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The Effect of Economic and Infrastructure Factors on the Formation of Electric Vehicle Supply Chain and Optimal Location Selection: Korea–US FDI*

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Abstract

Purpose – This study aims to present the changes and directions in the automotive supply chain in the face of changes in the global supply chain caused by external factors and the integration of industries resulting from internal factors. Assuming FDI in the Korean automotive industry in the US, this study analyzed the influential factors over the long term and derived the optimal location.

Design/methodology – For this analysis, the characteristics and current status of the automotive industry are presented. Additionally, the study emphasizes the necessity and direction of change. The factors influencing Korea–US FDI in the automotive industry and the electric vehicle industry were analyzed through panel analysis. The optimal location from the perspective of distribution costs was selected using linear programming under the assumption that local demand will be replaced by local production in the future.

Findings – This study found that the electric vehicle supply chain will change with the characteristics of the electric and electronic industries rather than with the traditional automotive industry. Additionally, in deriving the optimal location, the study emphasized the proximity to the consumption market.

Originality/value – The analysis method and conclusions of this study not only present the influential factors and direction of FDI in the automotive industry but also can be applied to other industries. Moreover, the study provides practical and policy implications for industries and governments considering FDI in the US.

Keywords: Automotive Industry, FDI; Panel Analysis, Supply Chain Management, Trade Policy
JEL Classifications: F13, F23, L11, L62, N72

1. Introduction

In May 2022, Hyundai Motors announced the establishment of a new electric vehicle plant in the US with a capacity of about 300,000 units. The Hyundai Motor Group is already operating production plants in Alabama and Georgia, each with a capacity of 350,000 units. Including production at the new plant, Hyundai will produce about one million units out of the 1.49 million units sold in the US in 2021 (Korea Automobile Manufacturers Association, 2021).

This has great implications for trade, logistics, and commerce. Since President Trump took office in 2017, the US has continuously pressed for investment in major industries such as

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automotive, electronics, and steel. This stance has been upheld by President Biden, and amid the COVID-19 pandemic, this has caused the major supply chains of the US to move away from being centered on China. Instead, supply chains are being reorganized such that they center on US allies. Through such a reorganization, the automotive supply chain, which follows a just in time (JIT) production philosophy, provided a lesson that supply chains should center on efficiency and trust between allies (Kim Yang-Hee, 2019; Ha Young-Kyou and Woo Su-Han, 2021). Further, the automotive industry is in the process of transitioning from vehicles with internal combustion engines to electric motor vehicles due to technological advances and global collaboration on environmental pollution. Both the internal and external environments of the industry are in the midst of change, and countries involved in the automotive industry are contemplating how to dominate the supply chain. Therefore, it is crucial to examine the current supply chain changes and provide guidance for the future.

The supply chain or procurement logistics of the automotive industry have been studied from various perspectives. However, there is limited research on the field's rapidly evolving internal and external environments. Moreover, there is limited literature on the factors that influence the automotive supply chain, as well as those that cause supply chains to integrate with other industries (Chung Ki-Ho, 2007; Kim et al., 2008; Jung Sung-Gug, 2011).

Therefore, this study aims to identify the changes in the factors that influence existing supply chains and electric vehicle supply chains, focusing on the Korean automotive industry in the US. Assuming further expansion of electric vehicle factories, this study focuses on identifying the factors forming the supply chain using panel analysis. The study also uses linear programming to derive an optimal location and distribution plan. The detailed analysis method is as follows.

First, in the panel analysis, economic and logistics infrastructure factors are assumed to influence the formation of the automobile supply chain. Under this assumption, economic and logistics infrastructure data from 30 major US states were selected as independent variables. Further, assuming that foreign direct investment (FDI) is proportional to the formation of the supply chain, FDI in the Korea–US automotive industry and electric vehicle industry were selected as dependent variables. Thus, allowing for an analysis of the factors influencing FDI in this industry.

Second, the optimal location and distribution plan were derived on the assumption that 500,000-unit electric vehicle plants would be expanded to the existing one-million-unit production plants to sufficiently meet local demand. According to the results of the panel analysis, three regions with high FDI-influencing factors were selected for the 500,000-unit plants, and the optimal distribution plan was derived by assuming that the location where distribution reached the existing one million units is the optimal location.

This study offers academic, practical, and policy implications. From an academic perspective, it will allow to investigate the causes, effects, and results of supply chain reorganization in trade, logistics, and commerce. From a practical perspective, it offers an insight into establishing new electric vehicle plants and configuring supply chains in the future. From a policy perspective, the study offers implications for government and industry investment in the US, in addition to providing background information for political and diplomatic negotiation strategies regarding US trade regulations.

