship between international trade and logistics, it is necessary to avoid exposure to the risk of logistics arising from the import and export process.

The contribution of this study can be acknowledged in the aspect that this study is the first to attempt an empirical study to establish safety culture and improve logistics safety behavior and safety performance by utilizing new logistics technology. In particular, it is of academic significance as it is the first study to investigate the relationship between the acceptance of logistics technology of the 4th industrial revolution, safety culture, logistics safety behavior, and logistics safety performance. In addition, there will be practical contributions in terms of suggesting the justification for the introduction of new logistics technology by verifying the relationship between logistics safety and performance through new logistics technology and ultimately suggesting that it is linked to the performance of exporting companies.

However, since the 4th industrial revolution logistics technology is still in its early stages, the results are not clear. In other words, this study has a limitation in that it can be limited to the perceived performance of employees of logistics companies, and not on the actual performance. Moreover, since the moderated mediating effect of safety culture has not been accurately identified, it is necessary to specifically confirm the role or importance of safety culture in logistics companies. In addition, the results may differ depending on the business

type of logistics company such as transportation, storage and loading/unloading, and forwarding, but there are limitations in that they cannot be reflected. In future studies, it is necessary to verify in-depth the effectiveness of the new logistics technology for logistics companies that directly use the 4th industrial revolution logistics technology in the logistics process.

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Comparative Study of the Requirements for the Buyer's Right to Require Delivery of Substitute Goods under the CISG and the Korean Civil Act

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Abstract

Purpose – This study aims to compare the requirements under the United Nations Convention on Contract for the International Sales of Goods (CISG) and the Korean Civil Act (KCA) regarding the buyer's right to require the delivery of substitute goods. The buyer's right to demand substitute delivery not only protect them from the seller's breach of contract but also preserves the contractual bond between the parties by providing an opportunity for sellers to protect their goodwill and circumvent the extreme remedy of avoidance. However, as substitute delivery entails additional efforts and costs for return and re-shipment, this right should not be allowed in every case of defect. Additionally, unlike the CISG, the KCA contains no specific provision related to the requirements for claiming substitute delivery. Therefore, it would be meaningful to examine and compare what requirements should be fulfilled before the buyer exercises the right in relation to non-conforming goods under the CISG and the KCA.

Design/methodology – We conducted a comparative study of the requirements under the CISG and the KCA regarding the buyer's right to require delivery of substitute goods given a seller's delivery of non-conforming goods. Additionally, we referred to the opinions from the CISG Advisory Council, the draft of the KCA amendment, and related precedents, mainly focusing on the existence and severity of defects, reasonableness, and timely notice and requests as the major requirements for substitute delivery.

Findings – The results of this study can be summarized as follows: First, the CISG provides more detailed requirements about the right to require delivery of substitute goods; by contrast, the KCA does not stipulate any such requirement. Thus, specific requirements for substitute delivery should be included when amending the KCA. Second, the CISG attempts to minimize overlapping and conflict with other remedies by specifying detailed requirements for the delivery of substitutes. Third, both the CISG and KCA require reasonableness for substitute delivery.

Originality/value – Although there are no explicit legal requirements for substitute delivery under the KCA, there has been relatively little discussion of this issue to date. Therefore, the findings of our study can guide future revisions of the KCA to fill this loophole. Moreover, the recently released CISG Advisory Council opinion that clarifies the continuing confusion and debate, can help distinguish which remedy is suitable for a particular case. It may provide practical advice for businesspeople in international trade as well as legal implications for the future development of the KCA.

Keywords: Breach of Contract, CISG, Korean Civil Act, Right to Require Delivery of Substitute Goods
JEL Classifications: K12, K40

1. Introduction

The most common type of seller breach of contract in the international sale of goods is the non-conformity of goods. Remedies for the non-conformity of such goods can be applied

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based on the contents of any prior agreement between the parties. If there is no agreement, the provisions of the applicable law prevail. According to Article 46(2) of the United Nations Convention on Contracts for the International Sale of Goods (CISG), in the event of the delivery of non-conforming goods, the buyer may require delivery of substitute goods as a remedy. The buyer's right to substitute delivery (the "Right") not only protects them from the seller's breach of contract but also preserves the contractual bond between the parties by providing a final opportunity for sellers to protect their goodwill and circumvent the extreme remedy of avoidance (Honold and Flechtner, 2009, 408). This remedy reflects the CISG's legislative principle of contract maintenance, which emphasizes preserving the contract as far as possible (UNCITRAL, 2016, 221).

In international trade, requiring substitute delivery brings about additional efforts and costs in relation to the re-shipment of conforming goods and the return of non-conforming first-delivered goods. Unconditional requests for substitute delivery even in the case of minor defects increase the burden on the seller and can impair their economic efficiency. If defects in delivered goods can be repaired, requesting a repair would save the seller the unnecessary cost of substitute delivery. Additionally, if the buyer can easily purchase substitute goods from the market, it would be better to claim damages for the repurchase. Therefore, the CISG limits the use of the Right by proposing certain requirements, such as a fundamental breach of the contract or timely request.

By contrast, in the case of the Korean Civil Act (KCA), Article 581(2) grants the buyer of generic goods the right to require delivery of substitute goods instead of avoiding contracts or claiming damages. As the seller has a duty to provide goods without defects, substitute delivery of conforming goods could be applied as a remedy in the event of a seller's non-performance. Although the Right only applies to generic goods, it is the only provision that acknowledges the buyer's right to request a cure for any defects in the delivered goods under Korean law.

However, the KCA contains no specific provisions related to the requirements for claiming substitute deliveries. As there is no explicit limitation to the Right, there has been relatively little discussion of this issue to date (Kim Jae-Hyung, 2015; Kang Hye-Lim, 2017). Although some scholars have even disagreed with the idea that the Right should be limited to certain circumstances owing to the lack of specific provisions in the KCA, the majority support the need to limit the Right (Kang Hye-Lim, 2017). The basis for limiting the Right is the principle of good faith or the doctrine of the abuse of rights, both of which are stated in Article 2 of the Code (Kim Jae-Hyung, 2015). If the defect can be eliminated with simple repair, along with the principle of good faith, the buyer's right to claim repair should be exercised first, and the right to request substitute delivery should be allowed only when the seller refuses the repair. In other words, if the seller's cost for substitute delivery is much greater than that of other remedies such as claiming damages, exercising the Right can be considered an abuse of rights and must be limited. In line with this discussion, the Korean Supreme Court has ruled that the Right may be limited in certain circumstances (judgment of 2012 Da72582, May 16, 2014).

If we agree with the opinion that the Right should be limited, we face another question: In which cases should it be restricted? To answer this question, this study examines, in particular, the requirements regarding the right to require delivery of substitute goods under the CISG, as well as related cases and literature. Furthermore, it attempts to compare these requirements to those under the KCA and to identify the legal implications for future revisions of the KCA. As a literature review and comparative study are the main methodolo-

gies of this study, we focused on the CISG, the KCA, the CISG Advisory Council opinion, and the draft KCA amendment as a basis for our research. Major requirements for substitute delivery, such as the existence and severity of defects, reasonableness, and timely notice and request, were examined and evaluated.

We expect the findings of our study to serve as a guide for future revisions of the KCA, which should fill the loophole regarding the right to require substitute delivery. Moreover, a suggestion from the recently released CISG Advisory Council opinion that clarifies the continuing confusion and debate, can help distinguish which remedy is suitable for a particular case. This comparative study may provide practical advice for businesspeople in international trade who are not certain about the right to request substitute delivery and elicit the legal implications for the future development of the KCA.

2. Non-conformity of the Goods

2.1. Existence of Non-conformity on Goods

2.1.1. CISG

The first requirement regarding the buyer's right to require delivery of substitute goods is the existence of non-conformity on goods. The CISG uses a broad and largely unified concept of "non-conformity," which embraces the concept of defect. If the goods do not conform with the contract, the CISG considers it a breach of the contract and grants buyers the right to require suitable remedies. The non-conformity of a delivered good with the contract is judged by considering not only quality, but also quantity, identity, and packaging (Kröll et al., 2018, 487).[1]

The conformity determination in CISG starts from the requirements of the contract, including the characteristics of the goods agreed upon by the parties. As CISG adopts the concept of subjective defect (Schwenzer, 2016, 594), the quality, quantity, and packaging required by the contract are the primary standards for non-conformity. If there are no details or insufficient details regarding the requirements in the contract, to determine the conformity of the goods, the following subsidiary criteria are used: First, the goods must be fit for the purposes for which goods of the same description would ordinarily be used. Second, they must be fit for any particular purpose expressly or implicitly made known to the seller at the time of concluding the contract. Third, they must possess the qualities of goods that have been presented as a sample or model. Fourth, they must be contained and packaged in the usual manner for such goods, or if there is no usage to determine the usual manner, the packaging must be adequate to protect and preserve the goods (CISG Art. 35).

2.1.2. Korean Law

[1] According to CISG Advisory Council opinion, CISG also requires delivery of goods free from any right or claim of a third party based on industrial property or other intellectual property rights. Articles 46(2) and (3) CISG express a general principle in the CISG of balancing both parties' interests in case of a breach of contract by the seller. Delivery of substitute goods not subject to such third-party rights may cure the defective performance. Where the defects can be repaired by fulfillment or termination of the third party right or claim through the seller, it is appropriate to apply Article 46(3) CISG (Bridge et al., 2021, 12).

Under Korean law, the seller is liable when delivering goods that are defective. This sales-specific liability is called the seller's guarantee liability for defective goods and is mainly intended to protect the buyer in the event the latter may not be properly remedied by virtue of the general liability rules (Lee Byung-Mun, 2009, 35). [2] As the seller's guarantee liability comes into play if there is a defect in the object of sales (KCA Art. 580), the buyer could request the delivery of conforming goods when guarantee liability is imposed on the seller (Baek Kyung-Il, 2015). Therefore, the existence of a defect could be a basic requirement for the Right, as under the CISG.

However, unlike the CISG, the KCA fails to define a "defect." As a result, scholars have different views regarding the definition of a defect in Korean law. There are mainly two opposing views: the objective criterion theory and the subjective criterion theory. The difference of these views comes from the conflicting theories regarding the legal nature of the seller's guarantee liability: the legal liability theory and the contractual liability theory. As the disputes about the definition of a defect and the nature of the seller's guarantee liability are closely connected, it is necessary to understand the latter first.

The legal liability theory states that the seller's guarantee liability is especially imposed by the law regardless of the contractual parties' intention. In the case of the specific goods which have an initial defect at the time of contract, the seller's contractual duty must be limited to the delivery of the goods in status quo at the time of contract (Lee, Byung-Mun, 2010, 4). They consider the seller has fulfilled the contractual obligation, though the delivered goods have a defect. Therefore, the legal liability theory insists that the seller's guarantee liability is imposed in order to adjust the imbalance between the defective delivery and the payment.

On the contrary, contractual liability theory insists that there is a contractual duty for the seller to deliver the goods free from defects both in the sales of specific goods and in those of generic goods (Lee, Byung-Mun, 2010, 4). The seller's guarantee liability is imposed based on the contract, namely, the parties' intention, and it is a liability for the breach of the contractual obligation.

Due to different stands toward the legal nature of the seller's guarantee liability, the former supports the objective criterion theory, and the latter supports subjective criterion theory by insisting that parties' intentions should not be disregarded (Lee Byung-Mun, 2001, 100).

The objective criterion theory argues that the specific criteria for defects should be based on the general standards of quality and performance that are normal for goods of the same kind (Kwak Yun-Jik, 2003, 148; Yoon, Gil-Hong, 2015, 214). For example, in the case of a used automobile transaction, a buyer whose hobby is collecting classic cars could purchase an old used car even if the quality of the car does not meet the usual standards because of low power, slow speed, and excessive noise. Although the buyer fully recognized and agreed with the performance and quality of the car, the delivery of that car will be considered a defect from the perspective of the objective criterion theory. In this sense, the existence of defects is objectively judged only by ordinary standards, regardless of the intention of the parties, as indicated by the relevant circumstances in the contract (Lee Byung-Mun, 2001, 83).

By contrast, the subjective criterion theory insists that the primary test for whether the

[2] Korean law imposes on the seller two kinds of liabilities: a general liability for default and the seller's guarantee liability for defective goods. The former is applied to three types of default: delay in performance, the impossibility of performance, and incomplete performance based on the fault principle. The latter is applied to a defect in quality, quantity, or title, and can be raised irrespective of the fault principle. (Lee, Byung-Mun, 2010, 4)

goods are defective is subjective; therefore, the intended use of the goods that both parties agreed on in the contract of sale becomes a criterion. Accordingly, there is a defect when the goods supplied do not reach the standard or purpose that the parties agreed on (Song, Deok-Soo, 2021, 200). In this case, the subjective criterion theory will not view the delivery of low-quality used cars to the buyer as a defect because the buyer fully recognized and agreed with the quality of the car. Therefore, the parties' intention is a critical factor in determining the existence of a defect from the perspective of the subjective criterion theory.

With regard to the two different views, more scholars have recently accepted the subjective theory as a more valid criterion for judging the existence of a defect.[3] By treating the parties' intention as the essence of the contract, the intended use of the goods should be considered first when testing the existence of a defect, regardless of the quality that is generally accepted. The concept of defect from objective theory is limited to supplementing the gap in the parties' agreement. (Song, Deok-Soo, 2021, 202) Thus, defects are primarily judged based on the agreement of the parties, but if the parties do not mention the purpose or essential nature of the goods at the time of the conclusion of the contract, it is appropriate to judge them based on the objective concept of defects (Lee, Eun-Young, 2007, 335). In conclusion, the existence of a defect in Korean law should be decided based on the parties' intentions first and then by ordinary standards.

2.2. Fundamental Breach and the Severity of the Defects

2.2.1. CISG

The buyer's right to demand the delivery of substitute goods also requires a fundamental breach of contract in addition to the existence of non-conformity on goods (CISG Art. 46). As the non-conforming goods previously delivered by the seller must be returned, the delivery of substitute goods necessitates additional transportation besides delivery of the substitute goods itself. The costs and risks associated with the re-shipment of conforming goods and return transport of non-conforming goods that have already been delivered to the buyer can be considerable (Schlechtriem, 2006, 95). In this sense, the delivery of substitute goods can be as expensive as avoidance of the contract (Schwenzer, 2016, 744). Therefore, the CISG imposes a higher requirement for requiring delivery of substitute goods to avoid the unnecessary transfer of goods (Huber and Mullis, 2009, 199).

According to CISG Art. 25, a fundamental breach of contract means a case in which a breach of contract by one of the parties causes damage to a degree that substantially deprives the other party of what it is entitled to expect under the contract. In general, parties can agree on what they expect from the contract, and these agreements can be inferred from the contract. If the contract does not clarify the essence of the contract, there could be an issue about what amounts of breach of contract are fundamental.

In this regard, the CISG Advisory Council emphasizes the importance of the purpose of the sale—that is, the purpose of use of the goods—as a decisive factor in determining fundamental breach. If nonconforming goods cannot be used for their intended purpose by the buyer, it constitutes a fundamental breach of contract (Bridge et al., 2021, 15). For example, a buyer in the resale business is interested in reselling goods, so the delivery of non-

[3] The objective theory has the limitation on ignoring the parties' agreements and intention on the purpose of the goods. Also, in a contractual relationship, the value of the goods for the seller and the buyer could not be objectively equivalent. Rather, it should be subjectively equivalent to make a transaction.

conforming goods that cannot be resold would be a fundamental breach.

Additionally, if non-conforming goods can be repaired without undue burden on the buyer, there is usually not yet a fundamental breach (Kröll et al., 2018, 684). In the case of motor vehicles, machinery, and technical equipment, it is often possible to achieve a complete cure of defects that seriously impair usability by conducting the relevant repairs (Schwenzer, 2016, 745). Except for some cases of reasonable refusal of repair, such as timely delivery or unacceptable disturbance to the buyer's business, repairs will reduce the seller's transportation cost for return. Therefore, if the nonconforming goods can be repaired, it does not constitute a fundamental breach of the contract, and the buyer can only use remedies such as requiring repair, claiming damages, or reducing the price.[4]

2.2.2. Korean Law

In addition to the existence of defects, though KCA does not include an explicit rule, the severity of defects appears to be one of the requirements for the Right. According to the Korean Supreme Court (May 16, 2014, 2012 Da72582), the Right could be limited when the defects of the goods are minor enough to achieve the purpose of the contract. This decision of the court is in line with provisions that the remedy of avoiding contracts is limited in similar circumstances (KCA 580(1), 575(1)). If the defect in the goods is minor, following general trade customs and the principle of good faith, it is sufficient for the seller to repair the defect or compensate for the damage. Thus, the Right would be allowed in the case of a severe defect in delivered goods, such that it is enough to prevent the purpose of the contract.

2.3. Comparison and Assessment

As discussed previously, the existence of defects is a basic requirement. Although the terminology used to deal with goods that do not conform with the parties' agreement is different—"defect" under Korean law and "non-conformity" under CISG—both are the basis of the seller's liability for the remedy. Without proving the existence of a defect, the buyer cannot rely on any right to remedy.

Furthermore, although the KCA does not include an explicit rule about the definition of a defect, the concept of a defect from the prevailing subjective criterion theory is similar to that of the CISG. The CISG adopts a subjective standard—the description of goods in the contract—which is considered the primary standard for conformity (Kröll et al., 2018, 487). Korean legal experts who support the subjective criterion theory also insist that a defect should be decided not only by ordinary standards but also by the parties' intentions. Thus, from a comparative law point of view, the objective criterion theory that emphasizes general standards loses its persuasive power.

Although there is not much practical difference between the two terminologies, the scope of the defects in the CISG is distinctively different from that under the KCA. In the CISG, the non-conformity of delivered goods embraces not only discrepancies in quality but also differences in quantity and defects in packaging. As these nonconformities are dealt with in a unitary manner, the buyer may rely on the same remedial scheme. By contrast, Korean law

[4] If there is no fundamental breach of contract under Article 25 of the CISG, the buyer has the right to claim for repair (Art. 46 (3)), the right to claim damages (Art. 45 (1) (b)) and the right to reduce the price (Art. 50). However, in case of fundamental breach, the buyer has the right to avoid the contract (Art. 49) and the right to claim delivery of substitutes (Art. 46 (2)) in parallel with a claim for damages.

deals with defects in quality, quantity, and packaging separately. Differences in both quantity and quality are categorized as defects, whereas defects in packaging are treated as matters of nonperformance. The matter of defect is governed by the seller's guarantee liability regime, resulting in remedies being available, regardless of the fault principle. Conversely, non-performance is governed by the rules of general liability, and all remedies are subject to the fault principle. In addition, the requirements of the seller's guarantee liability for differences in quantity are quite different from those for discrepancies in quality, being governed by separate provisions of the KCA (Lee Byung-Mun, 2001, 91).

Compared with the CISG, the liability system of Korean law could cause some complexities as to which liability is applicable. The main reason for the complexity is the separate stipulation of the remedies and requirements based on the type of default. Thus, when the sales contract is not properly performed, as agreed upon by the parties, the first thing to do is to check what type of default applies (Lee Byung-Mun, 2009, 35). After confirming what has happened to the goods, the available remedies or requirements for these remedies become clear. However, as the distinction between the defaults is artificial, confusion and debate related to the dual liability system has continued. While the CISG's liability system and remedies appear to be simple and clear, separately stipulated remedies in the KCA could be a source of the problem. Our study therefore focuses on a particular type of defect, namely, differences in quality, to avoid contradictions between different liability systems.

In addition to the scope of the defect, the CISG and KCA adopt different approaches to the issue of which degree of defect is a requirement for the Right. The CISG stipulates a fundamental breach of contract as a condition for substitute delivery, and if non-conforming goods can be repaired, there is usually no fundamental breach. Thus, the right to require substitute delivery would be limited if the non-conformity of goods is repairable.[5] In other words, the applicable remedies for particular cases are determined based on the availability of repair. For example, if repair is possible, it does not constitute a fundamental breach of contract, so buyers can only rely on remedies such as requiring repair, claiming damages, or asking for a reduction of the price. By contrast, if the repair of goods is impossible, buyers could request delivery of a substitute. In addition, buyers do not need to be confused regarding which remedies to choose, between requiring the delivery of substitutes and claiming for repair (Lee Yoon and Lee Byung-Mun, 2021, 110).

However, as discussed previously, the KCA does not explicitly address the requirements for substitute delivery, which could have helped distinguish this particular remedy from other available remedies. Furthermore, the right to request repair, which is generally discussed and compared with substitute delivery under the CISG, is not stipulated in the KCA. Given this lack of legal affirmation, the severity of defect conditions derived from judicial precedents can be considered a requirement for substitute delivery, corresponding to a fundamental breach of the contract requirement under the CISG.[6]

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[5] As we will discuss at the later part of the paper, repairability is not the only condition that limit the right to request substitute delivery. For example, the buyer's right to require delivery of substitute goods is excluded if it is not available or only available at very high costs.

[6] However, unlike the CISG, it is not clear whether claiming for repair is always limited even when the defect in the delivered goods is severe, and it is impossible to achieve the purpose of the contract. Moreover, even the buyer's right to request repair is debatable as to whether this right should be accepted in the KCA. On the premise that it is possible to claim the repair of defects, even if the defect is significant, it is reasonable to resolve the dispute with the repair when the defect can be repaired at a low cost. Therefore, the significance of defects in delivered goods alone cannot prevent additional

Consequently, an additional guide regarding repairability, to determine whether there has been a fundamental breach, from the CISG Advisory Council can serve as a standard to determine when to use the right to request substitute delivery versus requesting repair. Accordingly, more specific requirements for remedies will also be needed in Korean law to clearly guide which remedy should be applied.

3. Reasonableness

3.1. CISG

Unlike the buyer's right to request repair, which refers to reasonableness for balancing both parties' interests, there is no explicit reasonableness requirement regarding the buyer's right to claim the delivery of substitute goods. The drafters of the CISG did discuss whether to lower the threshold for substitute delivery by replacing fundamentality with mere reasonableness of substitution, but the proposal was dismissed considering the economic consequences of substitute delivery, that is, the costs for transportation (Bridge et al., 2021, 18). Therefore, it is unclear whether disproportionality also limits the claim for the delivery of substitute goods.

However, the prerequisite of reasonableness appears useful, and in line with the Convention's primary purpose of saving the seller's costs for substitute delivery when they outweigh the buyer's interest in receiving conforming goods. Also, the reasonableness requirement could be inferred from the observance of good faith under CISG Article 7(1) which demand two parties of the contract should exercise their rights and obligations with honesty so as not to betray the mutual trust (Powers, 1999, 351).[7] If it is physically impossible to replace the delivered goods or if it is possible only at a very high cost, the delivery of substitute goods is unreasonable. As the law should not encourage economically irrational behavior, balancing the interests of both parties is necessary when requesting the delivery of substitute goods. From this perspective, the CISG Advisory Council suggested that the buyer's right to require delivery of substitute goods is excluded if it is disproportionate with regard to all circumstances (Bridge et al., 2021, 18).

According to CISG Advisory Council opinion, to determine whether the claim for replacement is balanced, the following aspects should be considered: the position and ability of the seller to deliver substitute goods, the cost of substitution, the nature of the goods and their general substitutability, and the interests of the parties in the remedy (Bridge et al., 2021, 18). For example, if the buyer can easily purchase substitute goods from the market, the delivery of substitute goods would not be reasonable, as the cost of substitution would be considerable. Rather, it would be more efficient to compensate for the difference between the amount purchased in the market and the original sales amount based on the contract. In addition, if the parties have agreed on the upper limit of damages in the contract, requiring delivery of a substitute when the cost of doing so exceeds the limit of damage, could be unreasonable (Lee Yoon and Lee Byung-Mun, 2021, 99). The parties have arguably intended to limit costs for remedies by agreeing to a cap on damages; therefore, the cap could be a

controversies over exceptional cases.

[7] The good faith principle could be a prerequisite to the exercise of other CISG rights. A party might lose the right to avoid or seek specific performance if exercised in bad faith (Spangnolo, 2007, 275).

criterion for reasonableness.

Such reasonableness requirements may guide the buyer to choose other remedies when the seller's cost of substitute delivery exceeds the buyer's expected benefit. In some cases, the breach of the contract is fundamental, and using the right to claim delivery of substitutes can result in more cost and inefficiency than avoiding the contract. Therefore, adding the reasonableness requirement is in line with the intention of the CISG Advisory Council to present a specific and practical baseline for the buyer's exercise of the right to claim delivery of substitutes.

3.2. Korean Law

Although the KCA is silent on the detailed requirements of the Right, we can infer its position from the argument that, in some cases, substitute delivery should be limited based on the principle of good faith and the principle of prohibiting the abuse of rights. The principle of good faith is a general presumption that a contracting party must perform their contractual duties honestly, fairly, and in good faith in order not to destroy the rights of the other party. Thus, if the seller trusts that the buyer will not request substitute delivery, and if such trust can be objectively considered to have been formed, it will not be possible to request substitute delivery based on the principle of good faith. In addition, if the buyer can achieve the same function and condition as a new and conforming good by repairing, then claiming substitute delivery that impose higher costs on the seller than the repair would, is clearly an abuse of rights, so the Right should be limited in this case. Here, comparing the costs and benefits of each remedy leads to reasonableness, which is a critical requirement for the Right.

In addition to the preceding principle, judgments of the Korean Supreme Court and the draft of the KCA amendment provide some clues for the additional requirements for the Right. In 2014, the Korean Supreme Court (the "Court") ruled that the Right may be limited in certain circumstances under the principle of fairness. This decision of the Court is the first related to the limitation of requesting substitute delivery. In this case, the buyer requested the seller to deliver a new car because the speedometer broke down after receiving the new car, but the Court did not accept this request. The Court ruled that if the seller's claim for the delivery of conforming goods is allowed unconditionally and entirely without considering the severity of the defect or the extent of the cost caused by the delivery of substitute goods, it can lead to disproportionate consequences for the seller (Song, Deok-Soo, 2021, 205). Therefore, the right to request substitute delivery may be restricted in such exceptional cases. The Court also stated that if the defect in the delivered goods is insignificant and remedies for the buyer, such as repair or compensation for damages, are possible at a low cost, the restriction on the Right should be allowed when the cost for substituting goods is much higher compared to repair or damages. Accordingly, the Court calculated the cost for substitute delivery by deducting the value of the defective vehicle returned to the seller from the cost of procuring new vehicles of the same kind, which includes transportation costs and registration fees, and compared it with the cost for repairing, which includes labor cost and parts.