2. Characteristics of the Automotive Industry and Existing Research

2.1. Current Status and Prospects

Global finished vehicle production was once expected to exceed 100 million units per year but has declined slightly since peaking in 2018. It fell below 80 million units in 2020 due to the impact of COVID-19. Additionally, 2021 saw only a slight increase in year-on-year sales, and production did not recover to its pre-COVID-19 level.

Table 1. Global Automobile Production Status

(Unit: Million Units)

-		2016	2017	2018	2019	2020		2021	
1	China	28.1	29.0	27.8	25.7	China	25.2	China	26.1
2	USA	12.2	11.2	11.3	10.9	USA	8.8	USA	9.1
3	Japan	9.2	9.7	9.7	9.7	Japan	8.1	Japan	7.8
4	Germany	6.2	6.2	5.6	5.1	Germany	3.8	India	7.8
5	India	4.5	4.8	5.2	4.5	Korea	3.5	Korea	3.4
6	Mexico	3.6	4.1	4.1	4.0	India	3.4	Germany	3.4
7	Korea	4.5	4.1	4.0	4.0	Mexico	3.1	Mexico	3.1
8	Brazil	3.6	2.8	2.9	2.9	Spain	2.3	Brazil	2.2
9	Spain	3.0	2.7	2.8	2.8	Brazil	2.0	Spain	2.1
10	France	2.2	2.3	2.3	2.2	Russia	1.4	Thailand	1.7
Total		94.9	98.7	98.5	93.2	Total	78.2	Total	79.8

Source: Korea Automobile Manufacturers Association (2021).

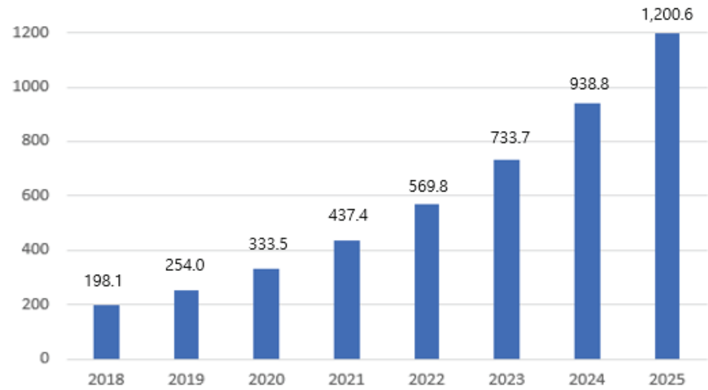
However, despite a decrease in overall production and a change in most of the top 10 rankings 4th to 10th places, China, the US, and Japan retained the top three spots. Although these rankings will remain the same for the foreseeable future, the electric vehicle supply chain may cause a change in the top three spots. Data on sales volume[1] of electric vehicles and policies to expand eco-friendly cars by country support this conjecture. Electric vehicle sales increased from 2.54 million units in 2019 to 4.374 million units in 2021 and are expected to reach 12 million units by 2025. Additionally, as the US, EU, and China decide to stop producing or selling internal combustion engine vehicles around 2030, the demand and supply of electric vehicles are expected to increase further.

Owing to this expected rise, Korean battery makers are already increasing local investment through joint ventures with several US companies. Hyundai Motors has announced the opening of an electric vehicle plant despite a drop in production across the automotive industry. It is not clear whether automobile production will return to its pre-COVID-19 levels, but the rankings in Table 1 may change depending on investment in the electric vehicle supply chain.

Many researchers have argued that FDI is motivated by avoidance of trade regulations, cost savings, securing sales bases, and aggregation of the same industry, investment in electric vehicles in the US will continue to expand in the future (Suh Jeong-Wook, 2004; Sturgeon et al., 2008; Akcaoglu and Erol, 2011; Underwood, 2012; Kim Jong-Wook, 2020).

[1] The sum of electric vehicles and plug-in hybrids.

Fig. 1. Global Electric Vehicle Sales Forecast and Plans to Expand Eco-friendly Vehicles in Major Countries

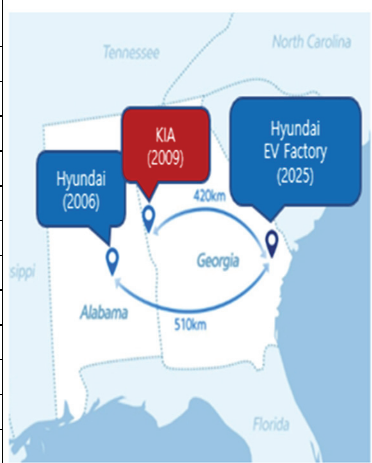


Sources: Bank of Korea (2022).