The Court's decision implies that it necessary to compare the consequences of substitute delivery with other remedies. After weighing the costs of substitute delivery and alternative remedies, we can determine whether substitute delivery is reasonable in each case. For example, the Right is allowed when the cost of substitute delivery is equivalent to the cost of defect repair. If the cost of substitute delivery is far above the cost of repair, the Right is limited. Therefore, reasonableness in this circumstance means that substitute delivery is more

reasonable than other remedies.

Subsequently, we find some suggestions related to the right to request the delivery of substitutes in the draft of the KCA amendment announced in 2014. Although the draft KCA amendment was not ratified by the National Assembly, the discussion and logic of the draft will provide good insight into the current KCA. The 2014 draft suggested establishing a new clause that recognizes the right to request a cure in Art. 388 (2), and this clause also stipulates specific criteria for limiting the right to request a cure. As the right to request a cure includes the right to request repair and substitute delivery, the requirements stated in the draft could be inferred to apply to the Right. The drafters thought that if the buyer's request for a cure caused extra cost and burden to the seller, it was necessary to limit the buyer's right to request a cure. As a result, the draft limits the right to request a cure when the cure causes excessive costs or when it is not reasonable to expect a cure (Kim Jae-Hyung, 2015, 1660).

Here, reasonable expectations should be determined by balancing the interests of both parties (Kim Jae-Hyung 2016, 124). Comparing the cost of substitution imposed on the seller with the actual or prospective benefit to the buyer, if the cost of the seller significantly exceeds the buyer's benefit, substitute delivery is not reasonable. When comparing the parties' interests, all the circumstances should be considered, such as the degree of defect, ease of repair, possibility of repairing defects, reduction of the value after the repair, value of goods without defects, whether the purpose of the contract is achieved, nature of goods, and value of defective goods returned to sellers. As a result, reasonableness in this circumstance can be determined by comparing the seller's cost and the buyer's benefit.

3.3. Comparison and Assessment

Both the CISG and KCA do not stipulate that exercising the Right should be reasonable, but the opinions of scholars and decisions of the Court suggest requiring the reasonableness condition for delivery of substitutes. Comparing CISG and KCA, although their detailed contents and purpose show a considerable difference, the basic idea about the necessity of reasonableness is similar.

The purpose of reasonableness requirements under the CISG is to save the seller's costs for substitute delivery when they outweigh the buyer's interest in receiving conforming goods. It only compares the seller's cost and buyer's benefit in the case of substitute delivery. Under this condition, the buyer must choose other remedies when exercising the Right is unreasonable. As a result, unreasonable substitute delivery, which causes excessive costs, will be restricted, so the parties can avoid inefficient consequences. In addition, the reasonableness requirement plays a role in distinguishing suitable remedies, just as the fundamental breach does.

In Korean law, there are two slightly different approaches for determining reasonableness. The first compares the cost of substitute delivery with other remedies, so substitute delivery is reasonable when the cost of other remedies is equivalent to or exceeds that of substitute delivery. The second approach compares the cost of the seller and the benefits of the buyer. If the interests of both parties are balanced by substitute delivery, it can be seen as satisfying the reasonableness requirement.

Both approaches can mutually supplement each another. The former needs to compare not only the cost of each remedy, but also the benefits they provide. The benefit of each remedy to the buyer might be different, and the purpose of the contract may not be achieved by some remedies. For example, if the value of the goods decreases significantly after repair, substitute

delivery would be accepted even at a higher cost. However, the latter approach must compare the balancing of parties' interests in other remedies. Although substitute delivery is reasonable considering the costs and benefits of the parties, it is possible that other remedies could fulfill the purpose of the contract at a lower cost. Therefore, both approaches should be considered when determining whether substitute delivery is reasonable.

Although both the CISG and KCA take the position that substitute delivery should be allowed in case it is reasonable, the CISG explicitly states that a fundamental breach of contract is a requirement for the Right. As a fundamental breach of contract is required, substitute delivery is strictly limited under the CISG compared to the KCA, which mainly requires reasonableness. The main reason for this strictness is to save unnecessary costs from returning non-conforming goods and re-shipment of conforming goods, as discussed. In international trade, substitute delivery generally incurs higher expenses than repair does, because of additional transportation costs. Therefore, as the CISG deals with matters in international trade, it is understandable that not only reasonableness but also a fundamental breach of contract is required for the right to request substitute delivery.

Should the KCA announce a higher threshold for the right to require substitute delivery than for the right to request a repair? This question arises from the premise that a claim for the delivery of substitutes leads to higher costs compared to the repair of defects. However, as the KCA also applies to domestic transactions in some cases, the premise is not always true. For example, if the good is not expensive and is frequently used on a daily basis, or if it costs more to repair the defects due to the nature of the item, a repair cannot be said to be a remedy that benefits the seller. Thus, the opinion that the right to request repair should be preferred over substitute delivery in any case, is invalid. Accordingly, considering which remedy is reasonable, regardless of the type of remedy, is an essential step before choosing the remedy to claim, and reasonableness should be decided on a case-by-case basis by regarding diverse circumstances (Bridge et al., 2021, 15).

As a result, we find that the CISG imposes stricter requirements on substitute delivery than the KCA does, as the former is applied only to international trade. Still, it is not clear whether the KCA also needs a much higher level of requirement for the Right, considering possible exceptions in domestic transactions. As the KCA and CISG are located in different legal environments, different levels of requirements would not be an incorrect conclusion. Instead, specifying reasonableness as a requirement for the delivery of substitutes must be reflected in the KCA.

4. Timely Notice and Request

4.1. CISG

If the buyer detects a lack of conformity of the goods following an examination, they should give notice of the non-conformity to the seller within a reasonable time (CISG Art. 39(1)). The notice must specify the nature of this lack of conformity. A reasonable time for notice should be decided regarding all circumstances of a specific case (Honnold, 1989, 104). The notice of lack of conformity should be given to the seller within at least two years from the time the goods were delivered to the buyer, unless this time limit is inconsistent with a contractual period of guarantee (CISG Art. 39(2)). This applies to cases where a lack of

conformity cannot be discovered on a reasonable examination. As buyers' right to claim remedies for a lack of conformity depends upon proper notification to the seller, timely and specific notification are a duty for the buyer (Kröll et al., 2018, 587).

In determining what is a "reasonable time" for notice, all the circumstances, such as trade usage and practice between parties and the nature of the goods, must be taken into account (Bergsten, 2004, 165). For example, early notice of the lack of conformity is required for perishable goods, such as fresh fruit. The time available to give notice must be determined separately for each defect. In addition, the determination of reasonable time involves balancing the interests of both the seller and buyer. The seller would be interested in clarifying the legal relationship between parties as quickly as possible, and the buyer would want more time to not lose their right to remedy (Schlechtriem, 2006, 93).

After notification, if the buyer wants to claim the right to request the delivery of substitute goods, the buyer must request it in conjunction with giving notice of non-conformity or within a reasonable time thereafter (Lookofsky, 2017, 113). If the buyer fails to do so within the time limit for requiring delivery of substitute goods, the buyer loses the right to claim substitute delivery. In addition, when there is no notice about the lack of conformity to the seller, the period should begin when the buyer actually discovers the defect (Huber and Mullis, 2009, 200). If the seller cannot receive the declaration from the buyer, the buyer bears the burden of proof that their request for substitute delivery was dispatched on time (Schwenzer, 2016, 748). With this requirement, the CISG intended to prevent unreasonable delays in a buyer's decision concerning the remedy to pursue.

There has been some discussion as to whether the time limit for requiring delivery of substitute goods should have the meaning as in Article 49(2)(b) of the CISG for a declaration of avoidance or as in Article 39(1) for the notice. The latter view tends to keep the reasonable time period rather short, suggesting a limit of approximately two weeks (Kröll et al., 2018, 682). By contrast, the CISG Advisory Council advised that the length of the reasonable period for substitute delivery must be coordinated with the period for a declaration of avoidance, which is more generous. As it is the buyer who often has to choose the remedy, they will need more time to make a difficult decision than simply giving notice of a non-conformity.

4.2. Korean Law

In cases where both parties are merchants and a transaction is commercial, Korean law imposes an express duty on the buyer to examine the goods and to notify the seller of any defects. The buyer's notice must be given to the seller immediately after discovering any defect in the goods (Korean Commercial Code, Art. 69(1)). The period of immediate notice should take into account all circumstances on the basis of reasonableness, especially regarding whether the buyer's delay in notice causes any economic harm to the seller (Lee Byung-Mun, 2001, 157).

If the defect is not immediately discovered on a reasonable examination, the buyer must give his notice of a defect at the latest within six months (Song, Deok-Soo, 2021, 205). The period begins from the date on which the buyer took the seller's delivery. If the buyer fails to notify the seller about the existence of defects within a period of six months, they may lose all their right to claim a remedy, including the right to require substitute delivery (Korean Commercial Code, Art.69(1)).

Furthermore, the buyer's rights conferred by the rules of the seller's guarantee liability must be exercised within six months from the time the buyer became aware of a defect in the quality

of the goods (KCA Art. 582). If the buyer wants a substitute delivery, he must request it within six months of discovering defects.

4.3. Comparison and Assessment

The primary objective of imposing on the buyer the duty to notify the seller of any defect in the goods is to protect the seller's interest and to prevent the seller from being subjected to claims by the buyer after a considerable time has elapsed after delivery (Kröll et al., 2018, 588). With this notice duty, the seller may consider the transaction complete after a certain time. In addition, notice duty may give the seller the opportunity to cure the defect in the goods by delivering the substitute or repairing the good, preparing for any possible disputes by securing necessary evidence, and taking the necessary steps for a claim against the supplier (Schwenzer, 2016, 638).

The rules to decide the notice period in the CISG and Korean law both take into account all the relevant circumstances of each case based on the principle of reasonableness. Although Korean law states that the notice must be given to the seller immediately after the buyer discovers any defect in the goods, the wording "immediately," which gives the impression of an inflexible rule of prompt notice, should be considered as a reasonable time in this context (Lee Byung-Mun, 2001, 156).

When a defect is not immediately discovered, Korean law gives the buyer a maximum of six months as a period of notice. Contrariwise, the buyer's notice of a lack of conformity in the CISG must be dispatched to the seller at least within two years from the time the goods were delivered to the buyer. Both periods begin when the goods are delivered to the buyer, but the maximum period of late notice is different, six months for the KCA and two years for the CISG. In Korean law, the buyer loses all right to claim a remedy if they fail to notice the defect within the specified period. However, under the CISG, the buyer might at least claim for a price reduction and claim damages, except for loss of profit, if there was a reasonable excuse for the failure of notice (CISG Art. 44).

Overall, the structure of notice duty in the CISG and Korean law shows similarity, and both deprive the buyer of the right to require substitute delivery when notice duty is not fulfilled. On the one hand, Korean law might be considered harsh to the buyer because they could lose all rights in respect of defects in goods without excuse. Compared with the CISG, which provides the last chance for buyers who are unfamiliar with the examination and notice requirement, depriving the whole right to claim the remedy seems quite strict. On the other hand, Korean law could be more generous when requesting substitute delivery, as it provides the buyer with six months from the time of becoming aware of a defect for exercising the Right. Therefore, it is difficult to say which law is better and which should be revised; instead, we would rather choose the suitable governing law considering the circumstances faced by each party. For example, traders can select or change the notice period and related duties as needed. If both parties need a longer period of notice, choosing the CISG as a governing law could be a solution. In addition, if both parties want a shorter duration for the notice, such as three months, they can change the period of notice duty by expressly adding that condition to the contract.

5. Others

5.1. Return of Non-conforming Goods

To exercise the buyer's right to require substitute delivery for non-conforming goods, the buyer must be able to return the goods originally delivered in substantially the same condition in which they were received (CISG Art. 82(1)). The costs related to restitution duty are borne by the seller, but the buyer will lose the right to request substitute delivery if they cannot fulfill the restitution duty (Schwenzer, 2016, 749). Although Article 82 of the CISG is part of the "Effects of Avoidance" section, this provision also applies to the delivery of substitute goods, as is clearly worded (Bridge et al., 2021, 18). This obligation is based on the idea that restitution is a natural consequence of the delivery of substitute goods. If there is no duty to return the originally delivered goods, some buyers could exploit the right to request substitute delivery as a tool for additional profit. In cross-border e-commerce, a similar situation occurs when the total transportation costs are comparatively high. Some unscrupulous consumers require substitute delivery without returning the originally delivered goods, which casts doubt on whether these goods even have serious defects to begin with. Therefore, the obligation of restitution is not only natural but also essential to minimize fraudulent claims for substitute delivery.

The buyer claiming a substitution need not return the non-conforming goods in exactly the same condition in which they were received, but a return of the goods in substantially the same condition is sufficient. The buyer does not lose the right to require substitute delivery due to mere usage of the returned goods, but if the goods are already processed, the buyer will lose the right. When the change in the condition of the goods makes it infeasible for the seller to accept the returned goods, the buyer fails to fulfill the restitution obligation (Bridge et al., 2021, 18). However, the buyer does not lose the right to claim substitute delivery in the following cases: if the reason why it is impossible to return the goods or to return the goods in substantially the same condition as at the time of the buyer's receipt is not due to the buyer's actions or omission; if all or part of the goods are lost or deteriorated as a result of the inspection; or if the goods or part of the goods have been sold, consumed, or transformed by the buyer before discovering the lack of conformity (CISG Art. 82(2)).

Another issue related to returning non-conforming goods is whether the seller's delivery of substitute goods and the buyer's restitution must be performed concurrently. In the case of avoidance of the contract, CISG Art. 81(2) explicitly states that restitution duties must be performed concurrently. However, there is no such provision to clarify the relationship between substitute delivery and restitution. Moreover, unlike an exchange of goods in return for payment, the concurrent exchange of goods in long-distance transactions would lead to considerable difficulties in practice (Schwenzer, 2016, 749). Therefore, considering both legal gaps and practical obstacles, it would be reasonable to allow the buyer to claim substitute delivery without having to offer restitution of the originally delivered goods at the same time (Kröll et al., 2018, 684).

Korean law does not mention returning non-conforming goods as a requirement for substitute delivery. Although the liability of restitution as a result of the avoidance of the contract is stipulated in KCA Art. 548, there is a lack of evidence to connect the restitution duty to substitute delivery. However, in practice, returning first-delivered goods is a common custom in trade even for consumers using e-commerce. If there is no obligation to return goods, the seller's cost of substitute delivery will increase excessively. In addition, without this requirement to restore the original state, there seems to be no way to limit malicious claims for substitute delivery. The KCA thus also must include returning the non-conforming goods

as a requirement for the Right.

5.2. Differentiation between Generic and Identified Goods

In Korean law, the delivery of substitute goods may only be considered in the case of defects in quality and where goods of a different kind have been delivered, and thus, almost exclusively in the case of generic goods (Yoon, Gil-Hong, 2015, 217). If the contract relates to an identified object, the delivery of substitute goods should not usually be expected from the seller (Bridge et al., 2021, 17). In short, the KCA distinguishes between generic and identified goods and excludes substitute delivery in the case of identified goods.

However, there is no such distinction between generic and identified goods in the CISG provisions. According to the CISG Advisory Council opinion, rather than distinguishing the nature of goods, the substitutability of the goods and the parties' interests in substitution should guide the application of the right for the delivery of substitute goods (Bridge et al., 2021, 16). [8]

Based on the preceding discussion, the KCA focuses on the types of goods; contrariwise, the CISG focuses on the characteristics of goods that are substitutable. Although substitutability is directly linked to the physical possibility of delivering new goods without defects, the substitutability of generic goods is derived from their general characteristics. Practically, there is not much difference in the result, but when we follow the guidelines of the CISG, we do not need to care about which goods are generic. Thus, the approach of the CISG seems to be much clearer and simpler than that of the KCA. Moreover, as the majority of trade concerns mass-produced generic goods, the importance of distinguishing generic and identified goods is diminishing. Accordingly, a more practical approach is to determine the substitutability of goods as a requirement for the Right rather than limiting it to generic goods.

5.3. The Buyer's Ignorance and the Absence of Negligence

Another requirement for substitute delivery in Korean law is the buyer's ignorance of the existence of a defect and the absence of negligence in failing to discover the defect (KCA Art. 580(1)). In other words, the Right is permitted if the buyer was unaware of the defect at the time of the contract, and defects in delivered goods were not found even though the buyer conducted an examination without a mistake. The underlying principle of this requirement is that in the case where the buyer purchases goods that show apparent defects, he is deemed to have agreed to the current state of the goods. Under this principle, the buyer cannot rely on remedies for the defects he already knows (Lee, Byung-Mun, 2001, 119).

The CISG also states that the seller is not liable for any lack of conformity if the buyer knew or could not have been unaware of the lack of conformity at the time of the contract (CISG Art. 35(3)). Thus, if the buyer did not know about the non-conformity, the seller's liability—which will lead to the right to require substitute delivery—arises. Both the CISG and KCA require the buyer's ignorance as to the existence of a defect.

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[8] The application of Article 46(2) CISG in case of identified goods is disputed. The traditional view in Germanic legal systems is that delivery of substitute goods may only be considered in cases of defects in quality and where goods of a different kind have been delivered, therefore, almost exclusively in case of generic goods. If the contract relates to an identified object, delivery of a substitute object usually should not be expected from the seller (Bridge et al., 2021, 17).

However, the wording of "could not have been unaware of" does not impose an obligation of examination, so there is not much difference between "knowledge" and "could not have been unaware of." For example, if a buyer who is normally supposed to examine goods negligently fails to discover a defect that one ought to have discovered by due examination, the seller is not liable under the KCA (Yoon, Gil-Hong, 2015, 214). However, the CISG does not guarantee that the buyer in the above cases loses his rights. In this context, the CISG seems quite in favor of the buyer compared to the KCA, which requires the absence of negligence.

6. Conclusion

This study examined the requirements in relation to the buyer's right to require the delivery of substitute goods through a comparative study based on the CISG and the KCA. The major findings of our study are as follows:

First, the CISG explicitly details the requirements for the Right, such as a fundamental breach of the contract and a timely request. By contrast, the KCA only recognizes the right to request substitute delivery but does not indicate any requirement for the Right. Although we could find requirements for the Right in the KCA, by analogy from articles related to the seller's guarantee liability, judicial precedents, and the literature, such gaps in Korean law could become a source of controversy when practitioners designate and use the KCA as the governing law. Therefore, specific requirements for substitute delivery should be included when amending the KCA. Such revisions not only fill the legal gap in Korean law but also promote the right to require substitute delivery. In practice, exercising the Right without the stated regulation involves the risk of dispute with the counterpart. If the requirement for substitute delivery is specified, the right to claim the delivery of substitutes will be much more actively used; therefore, remedies for the delivery of defective goods could be diversified.

In addition, given that the revision of the KCA will take considerable time and effort, the buyer who wants the right to substitute delivery as a remedy needs to insert relevant provisions into the sales contract. Provisions regarding remedies added to the contract will help prevent future disputes.

Second, the CISG attempts to minimize overlapping and conflict with other remedies by specifying detailed requirements for requiring delivery of substitutes. The CISG stipulates a fundamental breach of contract as a condition for substitute delivery, and the Right would be limited if the non-conformity of goods is repairable. Given this requirement, buyers can easily determine which remedies are allowed in each case. By contrast, Korean law merely suggests some requirements that do not exactly consider the relationship with other remedies. Therefore, more specific requirements for the Right that distinguish the possible remedies will also be needed in Korean law, to clearly guide the choice of remedy.

Third, although not explicitly expressed in the Articles, both the CISG and the KCA similarly require reasonableness for substitute delivery. The basic reason for requiring reasonableness is to save unnecessary costs and prevent disproportionate requests for substitute deliveries. To achieve this goal, both the CISG and KCA compare the seller's cost and buyer's benefit, and the KCA additionally compares the cost of substitute delivery with other remedies. As both methods have their strengths, it would be better to consider both methods, allowing them to supplement each other when determining the reasonableness of substitute delivery.

Lastly, comparing the right to require delivery of substitute goods under the KCA and CISG, the CISG has set stricter requirements on substitute delivery than the KCA has. As the CISG is the law for international trade, strict requirements seem to be reasonable to minimize additional transportation and related costs. Considering the different legal environments, there is no need to strengthen the relevant requirements for the Right in the KCA.

As discussed thus far, the CISG provides more detailed requirements about the right to require the delivery of substitute goods than the KCA does. The results of this comparative study clearly suggest that revision of the KCA is necessary. In particular, the lack of explicit provisions about the requirement of substitute delivery in the KCA makes it difficult to apply the Right in practice. In a situation where most of the goods sold are mass-produced generic goods and the exchange of goods becomes a common custom for people who use e-commerce, the KCA needs to add a detailed requirement for the right to require substitute delivery. Although the KCA does not need to follow every provision of the CISG, some requirements compared in our paper would be worth considering when amending the KCA in the future. Also, in international trade practice, it is recommended for the buyer who might need to rely on the right to require substitute delivery in the future to choose CISG as a governing law rather than KCA. As CISG provides more detailed and clear provisions, it will protect the buyer from costly conflict with the seller.

Although the findings of this study allow us to elicit some implications for the development of the KCA, comparing only the CISG and KCA is a limitation of our study. In the future, if additional comparative studies of the recently revised laws of other jurisdictions are conducted, more meaningful results can be derived.

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Research on Factors Affecting South Korea's OFDI Based on a Spatial Measurement Model

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Abstract

Purpose – This paper empirically investigates via a spatial lag model from the perspective of space economy to find the influencing factors of South Korea's OFDI along with 60 countries.

Design/methodology – In the study of regional economic phenomena, we must first test the corresponding spatial correlation, and on this basis, complete the construction of the spatial model. For the target research object, after testing the spatial correlation, if there is spatial correlation, a spatial measurement model is needed. This paper uses the global Moran's I index for calculation. Based on the characteristics and research needs of the research object, this paper selects the spatial lag model to verify the existence of the spatial effect and factors affecting OFDI.

Findings – Our results show that export scale, infrastructure, technology level, political stability, resource endowment, market size, distance and labor cost have a certain impact on Korea's OFDI, but at present the distance and market size factors are the most important influencing factors for South Korea's OFDI, The technical level and political stability have little effect on South Korea's OFDI, and are not main factors determining South Korea's OFDI.

Originality/value – Through spatial measurement verification, it was found that the spatial effect has a significant impact on OFDI, along with more than 60 countries. On this basis, relevant suggestions are put forward, which have strong practical significance for South Korea's OFDI to achieve healthy and sustainable development.

Keywords: OFDI, South Korea, Spatial Measurement Model, Sustainable Development
JEL Classifications: D12, F14, O53

1. Introduction

In the context of globalization, overseas direct investment, an important means of promoting national economic development, has received widespread attention. Many scholars at home and abroad have conducted analyses and research on overseas direct investment. In the past, the main research objects of academic circles were multinational companies and host countries. For multinational companies, in order to achieve strategic expansion in the context of globalization, are eager for overseas direct investment. Host countries, in order to achieve domestic economic development goals, are eager to attract foreign investment. It is precisely because of the coincidence of the needs of the two parties that the host country and multinational company are the two parties involved in multinational investment. In the past, most studies focused on the impact of overseas direct investment on host countries and

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multinational corporations, and there was very little research on the home country of multinational corporations. With the continuous expansion of the research content of transnational investment theory, the impact of transnational investment on investing countries has attracted attention. Policy circles and academic circles generally believe that, on the whole, the overseas investment of multinational companies has a positive impact on the country's employment, asset upgrading, and foreign trade. Even if different types of investment have different impacts on the domestic economy, in general, overseas investment has a positive impact on the home country's economy. Under the conditions of an open economy, the outflows and inflows of foreign direct investment are an important channel for an economy to enter the global market. For economies that are still in the developing stage, the introduction of overseas investment can help solve the lack of funds, promote the stability of the domestic economic structure, and play a very important role in promoting domestic economic development. For economies in a mature stage, investing overseas can help expand overseas markets in the context of economic integration, promote the upgrading of the domestic economic structure, and drive export trade. As an export-oriented economy, South Korea is guided by the international market and has a high degree of dependence on foreign countries. Overseas direct investment and foreign trade have developed rapidly, and a relatively complete foreign trade policy and overseas investment policy have been formed.

Since South Korea's dependence on foreign trade (the ratio of total imports and exports to GDP) has exceeded 80%, South Korea hopes to participate in the "Belt and Road" initiative to find an effective way to promote economic growth. For example, the focus of the "Belt and Road" initiative is infrastructure construction. The "New Eurasian Continental Bridge" construction plan to reach Europe from Lianyungang via Zhengzhou-Lanzhou-Urumqi-Almaty-Tashkent (Uzbekistan) will allow the transportation of Korean goods to Europe provides a more convenient channel, which is conducive to the growth of Korean enterprises and foreign trade. It plans to actively promote exchanges and cooperation between South Korea and China through the publication of the academic journal "The Belt and Road". On the whole, South Korea has a positive and affirmative attitude toward the "Belt and Road" initiative, and agrees with the government's participation in its construction.

The purpose of the study to guide the smooth progress of OFDI in South Korea. It is necessary to re-examine the main factors affecting OFDI in South Korea, and find and propose countermeasures accordingly. In view of this background, this article uses the relevant statistical data of 60 countries from 2004 to 2018 to empirically analyze factors affecting OFDI in South Korea from a spatial perspective, and propose relevant suggestions accordingly, and a view of providing certain ideas for the formulation of the top-level design of the relevant suggestions are put forward, which has a strong practical significance for South Korea's OFDI to achieve healthy and sustainable development.

2. Literature Review

2.1. Research on the Influencing Factors of OFDI

Domestic and foreign scholars have done substantial research on OFDI in South Korea, and have made significant contributions to research in this field. Some scholars have found that the size of the host country market is positively correlated with the level of South Korea's foreign direct investment, and that South Korea's foreign direct investment has motivation to

seek the market (Zhang and Daly, 2016). The scale of transactions between South Korea and the host country and the degree of openness of the host country have a positive impact on South Korea's OFDI, but if the trade costs are low, foreign trade companies may choose to export rather than choose foreign direct investment (Zheng Zhousheng, 2018 and Huang Shengtao,1997) .

PravakarSahoo and AshwaniBishnoi (2021) confirmed the positive effect of OFDI on economic growth, but found a substitution effect for domestic investment. This indicates that OFDI positively affects growth through its effect on trade and other positive spillover effect, rather than domestic investment.

KhelifaMazouz et al. (2021) found that OFDI from Latin America is more likely to be located in geographically proximate countries and in countries with a similar culture and language than that of OECD counterparts.

MuhammadArif et al. (2020) had empirical results that indicated that exchange rates, inflation, and corruption had a negative and statistically significant effect on OFDI in the host country. In contrast, law and order situations have an insignificant association with OFDI. The findings further demonstrate that the error correction term is negative and highly significant at a 1 % level of significance.