Table 2. Major Production Status Related to Electric Vehicles in Korea

(Unit: GWh[2]/Year)

Battery OEM	Joint Venture	State	Capa	Production
LG Energy Solution	GM	Ohio	35GWh	2022
		Tennessee	35GWh	2023
		Michigan	50GWh	2025
	Stellantis	Canada	40GWh	2024
	-	Michigan	5GWh	2022
		Arizona	11GWh	2024
SK ON	Ford	Tennessee	43GWh	2025
		Kentucky	43GWh	2025
		Kentucky	43GWh	2026
	-	Georgia	9.8GWh	2022
		Georgia	11.7GWh	2023
Samsung SDI	Stellantis	Indiana	23GWh	2025



Sources: US Department of Energy (2022) and Hyundai Motors (2022).

2.2. Factors Influencing the Automotive Supply Chain and the Need for FDI

The factors influencing the supply chain of the Korean automotive industry can be largely divided into trade regulations, trade wars, and COVID-19. Trade regulations and wars can

[2] Assuming that the Tesla standard model is 51 kWh with 1 GWh = 1,000,000 kWh, 10 GWh is the amount that can produce 200,000 electric vehicles.

be considered similar, but with a key difference: trade regulations target a specific country or item, and trade wars are policy and institutional regulations between countries (Ha Young-Kyou and Woo Su-Han, 2019/2020).

Table 3. Status of Trade Regulations for Korea by Country (steel regulations in parentheses)

-	Total	Number of Cases by Regulating Country							
		USA	India	China	Türkiye	Canada	Brazil	Thailand	etc.
2013	127	11 (8)	24	17	10	4	10	5	46
2014	158	15 (12)	28	11	14	8	11	7	64
2015	166	18 (12)	26	12	12	8	11	7	72
2016	180	23 (18)	32	13	10	8	10	12	72
2017	187	31 (20)	28	14	15	10	11	9	69
2018	194	38 (28)	26	16	15	14	11	8	66
2019	210	40 (30)	32	17	15	13	10	7	76
2020	229	46 (33)	34	16	14	13	7	9	90
2021	210	47 (33)	17	14	19	14	6	8	85

Source: KOTRA (2022).

Trade restrictions on the automotive industry or related sectors entail high tariff policies, instances of regionalism such as the USMCA[3] (the US, Mexico, Canada), and the Trade Expansion Act[4]. The US government has simultaneously restricted imports of Chinese parts and raw materials and invested in goods and services of key industries. These regulations have a common objective to directly and indirectly restrict Chinese parts and raw materials, which have gradually led to the US–China trade war. Direct or indirect pressure on China has continued during the Biden administration, and it did not stop at a specific country and product. Instead, US policy pressured the transition of supply chains across the country or its allies. In addition to economic factors, US policy also contains elements of diplomatic and political factors to keep China in check (Hong Sung-Kyu, 2019; Kim Yang-Hee, 2019; Chung and Han, 2019).

Table 4. USMCA Complete Car and Parts about Value Content

Regional Value Content	Labor Value Content	Tariffs on Finished Vehicles
Core Parts: 75% Principal Parts: 70% Complementary Parts: 65% Aluminum and Steel: 70%	40% ($16/h)	0% to 2.6 million units (2.5% is imposed on up to 1.6 million units if satisfying NAFTA)

Source: USTR (n.d.).

Like most manufacturing industries, the automotive industry has concentrated its main supply chain in China. Although direct and indirect pressure from the US hit companies that rely on these supply chains in China, it was not easy to give up the Chinese market, considered

[3] As a result of the NAFTA negotiations for amendment, USMCA was reborn, and regional production regulations for each item were strengthened in the automobile industry.

[4] A law that stipulates that import restrictions and tariffs can be imposed if it is judged to be an imported product directly related to the national security of the US.

the hub for production, logistics, and sales. However, the regional blockade caused by COVID-19, in addition to rapid fluctuations in logistics costs due to uncertainty in import and export volume, served as an opportunity to accelerate the transition of supply chains to sales markets and share supply chains among allies apart from China.

Notably, the US has applied strong import regulations to the automotive industry in the past. It has been aggressively encouraging local investment by applying direct and indirect regulations on mass-producing automakers from Japan and Korea and has also taken the lead in the negotiations regarding the Korea–US Free Trade Agreement (FTA).