Jason Heavilina and Hilmi Songur (2020) empirically examined the relation between institutional distance and OFDI. They also found that host country political stability, government effectiveness, control of corruption, and rule of law attract OFDI.

Ryu Hanbyul and Jeong Young Sik (2020) examined how South Korea's OFDI was affected by an increase in the labor costs of the manufacturing industry in host countries. The results indicated that worker wages in Asian developing countries generally have a negative impact on South Korea's OFDI. but it did not find evidence that labor costs had a significant impact on South Korea's OFDI to European or developed countries.

Lee Joun Wo and Lee Jong Ha (2019) analyzed the spillover effect of technology on R&D investment. In particular, they analyzed the effect of setting the OFDI path of the technology.

Lee et al. (2015) found that firm R&D had significant effects on exports and OFDI increased directly and indirectly through TFP estimate increases, where its magnitude of effectiveness was stronger on exports than OFDI.

Kim et al. (2019) introduced a revised gravity model on exports and OFDI using 7,000 firms with survey and financial data from 2006 to 2017. Through fixed effects panel models and PSM methods, it rejected many of the prior studies by incorporating various gravity factors in the empirical models, such as the distance to the host country, average tariff rate, foreign exchange rate, and population, etc.

Jin Mingyu and Wang Dachao (2009) found that South Korea's OFDI promoted the optimization of domestic industrial structure, reduced the proportion of the domestic primary and secondary industrial structure, and significantly increased the proportion of domestic tertiary industrial structure.

Zang Xin et al. (2006) found that South Korea's OFDI developed rapidly in recent years, and investment in China has increased significantly. At the same time, South Korea has begun to implement a new round of industrial policies to further increase the pace of industrial restructuring.

Guo Zi-Han and Oh Dae-Won (2021) used panel data of Southeast Asian countries from 2003 to 2017 and introduced structural indicators of host countries to analyze the impact of the industrial upgrade of host countries on the flow direction of China's OFDI. As a result, it

found that China's OFDI has a preference of "low value-added industry", "low GDP per capita", and "high total factor productivity".

Dai Yunhai (2020) empirically studied determinants of China's OFDI to South Korea, with PANELDATA data introduced combining time series with a cross-section. It showed that GDP per capita, foreign exchange rate, internet utilization rate, service industry count, consumption index per capita were all verified as determinants of Chinese OFDI to South Korea, and several suggestions were proposed for South Korea to attract Chinese OFDI.

2.2. Research on Factors Affecting OFDI from the Spatial Model

There is representative literatures on the influence factors of the research spatial model and OFDI.

Hyojin Kwak et al. (2021) utilized a spatial panel model that considered cross-sectional dependency among firms, and examined the productivity spillover effects of multinational firms toward other firms within South Korea's electronic component industry, which is the most active in OFDI.

Shin Beumseok (2017) used a spatial econometric model and the methodology was basically that same as Blonigen et al. (2007). It is difficult to clearly cut the determinant of South Korean OFDI and pinpoint a single one of these two because the spatial lag variable shows quite different signs from model to model. All told, it may be safe to say that the determinant of South Korea's OFDI can be either depending on the conditions of host countries.

Huiqun Liu et al. (2022) used the Spatial Durbin Model (SBM) to measure the total factor energy effciency (TFEE) in 29 provinces in China and constructed a panel vector autoregressive (PVAR) model to empirically analyze the dynamic influence of OFDI on TFEE. There is an interaction relationship between OFDI and technological innovation. OFDI can improve TFEE to a certain extent, but the role is still weak and has lagging characteristics.

Fei Shi et al. (2021) analyzed OFDI enterprises in China using geographical information system (GIS) spatial analysis methods, and the change in the spatial distribution of OFDI enterprises in 2018. It explored the influencing factors that had an impact on this change. The factors influencing the spatial distribution of OFDI enterprises have been gradually changing from one dominant factor, technological innovation capability, to four core factors, namely, urbanization level, economic development level, technological innovation capability, and degree of economic openness.

Li, SY and Fabus, M (2019) used a spatial measurement method to test China's spatial pattern change of OFDI in EU member states, and found there were spatial agglomeration effects and spatial spillover effects. The spatial panel analysis method was used to test factors affecting the spatial distribution of China's OFDI in the EU. It is found that market size, technology level, and investment freedom of the host country have positive effects on the location selection of China's OFDI in the EU.

In summary, many scholars have made fruitful achievements in the study of the influencing factors of South Korea's OFDI, and have formed a sound theoretical system, which provides a solid theoretical basis for research in the field. However, combined with the current global economic pattern, it was found that research in this field still has room for expansion. First, in the selection of influencing factors, scholars start from the layout of OFDI in South Korea, mainly considering more economic factors, with a lack of research on the impact of economic factors. Second, in the empirical analysis, the cross-section data is selected to construct more models, resulting in fewer data samples, which makes the model estimation results biased.

Third, there are few studies that incorporate spatial effects into the model, and it is possible to generate biased estimates that affects the accuracy of the results. Therefore, this paper considers the spatial effect to construct an econometric model, empirically analyzes the main factors affecting South Korea's OFDI, and further strengthens the recommendations for different countries.

3. Empirical Method and Data

3.1. Spatial Correlation Test

In the study of regional economic phenomena, we must first test the corresponding spatial correlation, and on this basis, complete the construction of the spatial model. For the target research object, after testing the spatial correlation, if there is spatial correlation, a spatial measurement model is needed. Generally, the spatial autocorrelation in existence can be tested by the following two methods. Method 1, verifies the global spatial autocorrelation, and the most commonly used is the global Moran's I. Method 2, tests the local spatial autocorrelation, and mainly uses the Local G index or the local Moran's I index. This paper uses the global Moran's I index to calculate:

$$Moran's\ I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(Y_i - \bar{Y})(Y_j - \bar{Y})}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}}$$

$$W_{ij} = \begin{cases} 1 & \text{Area } i \text{ and area } j \text{ are adjacent} \\ 0 & \text{Area } i \text{ and area } j \text{ are not adjacent} \end{cases}$$

Where *Yi, Yj* represent observations for the *i*-th or *j*-region, and n represents the number of regions. The Moran's I index reflects the spatial correlation of spatially adjacent inter-regional variables. The value is usually between -1 and 1. Greater than zero is a spatial positive correlation, and less than zero is a spatial negative correlation. The greater the absolute value, the larger the absolute value, indicating the degree of autocorrelation is large. If it is zero, it is irrelevant. In this paper, the spatial correlation is verified using OFDI as an example.

3.2. Spatial Measurement Model

3.2.1. Model Selection

Hordijk and Paelinck (1976) first proposed spatial econometrics. If the region has spatial autocorrelation, a spatial econometric model is needed in the construction of the econometric model. Based on the characteristics and research needs of the research object, this paper selects the spatial lag model to verify the existence of the spatial effect and the factors affecting OFDI.

The main function of the spatial lag model is to verify the spatial spillover effect caused by the dependent variable. At the same time, with the spatial conduction mechanism, the influence factors of the dependent variable can be used in other regions, and the spatial lag

model is expressed with the following formula:

$$Y = \rho W_{\mathrm{y}} + X\beta + \varepsilon$$

Among these, *Wy*, *W*, *X*, and *Y* represent the spatial lag dependent variable, the spatial weight matrix, the explanatory variable matrix, and the dependent variable vector, respectively. ρ denotes a spatial regression coefficient, the significance of which is to reflect the degree of overflow or diffusion for adjacent spatial units. The meaning of the parameter β is to reflect the influence of the independent variable *X* on dependent variable *Y,* and the role of *Wy* lies in the spatial distance. The influence of the spatial distance is reflected, and ε represents the random error vector.

3.2.2. Variable Selection and Data Source Description

Based on the different characteristics of South Korea's OFID, along with more than 60 countries, this paper selects the host country infrastructure (INFR) of the host country, the labor cost of the host country (WAGE), the distance between South Korea and the host country (DIST), the political stability of the host country (Poli), and the host country. The level of technological innovation (TECH), export level (EX), host country resource endowment (RN), market size (GDP) and other indicators are included to verify the impact on South Korea's OFDI.

On the basis of considering the availability of data, this paper selects more than 60 countries as the research object, except for countries where data is difficult to obtain and missing. This paper selects 60 countries along the route as research samples. The data selection interval of this paper is from 2004 to 2018, mainly from the "Korea Foreign Direct Investment Statistics Bulletin", "World Bank Database" and the Global Governance Indicators (WGI) Database.

3.2.3. Model Construction

The empirical analysis of this paper consists of two parts. One verifies the influencing factors of Korea's OFDI, and the other verifies the existence of South Korea's OFDI spatial effect. In a study by Baltagi et al. (2007), two models were constructed. One does not include spatial effect . The second included a spatial effect to verify the impact of South Korea's OFDI. The traditional econometric model that does not contain spatial effects (no "spatial effect") is:

$$\begin{aligned} LnOFDI_{i,t} = \alpha_i + \beta_1 LnGDP_{i,t} + \beta_2 LnWAGE_{i,t} + \beta_3 LnAGDP_{i,t} + \beta_4 LnRN_{i,t} + \beta_5 LnTECH_{i,t} \\ + \beta_6 LnEX_{i,t} + \beta_7 LnPOLI_{i,t} + \beta_8 LnDIST_{i,t} + \beta_9 LnINFR_{i,t} + \gamma_t + \varepsilon_{i,t} \end{aligned}$$

Where *t* represents the year, *i* represents the country, αi and γt represent regional and temporal disturbances, respectively, and $\varepsilon i,t$ represents the disturbance term. The model mainly verifies that South Korea's OFDI is affected by the host country itself, regardless of the influence of neighboring countries on Korea.

The spatial econometric model containing the "spatial effect" is:

$$Lneco_{i,t} = \alpha_i + \beta_1 LnGDP_{i,t} + \beta_2 LnWAGE_{i,t} + \beta_3 LnAGDP_{i,t} + \beta_4 LnRN_{i,t} + \beta_5 LnTECH_{i,t} + \beta_6 LnEX_{i,t} + \beta_7 LnPOLI_{i,t} + \beta_8 LnDIST_{i,t} + \beta_9 LnINFR_{i,t} + \gamma WX_{-i,t} + \gamma_t + \mu_{i,t}, \qquad \mu_{i,t} = \rho W\mu_{-i,t} + \varepsilon_{i,t} \ , |\rho| \leq 1$$

Where *t* represents the year and *i* represents a country along the Belt and Road. αi and γt represent regional and temporal disturbances respectively, $\varepsilon i,t$ represents the disturbance term, and ρ is the spatial lag coefficient. *WX*-it is a spatial lag term used to verify the spatial effect affecting South Korea's OFDI. If *WX*-it is not significant, there is no "spatial effect"; conversely, if one or more *WX*-it are significant, then the spatial effect exists, and the coefficient and significance level of *WX*-it reflects the explanatory variable direction and size of impact.

4. Empirical Results

4.1. Results of the Spatial Correlation Test

This paper introduces the Rook first-order neighbor weight matrix to measure the spatial correlation of South Korea's regional per capita GDP. The results using the GeoDa software to calculate the global Moran's I index are shown in Table 1.

Table 1. Statistics of South Korea's Foreign Direct Investment Moran's I Index

Year	OFDI		Year	OFDI	
	Moran	Pvalue		Moran	Pvalue
2004	0.5012	0.0011	2012	0.5213	0.0011
2005	0.5430	0.0004	2013	0.5231	0.0014
2006	0.5213	0.0012	2014	0.5565	0.0009
2007	0.5089	0.0010	2015	0.5343	0.0010
2008	0.5334	0.0024	2016	0.5321	0.0006
2009	0.5090	0.0004	2017	0.5334	0.0002
2010	0.5121	0.0015	2018	0.5349	0.0022
2011	0.5334	0.0024			

Source: GeoDa software's calculate.

It can be seen in Table 1 that the Moran's I index of OFDI is positive and the magnitude is greater than 0.5, indicating that there is a strong positive correlation spatial effect of OFDI; that is, OFDI is not only affected by the inflow region factor, but also the influence of neighboring countries in the region, such as the impact of resources, talents, information, and technology in neighboring countries in the region. According to this conclusion, the spatial measurement model should be selected when studying the factors affecting OFDI in South Korea, which can more accurately reflect the problem.

4.2. The Results of Spatial Econometric Regression Analysis

In this paper, the maximum likelihood method (ML) proposed by Elhorst (2016) was used, and a space measurement regression analysis is performed via Matlab software. Maximum Likelihood Estimation (MLE) can not only effectively overcome the estimation bias caused by endogenous problems, it can also scientifically reflect the spatial dependence of countries and accurately measure the direction and extent of the influence of the "spatial effect". The estimated results are shown in Tables 2 and 3 below.

Table 2. Regression Results for Spatial Effects Not Considered

Variable	Central Asia	West Asia	South Asia	Southeast Asia	CIS	EU
LnGdp	0.012***	0.142***	0.133***	0.203***	0.244***	0.171***
LnWage	-0.934	-0.124*	0.218**	0.106**	-0.135 *	-0.494**
LnRn	0.504***	0.586***	0.304***	0.481***	0.419***	0.619***
LnTech	0.203	0.278	0.304	0.328	0.217	0.117
LnEx	0.304*	0.124*	0.621***	0.317*	0.205*	0.319*
LnPoli	-0.221	-0.124	0.218	0.332	-0.232	0.121
LnDist	0.117*	0.142	0.124*	0.688*	0.176	0.118
LnInfr	-0.317*	-0.222*	0.517*	0.664*	-0.117*	0.688**

Notes: 1. *p<0.1, **p<0.05, ***p<0.001.
Source: Matlab calculation.

Table 3. Regression Results for Spatial Effects are Considered

Variable	Central Asia	West Asia	South Asia	Southeast Asia	CIS	EU
LnGdp	0.316***	0.217***	0.287***	0.435***	0.323***	0.235***
LnWage	-0.401**	-0.217**	0.342**	0.125**	-0.144**	-0.521***
LnRn	0.518***	0.786***	0.338***	0.533***	0.532***	0.766***
LnTech	0.312	0.324*	0.318*	0.318	0.339*	0.417
LnEx	0.434**	0.438**	0.717***	0.438**	0.333**	0.611***
LnPoli	-0.328*	-0.226	0.338*	0.318*	-0.387*	0.328*
LnDist	0.158**	0.218**	0.555**	0.838***	0.122	0.137
LnInfr	-0.332**	-0.237**	0.539**	0.676**	-0.323**	0.872**

Notes: 1. *p<0.1, **p<0.05, ***p<0.001.
Source: Matlab calculation.

4.2.1. Without Considering Spatial Effect

In this paper, the spatial effect is not included in the spatial econometric model. It can be seen from Table 2 above that at least 6 variables are significant.

Market size of the host country: Among the six regions verified, the elasticity coefficient of market size's impact on South Korea's OFDI is positive; that is, there is a positive impact relationship, and the level of significance is high. Among these, the market size(GDP) of the countries in the Commonwealth of Independent States (CIS) and Southeast Asia have the highest elasticity coefficient for South Korea's OFDI, and when the market size decreases by

1%, OFDI increases by 0.244% and 0.203%. The market size of countries that attract South Korea's OFDI shows that market size is the main factor affecting South Korea's OFDI.

Labor costs in the host country: From the regression results, the labor costs of countries along the CIS , Western Asia and the EU are inversely related to South Korea's OFDI; that is, the lower the wage level, the more attractive OFDI in South Korea. Labor costs in countries along the coast of the EU, West Asia, and CIS are negatively correlated with South Korea's OFDI, and for every 1% decreases, investment increased by 0.494%, 0.124%, and 0. 135%, mainly because labor costs in these countries are much lower than South Korea's. Recently, South Korea has a large investment value in the region relative to the labor cost of domestic labor.

The political stability of the host country: From the regression results, the degree of political stability has an insignificant coefficient of elasticity on South Korea's OFDI, and is positively related to countries along Southeast Asia, South Asia, and the EU, and was negatively related to Central and West Asia and the CIS. The low level of significance means that the political stability of the host country is not an important factor affecting South Korea's OFDI.

Scale of exports: Among the six regions studied, the scale of exports is positively correlated with South Korea's OFDI, with South Asia being the most significant, with a high coefficient of elasticity and a 1% level of significance. When the scale of exports increases 1%, OFDI increases by 0.621%, mainly because South Asia has a larger population and a larger consumption potential determines that the huge consumption potential of South Asia's economy has attracted foreign direct investment willingness and promoted the level of foreign direct investment in South Asia.

The resource endowment of the host country: The resource endowment has a great influence on South Korea's OFDI. From estimation results, the EU, West Asia, and Central Asia have the most significant impact on South Korea's OFDI level, and when the resource endowment of the host country decreases by 1%, OFDI increases by 0.619%,0.586%, and 0.504%, which is mainly due to abundant energy resources such as oil and gas in the region. The development of the economy is limited by the total amount of energy. Every year, a large amount of energy resources need to be imported to meet domestic demand. In countries with resource endowments, South Korea can directly participate in energy mining projects in the host country and increase the pricing power of energy. It is of great significance to the improvement of South Korea's energy supply.

The level of technological innovation in the host country: From the estimation results, the influence of the technological innovation capability of the host country on the level of South Korea's foreign direct investment is not significant. Only when considering the spatial effect, several regions have an impact on South Korea's OFDI at a lower level of significance. Mainly, countries along the Belt and Road are mostly developing, their economic development is relatively backward, the investments in technological innovation is lower, and the overall innovation ability is not strong, so South Korea's OFDI is less affected by the host country, indicating South Korea's OFDI is not technology seeking.

The distance between South Korea and the host country: It can be seen from the regression results that the distance between South Korea and the host country has a greater impact on South Korea's OFDI. The performance is more prominent in Southeast Asian countries. The elastic coefficient of the distance index reaches 0.688%, and is significant at 10%. At the Statistical P value level, West Asia, CIS, and European countries with relatively long distances have no significant impact on South Korea's OFDI. In reality, South Korea's investments are

mainly concentrated in countries along Southeast Asia, accounting for more than 70% of the total, mainly related to distance, and indicating that distance is one of the main factors affecting South Korea's OFDI.

Host country infrastructure: The empirical results show that the infrastructure of the host country reflects different directions of influence in different regions. The better the infrastructure Southeast Asia, South Asia, and European countries, the stronger the willingness of South Korea enterprises to invest. The elastic coefficient of host country infrastructure index reaches 0.688, and is significant at 5%. In Central and Western Asia and the Commonwealth of Independent States, the coefficient of elasticity is negative, and the degree of infrastructure construction in the host country is negatively correlated with South Korea's OFDI. This also shows that South Korea and relevant countries have cooperated on infrastructure, and South Korea is constantly intervening. There is a negative correlation between investments in the field.

4.2.2. Under Consideration of the Spatial Effect

In this paper, the spatial effect is included in the spatial econometric model. It can be seen from Table 3 that at least 8 variables after the inclusion of the spatial effect are significant.

Market size of the host country: Among the six regions verified, the elasticity coefficient of market size impact on South Korea's OFDI is positive; that is, there is a positive impact relationship, and the level of significance is high. Among these, the market size (GDP) of countries in Southeast Asia and CIS has the highest elasticity coefficient for South Korea's OFDI, and the market size of countries decreases by 1%, and OFDI increases by 0.435% and 0.323%. The market size can attract South Korea's OFDI, and shows that the market size is the main factor affecting South Korea's OFDI.

Labor costs in the host country: From the regression results, the labor costs of the EU, and Central and Western Asia, and CIS are negatively related to South Korea's OFDI.The lower the wage level, the more attractive OFDI in South Korea. Among these, the labor cost of European countries has the highest elasticity coefficient for South Korea's OFDI, and when the labor cost decreases by 1%, and OFDI increases by 0.521%.

The political stability of the host country: From the regression results, the degree of political stability has a significant coefficient of elasticity on South Korea's OFDI, and is positively related to Southeast Asia, South Asia, and European regions, and is negatively related to Central Asia and the CIS. The low level of significance means that the political stability of the host country is an important factor affecting South Korea's OFDI.

Scale of exports: Among the six regions studied, the scale of exports was positively correlated with South Korea's OFDI. South Asia was the most significant; with a high coefficient of elasticity and a 1% level of significance, and when the scale of exports increased by 1%, OFDI increased by 0.717% .

The resource endowment of the host country: The resource endowment has a great influence on South Korea's OFDI. From the estimation results, European regions, and West Asia have the most significant impact on South Korea's OFDI level; When the resource endowment of the host country decreases by 1%, OFDI increases by 0.786% and 0.766%, which is mainly due to abundant energy resources such as oil and gas in the region.

The level of technological innovation in the host country: From the estimation results, the influence of the technological innovation capability of the host country on the level of South Korea's foreign direct investment is significant. Only when considering the spatial effect,

several regions have an impact on South Korea's OFDI at a 10% level of significance. The level of technological innovation West Asia, South Asia, and CIS are positively related to South Korea's OFDI, The lower the wage level, the more attractive OFDI in South Korea. Among these, CIS has the highest elasticity coefficient for South Korea's OFDI, and when the level of technological innovation in the host country increases by 1% , OFDI increases by 0.339%.

The distance between South Korea and the host country: It can be seen from the regression results that the distance between South Korea and the host country has a greater impact on South Korea's OFDI. The performance is more prominent Southeast Asian countries. The elastic coefficient of the distance index reaches 0.838%, and is significant at 1%. At the Statistical P value level, the CIS and European countries with relatively long distances have no significant impact on South Korea's OFDI.

Host country infrastructure: The empirical results show that the infrastructure of the host country reflects different directions of influence in different regions. The better the infrastructure in Southeast Asia, South Asia, and European countries, the stronger the willingness of South Korea enterprises to invest. The elastic coefficient of the host country infrastructure index reaches 0.872%, and is significant at 5%.

5. Conclusions and Suggestions

5.1. Conclusions

This paper used a spatial panel data model to analyze factors affecting South Korea's OFDI from the perspective of a spatial model. South Korea's OFDI is significantly affected by spatial effects. In addition, from a traditional perspective, host country heterogeneity factors such as the availability of natural resources, infrastructure levels, and labor costs in the host country also have an important impact on South Korea's OFDI, and have been affected by host countries at different levels of development. The factors are different. Specifically, the main conclusions of this paper are as follows.

The Moran's I index of OFDI is positive and the magnitude is greater than 0.5, indicating that there is a strong positive correlation spatial effect of OFDI. OFDI is not only affected by inflow regional factors, but also affected by neighboring countries in a region. Therefore, the spatial measurement model should be selected when studying the factors affecting OFDI in Korea, which can more accurately reflect the problem.

Among factors affecting South Korea's OFDI, distance, market size, and resource endowment are the most important factors affecting South Korea's OFDI. Technical level and political stability have little effect on South Korea's OFDI, which are not the main factors determining South Korea's OFDI. In general, Korea has a strong desire to invest in countries with large markets, abundant natural resources, and low labor costs. At the same time, the empirical results show that the significance level of each indicator under the third-party effect is significantly improved and the goodness of fit is also improved, indicating that South Korea's OFDI in the 60 countries has a significant impact on spatial effects. South Korea should attach importance to the existence of special effects, continuously strengthen exchanges and cooperation with countries, and promote the healthy development of South Korea's OFDI.

It can be seen that the significant spatial effect means that South Korea's OFID in more than 60 countries is not only related to the two main bodies of South Korea and the host country, it is also closely related to the neighboring countries of the host country.

This study used a spatial model and the methodology was basically the same as Shin Beumseok (2017) and Hyojin Kwak et al. (2021) but the selection data period and the subject countries were better.

Therefore, in the process of foreign investment, South Korea should not only focus on bilateral relations, it should also establish a cooperative win-win mechanism and strive to achieve regional coordinated development. South Korean enterprises should pay attention to the agglomeration effect of South Korea's OFDI, pay attention to experience accumulation, help, maintain a good investment image, establish good long-term cooperative relations with the host country, reduce the blindness of foreign investment or economic and trade cooperation, and more actively and effectively "go out". The paper will explore the countermeasures and suggestions based on the current state of OFDI in South Korea.

5.2. Suggestions

This paper has several suggests to improve the industrial level of investment cooperation and achieve sustainable development of investment cooperation. Through empirical analysis, labor cost, basic implementation, resource endowment and distance all had a significant impact on Korea's OFDI. Furthermore, the results seem somewhat different from the factors of other OECD countries and China's OFDI (KhelifaMazouz et al.,2021, and Guo Zi-Han, Oh Dae-Won 2021) which is in a relatively early stage.

Therefore, we should make full use of the advantages of countries along the route to improve the level of industrial cooperation and improve the quality of investment cooperation. For example, South Korea should make full use of the advantages of countries along the route to carry out investment cooperation, such as low-cost labor in countries, advantages of distance, and advantages of resource endowments, which can make the layout of South Korea's foreign direct investment more reasonable and scientific, which can not only promote the upgrading of the domestic industrial structure, it can also promote the upgrading of traditional industries in the host country and achieve a technology-intensive economic growth mode.

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Is It Possible to Achieve IMO Carbon Emission Reduction Targets at the Current Pace of Technological Progress?*

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Abstract

Purpose – The primary purpose of this study is to verify whether the target set out by the International Maritime Organization (IMO) for reducing carbon emissions from ships can be achieved by quantitatively analyzing the trends in technological advances of fuel oil consumption in the container shipping market. To achieve this purpose, several scenarios are designed considering various options such as eco-friendly fuels, low-speed operation, and the growth in ship size.

Design/methodology – The vessel size and speed used in prior studies are utilized to estimate the fuel oil consumption of container ships and the pace of technological progress and Energy Efficiency Design Index (EEDI) regulations are added. A database of 5,260 container ships, as of 2019, is used for multiple linear regression and quantile regression analyses.

Findings – The fuel oil consumption of vessels is predominantly affected by their speed, followed by their size, and the annual technological progress is estimated to be 0.57%. As the quantile increases, the influence of ship size and pace of technological progress increases, while the influence of speed and coefficient of EEDI variables decreases.

Originality/value – The conservative estimation of carbon emission drawn by a quantitative analysis of the technological progress concerning the fuel efficiency of container vessels shows that it is not possible to achieve IMO targets. Therefore, innovative efforts beyond the current scope of technological progress are required.