Furthermore, the US passed the Inflation Reduction Act in August 2022, under which the government will provide subsidies only to electric vehicles produced in the country. This has been interpreted as an intention to keep China in check in the value chain of electric vehicles by restricting the use of battery parts and minerals from certain countries, such as China, to below a certain percentage. This will be a negative factor for Hyundai Motors, which has a 9% market share of electric vehicles in the US, following Tesla (Farrell and Newman, 2019; Mahajan et al., 2022).

From the moment internal combustion engines begin to be replaced by electric vehicles, related businesses are expected to face continuous regulation to gain an advantage in the value chain of electric vehicles. FDI in related industries, such as batteries, is required to maintain or increase local sales (Jung Jae-Woo and Hong Jae-Sung, 2021; Ha Young-Kyou, 2022).

2.3. Characteristics and Changes in Automotive Supply Chain

Generally, a supply chain optimally manages a cycle leading to the procurement, production, and sale of raw materials and parts of a product. The automobile is thoroughly planned and produced with 20,000 to 30,000 parts, and the supply chain management technique in the automotive industry is represented by JIT. This means that in addition to the cost factors facing all companies, logistics lead time, port congestion rate, logistics stability, customs clearance, and emergency response are also crucial factors (Nil et al., 2015; Wang and Yeo, 2018).

However, the aforementioned logistics disruption, supply chain reorganization, and the use of regional agreements due to COVID-19 adhere to the concepts of optimal transportation and optimal storage rather than JIT, and the transition to the electric vehicle production system will again change the supply chain. If engines and transmissions, which are core procurements in the automobile industry, are replaced with motors and batteries, not only will the number of parts in the production process decrease sharply, but it will also lead to a reorganization of the supply chain between the automotive industry and the electric and electronic industry. At present, Korean automobile-related battery manufacturers that have entered the US have partnered with automobile manufacturers and shared their supply chains (Table 2). The Korean automotive industry is not immune to this trend, considering cooperation with battery manufacturers, efficiency, and cost.

Therefore, considering the long-term electric vehicle supply chain, the optimization technique for location selection and post-production distribution will be a more important management technique for supply chain management in the automotive industry, than the existing JIT technique (Edgar et al., 2003; Alessandro et al., 2012; Truong and Azadivar, 2015; Ha Young-Kyou and Woo Su-Han, 2021).

2.4. Optimal Location Selection and the Automotive Industry

The selection of an optimal location is a crucial factor in determining the stability of procurement and the economic feasibility of sales in terms of overseas investments in the manufacturing sector. In particular, the stable operation of production lines is critical in the automotive industry. In addition, there have been diverse studies on stable procurement methods (Nils et al, 2015; Woo et al, 2018; Ha Young-Kyou and Woo Su-Han, 2020). However, most research on automotive logistics focuses on procurement logistics, and it is rare to find investigations on sales and distribution exerting direct impacts on corporate profits. Thus, research that takes the perspective of sales and distribution in connection with new investments is essential.

Research methods regarding sales and distribution encompass the gravity model, linear programming, mixed integer linear programming, and the analytical hierarchy process (AHP). While each method has significance, linear programming is frequently used for analysis from the sales cost perspective. It is a method that optimizes objective functions by inputting decision-making variables and has been widely applied to decision-making processes for transportation, allocation, and optimal routes.

In this study, candidate regions for EV investment locations were selected based on the influencing factors derived from the panel analysis, and a distribution cost-based model was established based on the candidate regions. In addition, the constraint formula was designed to distribute the maximum production capacity by sales ratio by region.

Moreover, there was no difference between procurement logistics and production logistics at the time of the initial investment by automobile companies due to the availability of free land provided by local governments, reductions in and exemptions for corporate taxes, and infrastructure support (Suh, Jeong-Wook, 2004; Park Chi-Hyoung and Won Sung-Soo, 2015; Jo Hyung-Je and Jeong Jun-Ho, 2016). Hence, linear programming is an appropriate method for this study, considering the sales and distribution perspective.

3. Empirical Analysis

3.1. Data Collection and Definition of Variables

Referring to existing research, the variables for this study were configured as follows. Independent variables were divided into economic or logistics factors and infrastructure factors, and 10-year data (2012–2021) from 30 US states were collected through the US Department of Commerce and the US Department of Transportation. The United States is one of the countries with the most advanced automotive industry, and across almost all the US states, many types of automotive industrial clusters have been formed. Therefore, in order to reflect the characteristics of each of the US states, this study configured the panel data of 30 US states, which account for around 90% of the total population and industry of the US.

As dependent variables, data on FDI in the automotive industry and the electric vehicle industry from 2012 to 2021 were collected through the Export–Import Bank of Korea.