Keywords: Carbon Emissions, Container, Technological Progress, IMO
JEL Classifications: Q55, Q56, R41

1. Introduction

Starting with the Marine Pollution Treaty (MARPOL) in 1973, the International Maritime Organization (IMO) has discussed the reduction of air pollutant emissions and proposed various regulations on environmental protection. The Marine Environmental Protection Committee (MEPC), at its 72nd session held in 2018, adopted an initial strategy on the reduction of greenhouse gas (GHG) emissions from ships. To reduce GHG emissions from the shipping sector, they set targets to reduce the Carbon Intensity Indicator (CII), the average emission per transport unit, by at least 40% by 2030 compared to the 2008 level, and 70% by

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2050. For a long-term goal, it aims to reduce the total GHG emissions from the shipping sector by 50% by 2050 compared to the 2008 level.

Since 2013, the Energy Efficiency Design Index (EEDI) has been applied to newly built ships, and it is scheduled to be applied to existing ships from 2023 (MEPC 76). To meet this mandatory measure once it comes into effect, existing ships would have to lower their CII by 2% annually from 2024 to 2026 based on 2019. The number of the global fleet was 86,082 in 2012 when the EEDI regulation was not yet implemented, which is 86.6% of the 99,430 ships as of 2020. Existing ships ordered before 2012 are likely to fall short of the ratings required by the regulation. According to a survey by the Ministry of Oceans and Fisheries, only 15% (146 ships) of the 990 national-flag vessels satisfy the Energy Efficiency Existing Ship Index (EEXI) regulation (Ministry of Oceans and Fisheries, 2021).

As of 2020, container ships, the subject of this study, only account for 5.4% (5,400 vessels) of the world's total fleet. However, they cover 17% of global vessel travel as well as 25% of the total ship fuel consumption indicating a high proportion of fuel consumption compared to other ship types (Czermański et al., 2021). In addition, containers have a high cargo value among various maritime trades as they are responsible for transporting intermediate and final goods. They are also closely related to the real economy. Containers are a type of ship that can be markedly affected by environmental regulations; for example, if a carbon border tax promoted by the European Union (EU) is imposed, the high fuel consumption by containers will increase the burden on shipowners.

There are three main approaches to achieve carbon-neutrality in the shipping sector. The first involves a policy approach, which comprises the enactment of laws and regulations. In addition to the mandatory measures of the IMO to reduce the carbon intensity of ships, the EU confirmed the introduction of a carbon border tax in July 2021. A carbon neutrality law is being promoted in Korea, and voluntary participation through RE100 is taking place in the private sector. The second approach involves shipping companies attempting to reduce carbon emissions through changes in ship operation and navigation methods. The average container speed was recently lowered to around 14 knots compared to over 19 knots in 2008, thereby fuel efficiency has been improved. In addition, shipping companies are lowering CII by increasing vessel size and improving fuel efficiency by optimizing navigation routes. The third approach is a strategy to minimize ship emissions through technological progress. In addition to improvements in engine designs and hull shapes, fuel consumption can be further reduced by installing solar and wind-powered equipment. Furthermore, to achieve complete carbon neutrality, it is necessary to introduce zero-carbon ships that use hydrogen or ammonia as a marine fuel, and plans are simultaneously being promoted to produce such fuels through eco-friendly methods.

The primary purpose of this study is to verify whether the target set out by the IMO for reducing carbon emissions from ships can be achieved by quantitatively analyzing the trends in technological advances in fuel oil consumption in the container shipping industry. Fuel efficiency improvement for each year-of-built and EEDI regulation is added to the variables used in previous papers for consumption estimation. The inclusion of the year-of-built variable is one of the main points that differentiate this paper from existing research because the change in fuel efficiency along the timeline is interpreted as technological advances.

The structure of this paper is as follows: Chapter 2 reviews existing papers relating to IMO regulations and carbon emission; Chapter 3 estimates the fuel consumption of container ships by measuring the technological progress; Chapter 4 estimates carbon emissions by 2050,

considering the technological progress; and Chapter 5 draws conclusions and implications of the study.

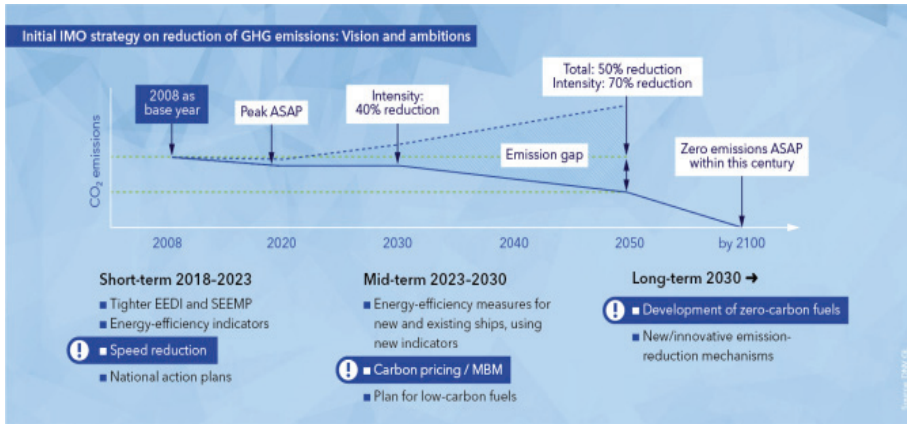
2. Literature Review on Carbon Emission in the Shipping Sector

2.1. IMO Regulations

IMO regulations on GHG emission started with the Resolution adopted at the IMO Assembly held in December 2003 and implemented from the 62nd session of the MEPC held in July 2011. The MEPC adopted the Resolution on ship energy efficiency regulations at its 62nd session, introducing the EEDI for new ships and Ship Energy Efficiency Management Plan (SEEMP) under MARPOL Annex VI Regulations. It also adopted the Resolution on data collection on ships' fuel consumption at the 70th session and a long-term roadmap for reducing the total GHG emissions at the 72nd session in 2018.

The Resolution adopted at the 72nd session of the MEPC states that the CII, the fuel efficiency index of the shipping sector, should be improved by 40% or more by 2030, and the total GHG emissions from the shipping sector should be reduced by 50% compared to 2008 level. The ultimate goal is to achieve zero GHG emissions by 2100. The MEPC confirmed at its 76th session that the fuel efficiency for existing ships should be regulated from the end of 2022. Vessels of 5,000 G/T or more, which are currently operating, are required to record the method of CII calculation to be applied from 2023 in the SEEMP by the end of 2022. The attained CII rating ranging from A to E should be calculated based on the annual fuel consumption performance reporting system i.e. Data Collection System (DCS). For ships that record an E rating for three consecutive years, a corrective energy efficiency improvement plan must be submitted. Furthermore, these ships can only operate if they are additionally equipped with power-limiting or energy-reducing devices. The CII regulations have become increasingly strict each year; by 2023, ships are required to reduce GHG emissions by 5%compared to the 2019leveland by an additional 2% each year until 2026.

Fig. 1. The IMO Goal to Reduce GHG Emissions



Source: DNV·GL (2019).

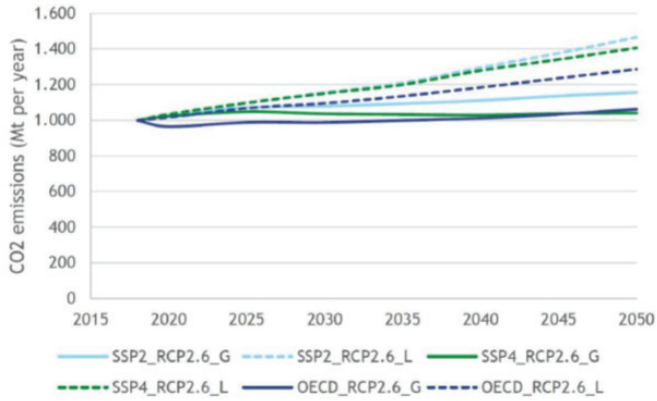
2.2. Literature on Carbon Emissions in the Shipping Sector

2.2.1. Carbon Emission Study Conducted by the IMO

The IMO has researched carbon emissions since 2000, and the latest outcome was the 4th IMO Greenhouse Gas Study published in 2020. This study estimates GHG emissions using the bottom-up and top-down approaches. The bottom-up approach estimates transport demand using GDP, population growth, and socio-economic scenarios; subsequently, the fuel consumption is estimated to calculate GHG emissions by predicting the fleet based on the size of the ship and by estimating ship fuel consumption using fuel efficiency. Consequently, various factors such as GDP, population, and urbanization are used and the socio-economic path as presented in studies by van Vuuren et al. (2011) and Riahi et al. (2017) is also applied for the construction of five energy scenarios. The top-down approach derives estimations using the sales volume of fuel oil used in shipping, the methodologies and assumptions of which are the application of the method used by the International Energy Agency (IEA, 2020).

According to the IMO (2020), GHG emissions are projected to increase from 1 billion tons in 2018 to up to 15 billion tons in 2050. This is an increase of 0-50% and 90-130% compared to 2018 and 2008 levels respectively.

Fig. 2. Projections of GHG Emissions by the IMO



Source: IMO (2020), p. 37.

2.2.2 Literature on Ship Fuel Consumption and Carbon Emissions

Machine learning is being used to estimate carbon emissions using fuel consumption. Wang et al. (2018); Uyanik, Karatuğ, and Arslanoğlu (2020); and Moreira, Vettor, and Guedes Soares (2021) make estimations using Lasso, Support Vector Regression (SVR), and Artificial Neural Networks (ANN). In most studies, including Meng, Du, and Wang (2016), ship length, width, speed, and wave height are used to estimate significant variables. Le, L. T. et al. (2019) derives an estimation model using the speed and operating time for five ship classes, which are identified from operation data of 100 to 143 container ships that operated between 2012 and 2016. Lu, Turan, and Boulougouris (2013) predict that improving energy efficiency through operational optimization would reduce GHG emissions. Accordingly, a novel fuel

consumption estimation formula is derived based on the modeling suggested by Kwon (2008) for Suezmax tankers.

Johansson, Jalkanen, and Kukkonen (2017) present the Ship Traffic Emission Assessment Model that can estimate pollutant emissions (nitrogen oxide, particulate matter, and GHG) by continent and size by analyzing 8 billion AIS data from 90,000 ships as of 2015. The result shows that bulk carriers and tankers emit 4.7g and 6.1g of carbon per ton·km respectively and containers emit 9.7g. Psaraftis and Konovas (2009) estimate the GHG emissions of the global merchant fleet (bulk, tanker, container, LNG/LPG, and Ro-Ro ship) using the ship data of Lloyds-Fairplay. They show that 840 million tons of GHGs have been emitted as of 2007, assuming an annual operation of 320 days.

Cariou (2011); Lindstad, Asbjørnslett and Strømman (2011); and Chang and Chang (2013) study the reduction of GHG emissions through a low-speed operation. Lindstad, Asbjørnslett and Strømman (2011) suggest that the amount of GHG emissions could be reduced by 62% when the container ship speed (relative to the design speed) is reduced by 67%. Chang and Chang (2013) measure the change in carbon emissions when decelerating the average ship speed (14.4 knots) by 10/20/30%, resulting in the decrease of carbon emission by 19/36/56% respectively.

Gilbert (2014) and Bouman et al. (2017) introduce technologies that can minimize GHG emissions in the shipping sector. Notably, Bouman et al. (2017) identify six major fields (hull design, vessel enlargement, power and propulsion, speed, fuel, weather, and schedule) and 22 sub-fields where GHG emissions can be minimized. The results of reduction estimation indicate that a significant reduction in GHG emissions is impossible unless eco-friendly fuels such as hydrogen and ammonia are used.

2.2.3 Literature on Applications of Technological Changes

The 3rd and 4th IMO Greenhouse Gas Studies published in 2014 and 2020 consider technological progress. The 3rd IMO Greenhouse Gas Study (2014) collectively reflects the effects of EEDI application from Phase 0 to Phase 3. Since EEDI has only been applied to new ships built since 2013, the absence of related information is complemented by assumptions regarding fuel consumption reduction.

Table 1. Fuel Consumption Reduction by EEDI Application

Reduction relative to original baseline	Reduction relative to baseline, taking SFC into account
0%	-7.5%
10%	2.5%
20%	12.5%
30%	22.5%

Note: SFC refers to specific fuel consumption.
Source: IMO (2014), p. 280.

The 4th IMO Greenhouse Gas Study (2020) applies technological progress that is divided into 16 groups. The projections for 2050 are made based on scenarios regarding penetration rates of new technologies in the areas of alternative fuels, weight-lightening, and engine improvements.

The IEA (2020) projects that carbon emissions would be reduced by more than 60% by using new technologies, including eco-friendly fuels, that are not currently commercialized. Looking at the relative contribution to carbon emission reduction, the reduction effect of technological improvement and eco-friendly fuel is greater than that of operational efficiencies such as fleet optimization and low-speed operation.

3. Estimation of Technological Progress (Methodology)

3.1. Data

The data used to estimate the fuel consumption is the container ship database provided by IHS as of 2019. It includes various data such as IMO number, ship size (e.g., length), number of loadable containers, country of construction, shipyard, fuel consumption, design speed, and engine type. As of 2019, about 5,300 container ships are in operation, of which information on 5,260 ships is included in this DB (Clarkson, 2021). However, the fuel consumption records of some ships are missing in this DB hence, data for 4,744 ships are used for the study.

The descriptive statistics on the fuel consumption (ton/day), the number of loadable containers (TEU), design speed for ship operation (knots), and year of built are shown in Table 2. The statistics on the EEDI variable are not presented as they are dummy variables to show whether the ships are built after 2015. The average daily fuel consumption is 113 tons, and the average number of loadable containers is 4,391TEU, the average design speed is 21.2 knots, and the mean year of construction is 2007. The standard deviation of the number of loadable containers is found to be very large at 3,971.5 due to the ship size increases.

The design speed shows the highest correlation with ship fuel consumption (0.8555), followed by the number of loadable containers (0.8147) and the year of built (0.2214).

Table 2. Descriptive Statistics by Variables

Variables	Average	Maximum	Minimum	Standard deviation
Fuel consumption (ton/day)	112.9	326.1	4.3	78.4
Number of loadable containers (TEU)	4,391.1	21,237.0	95.0	3,971.5
Design speed (knots)	21.2	10	27.5	3.04
Year of built	2006.9	2019	1971	6.49

Table 3. Correlation between Variables

Variables	Fuel consumption	Number of loadable containers	Design speed	Built year
Fuel consumption	1			
Number of loadable containers	0.8147	1		
Design speed	0.8555	0.5594	1	
Built year	0.2214	0.4085	0.1585	1

3.2. Research Model

Studies on carbon emissions in the shipping sector generally estimate the fuel consumption based on ship size and speed and occasionally use actual operational data such as weather data e.g., wind, wave height. Wang et al. (2018) and Le et al. (2020) estimate fuel consumption using variables such as ship size and speed. Moreira and Vettor, Guedes Soares (2021), and Uyanik, Karatuğ, and Arslanoğlu (2020) use machine learning to improve the accuracy of estimation.

In addition to ship speed and size which have been used in previous studies, the estimation in this study considers the pace of technological progress and EEDI with the year of construction. The reduction rate of fuel consumption according to the year of construction of the ship can be interpreted as 'technological progress'. The EEDI variable is applied as a dummy variable because the IMO mandated a 10% reduction in fuel efficiency for all ships built after 2015. Tokuşlu, A. (2020) includes the EEDI variable in estimating the reduction of fuel consumption. This research expands the scope of container vessels to the entire container fleet built since 2015 while Tokuşlu, A. (2020) restricted his analysis to the operation data of one vessel.

$$\ln(fuel\_consumption) = \beta_1 + \beta_2 \cdot \ln(ship\_speed) + \beta_3 \cdot \ln(ship_{size}) + \beta_4 \cdot built\_year + \beta_5 \cdot dm\_EEDI + \varepsilon$$

- fuel_consumption: Amount of fuel consumed by the ship (MT)
- ship_speed: Design speed for ship operation (KTS)
- ship_size: Number of loadable containers (TEU)
- built_year: Year of construction
- EEDI: Ships subject to the regulation (Phase 1: ships built after 2015)

3.3. Empirical Results

3.3.1. Results of Linear Regression Analysis

Two models are applied to review the difference in variables before and after applying EEDI. The result shows that the construction year of the ship affects fuel consumption. The fuel consumption changes 0.8% on the year of construction in Model 1, which excludes the EEDI variable, and 0.57% in Model 2. Since the main object of this study was to estimate the pace of technological progress, the fuel consumption reduction coefficient of 0.57% derived from Model 2 was used to estimate the future carbon emission of container ships.

Speed has the most significant influence on the fuel consumption of container ships; the fuel consumption increased by 2.5% when the speed increases by 1%. The ratio is close to the 'Cube Rule'. The fuel consumption increases by 0.5% when the size of the ship increases by 1%, indicating that the scale economy is functioning. The influence of the EEDI variable applied to ships built after 2015 is estimated to be 10.8%, which indicates that the ratio of 10% in the first phase of EEDI regulation is abided by.

Linear regression analysis requires independence among variables because the reliability decreases if the correlation is high. Therefore, multicollinearity between variables included in the model must be verified, for which the most commonly used method is Variance Inflation

Factor (VIF) analysis. The result of multicollinearity verification shows that the values of the VIF of all variables are below 3, confirming no problem. The criteria for multicollinearity is a VIF of 10 or higher.

Table 4. Linear Regression Analysis Results

Variable	Model 1	Model 2
Constant	8.696912*** (11.76717)	4.292152*** (05.279854)
ship_speed	2.553202*** (116.4059)	2.492840*** (112.4754)
ship_size	0.501157*** (128.8189)	0.505501*** (131.3665)
built year	-0.00799*** (-21.7976)	-0.005712*** (-14.05790)
dm_EEDI		-0.108156*** (-12.16762)
$\bar{R}^2$	0.96659	0.967595

Note: *** means coefficients are significant at 1% level.

Table 5. Multicollinearity Verification Results (VIF)

Variables	VIF value
Constant	-
ship_speed	2.61
ship_size	2.92
built year	1.61
dm_EEDI	1.42

3.3.2. Results of Quantile Regression Analysis

In addition to the linear regression analysis for the estimation of all ships, quantile regression analysis is used to analyze how the coefficients vary from small to large vessels.

Unlike linear regression analysis using the mean, quantile regression analysis uses the median value. While linear regression analysis minimizes the prediction error (e_i)by minimizing $\sum_i e_i^2$ using the ordinary least squares (OLS), quantile regression minimizes $\sum_i |e_i|$. This study used a linear programming method for optimization, in the same way as the least-squares method or the most-likelihood estimation method. The q^{th} quantile regression estimator $\hat{\beta}_q$ is minimized for the following objective function β_q.

$$Q(\beta_q) = \sum_{i:y_i \geq x_i'\beta}^{N} q|y_i - x_i'\beta_q| + \sum_{i:y_i < x_i'\beta}^{N} (1-q)|y_i - x_i'\beta_q|$$

This method has several advantages. First, estimates from quantile regression analysis can lead to more robust estimates than linear regression which responds significantly to outliers

and is inefficient when the dependent variable is not normally distributed. Second, various characteristics that affect variable properties can be obtained. This study seeks the difference in the degree of the influence of each variable, depending on the quantile of fuel consumption. Third, unlike the least-squares method, the consistency of the quantile regression estimator is not dependent on the presence of a conditional mean. Fourth, since quantile regression is not affected by monotonic transformation, the inverse transformation can be used to interpret the results (Cameron, A. C. and P. K. Trivedi, (2010)).

Quantile regression analysis results reveal that the influence of the speed, which has the most significant influence on fuel consumption, gradually decreased from the 1st quantile (low fuel consumption) to the 9th quantile (high fuel consumption). On the other hand, the influence of ship size increases as the quantile increases. The effect of the built year (as a coefficient for technological progress) increases as the size of the ship increases. The effect of the pace of technological progress is only 0.44% in the 1st quantile, which doubles to 0.86% at the 9th quantile. This shows that a relatively more significant improvement in the technological progress for large ships than that for small ships results in higher fuel efficiency for large ships.

Table 6. Results of Quantile Regression Analysis

Ship size	**1st quantile**	**2nd quantile**	**3rd quantile**
Constant	0.444922	-2.19143**	0.425707
ship_speed	2.991615***	3.006738***	2.867138***
ship_size	0.4369***	0.432543***	0.460277***
built year	-0.00436***	-0.00303***	-0.00421***
dm_EEDI	-0.1361***	-0.1294***	-0.1346***
$\bar{R}^2$	0.822464	0.832568	0.843287
Ship size	**4th quantile**	**5th quantile**	**6th quantile**
Constant	2.242242***	2.869113***	3.094442***
ship_speed	2.541143***	2.430732***	2.283524***
ship_size	0.506917***	0.524525***	0.542092***
built year	-0.00478***	-0.00498***	-0.00492***
dm_EEDI	-0.17756***	-0.12333***	-0.12911***
$\bar{R}^2$	0.848418	0.847616	0.845609
Ship size	**7th quantile**	**8th quantile**	**9th quantile**
Constant	5.640926***	6.564444***	10.95583***
ship_speed	2.200705***	2.037928***	2.07712***
ship_size	0.554463***	0.572928***	0.565929***
built year	-0.0061***	-0.00637***	-0.00857***
dm_EEDI	-0.05812***	-0.04288***	-0.02882**
$\bar{R}^2$	0.836597	0.823849	0.793028

Note: *p<0.1, **p<0.05, ***p<0.001.

The change in the coefficient value for each quantile shows the change in the variables according to the fuel consumption. The coefficient values of ship speed and year of construction decrease as the quantile increases, while the coefficient values of ship size and EEDI variables increase as the quantile increases.

4. Estimation of Carbon Emissions by Container Fleet

Considering the IMO regulations have been applied since 2008, carbon emissions are estimated using the formula for estimating fuel consumptions as presented in Chapter 3. As of 2008, a total of 4,398 container ships were operated with an average operating speed of 19 knots (Clarkson, 2021). The average number of sea days is 250 days as applied by Czermański et al. (2021), and the fuel consumption during berthing and anchoring is applied as 6.0% of that of the sea days following Comer et al. (2017). When estimating carbon emissions based on the estimated fuel consumption, the suggested conversion factor of 3.114 is applied following IMO (2020). As a result, as of 2008, the container ship used 74.03 million tons of fuel and emitted 230 million tons of carbon.

Table 7. Carbon Emission Estimation of Container Fleet as of 2008

Category	Less than 3,000TEU	3,000-7,999TEU	8,000-15,000TEU	15,000TEU or more
Daily fuel consumption based on fleet, 2008	47.3	87.4	119.4	166.7
Number of ships in operation	3,096	1,131	164	7
Year of construction	1998	2002	2005	2007
Total fuel consumption (navigation + berthing/ anchoring)			74,028	
Carbon emission (thousand tons)			230,523	

The later the newbuilding of ships, the better the efficiency of fuel consumption because of the application of EEDI and technological progress. As of the end of 2019, the mean year of construction of 3,000-7,999TEU-class ships is 2007, and the average size is 4,909TEU. The fuel consumption of these ships is estimated at 65.8 mt/day. However, that of ships built in 2030 is expected to decrease to 45.1 mt/day and those built in 2050 to 38.1 mt/day. Such an improvement is similar for all types of ships, and the fuel efficiency of ships built in 2050 is expected to be improved by 30% from the 2020 level.

Owing to technological progress in ships, the amount of carbon emitted by one container ship is expected to decrease to below-50% in 2050 compared to 2008 levels. On the other hand, as of 2019, the number of container ships increased by 20.7% and the capacity by 101.9%, compared to 2008 levels. For simplicity in estimating carbon emissions, it is assumed that the container fleet in 2019 remains the same throughout 2050, and efficiency increases annually. The result shows that carbon emissions are estimated to decrease by 35.2% in 2050 compared to 2008 levels. In other words, if the current pace of technological progress is

maintained, it is not possible to meet the IMO target of reducing carbon emissions by 50% compared to the 2008 level. Moreover, since the analysis assumes the fleet is unchanged, it will be even harder to satisfy the IMO carbon emission regulations with the fleet growth in the future.

Table 8. Projection of Fuel Consumption and Carbon Emission

Unit: tons, thousand tons

Category	Less than 3,000TEU	3,000-7,999TEU	8,000-15,000TEU	15,000TEU or more	Carbon emissions (thousand tons)
2008	47.3	87.4	119.4	166.7	230,523
2020	28.8	54.9	80.4	107.8	214,568
2030	23.7	45.1	66.4	89.4	177,000
2040	22.1	41.9	61.7	83.1	164,540
2050	20.0	38.1	56.0	75.4	149,363

Note: Assuming 17 knots of speed, the fuel consumption for each ship type is calculated based on the average size of each ship class. Fuel consumption by type is applied when estimating carbon emissions for 2020, 2030, 2040, and 2050.
Source: Author's estimation.

5. Conclusion

In this study, first, the current technological progress is quantitatively analyzed and applied to estimate future carbon emissions. The empirical analysis demonstrates that the annual technological progress of container ships is estimated to be 0.57%. However, the IMO GHG emission regulations would not be satisfied with the current pace. Even under the assumption that the number of container ships in 2019 remains the same until 2050 while technological progression in fuel efficiency sustains, the decrease in carbon emissions was limited to 35.2% compared to 2008 levels. Second, the results of quantile regression analysis show the effects of difference in technological progress on the fuel consumption level of the ships; the higher the fuel consumption, the higher is the improvement in fuel efficiency. This indicates that CII would markedly increase as the enlargement of ships progressed. Third, using the ship DB, a fuel consumption estimation formula is devised based on the ship size, speed, and year of construction, enabling the estimation of fuel consumption and carbon emissions of the container fleet in 2008, leading to the estimation that the carbon emissions would be reduced by 2050. Fourth, it is confirmed that the EEDI regulations, which were initiated in 2013, have been applied to container fleets. This study, which performs the EEDI analysis on the entire container fleet, is significant because its results can be compared to the results reported by Tokuşlu, A. (2020), which reviews the EEDI satisfaction of one container ship.

However, this study has some limitations. The carbon emission projection is underestimated because the size of container fleets between 2020 and 2050 is anchored to the 2019 level. In addition, carbon emissions are estimated using the specifications of the vessel, while the possible differences caused by the distance and speed of the ship are not reflected. This research can be meaningfully expanded in the future when scenario analyses and other models such as system dynamics or AI models are employed.

Recently, large shippers, such as Amazon and IKEA, announced that they would transport cargo using zero-emission vessels from 2040 (Lloyd's List, 2021). Currently, "how" is more important than "how much" in ocean transportation. Recently, the selection criteria for large forwarders as well as shippers include the fleet operation with eco-friendly ship certifications or efforts against GHG emissions. Gilbert (2014) warns that short-sighted and weaker regulations may weaken their enforcement power by offering various alternatives to shipping companies. Since IMO regulations are challenging to conform to at the current pace of technological progress, it is time for shipping companies to make additional changes to achieve carbon neutrality.

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