Many scholars studying the automotive industry have commonly emphasized that such factors as location (local economy, accessibility for procurement and sales, population, etc.), procurement of manpower, and costs need to be considered. Not only is the automotive industry highly labor-intensive on the manufacturing front, but the role of logistics personnel is also very important in procurement and sales and logistics (Larsson, 2002; Frigant and Layan, 2009; Chiappini, 2012; Contreras et al. 2012). In this regard, this study selected and classified factors that can comprehensively reflect local economy and manpower as economic and logistics variables, while GDP, industrial intensity, employment and corporate tax were classified as major variables.

Table 5. Configuration and Definition of Variables

Variable			Unit	Source
Economic & Logistics Variable	GDP	Log_GDP	$	US Department of Commerce
	Industrial Intensity	Log_IT	%	US Department of Commerce
	Logistics Employment	Log_TE	number of people	US Department of Transportation
	Total Employment	Log_AE	number of people	US Department of Commerce
	Corporate Tax	Log_CX	%	Tax Foundation
Infrastructure Variable	Road Length	Log_RL	Mile	US Department of Transportation
	Road Investment	Log_RI	$	US Department of Transportation
	Infrastructure Investment	Log_LI	$	US Department of transportation
	Port	Log_PT	Coefficient	US Department of Transportation
	Land Price	Log_LP	Coefficient	Lincoln Institute of Land Policy
Subordination variable	*Korea → USA Automotive Industry FDI*		*$*	*The Export-Import Bank of Korea*
	Korea → USA Electric Vehicle Industry FDI		$	

Source: The Export–Import Bank of Korea (2022) and US Department of Commerce (2022).

Additionally, the automotive industry has its own independent infrastructure system. Although such infrastructure system is maintained independently, it also requires access from the home country as well as highway access after industrial complexes are established (Kaneko and Nojiri, 2008; Krzywdzinski, 2014; Klier and McMillen, 2015). Consequently, factors that can reflect all of such aspects were classified as infrastructure variables, road length, road investment, infrastructure investment, port and land price were included as major variables.

Table 6. FDI Amount by Industry

(Unit: USD Million)

-	Automotive Industry FDI	Electric Vehicle Industry FDI
2012	30	139
2013	90	160
2014	35	152
2015	62	127
2016	66	322
2017	214	339
2018	58	473
2019	126	266
2020	125	861
2021	311	1,595

Source: The Export–Import Bank of Korea (2022).

3.2. Selection of Models

The variables in this study are year-based panel data. As the data have both cross-sectional and time series characteristics, it is highly likely to violate the assumption of the error term during regression analysis. Therefore, the fixed effect model of an error-component model, which can control the heterogeneity of the error term was used. To this end, the F-test, the Lagrangian Multiplier (LM) test of Breusch and Pagan, and the Hausman test were sequentially performed to reduce statistical errors.

Table 5 shows the verification results of the F-test, LM test, and Hausman test based on three dependent variables. When the dependent variables were Log_AFDI and Log_EFDI, the F-value was 5.03 and 9.00, respectively, and the null hypothesis was rejected at the 1% significance level. This means that the fixed effect model is more efficient than pooled OLS.

Additionally, as a result of the LM test of Breusch and Pagan, the p-values for all two dependent variables were confirmed to be 1.000. Thus, the null hypothesis was accepted. This means that the random effect model of pooled OLS is more efficient.

Subsequently, a Hausman test was conducted to compare the efficiency between the fixed effect and the random effect model. When the dependent variables were Log_AFDI, and Log_EFDI, the values of chi2 were found to be 201.02 and 285.23, respectively, and the p-value showed significant results at the 1% significance level.

Table 7. Model Fit Analysis

-	F-test f-value (p-value)	LM-test Chi bar2 (p-value)	Hausman test Chi 2 (p-value)
Automotive Industry FDI (Log_AFDI)	5.03*** (0.000)	0.00 (1.000)	201.02*** (0.000)
Electric Vehicle Industry FDI (Log_EFDI)	9.00*** (0.000)	0.00 (1.000)	285.23*** (0.000)

In other words, the null hypothesis was rejected at the 1% significance level, resulting in the fixed effect model being more effective than the random effect model. Based on these three statistical verification results, it was established that it was reasonable to use the fixed effect model.

The formulas and technical statistics of this study are as follows:

$$AFDI_{it} = \beta_0 + \beta_1 log(GDP) + \beta_2 log(IT) + \beta_3 log(TE) + \beta_4 log(AE) + \beta_5 log(CX) + \beta_6 log(RL) + \beta_7 log(RI) + \beta_8 log(LI) + \beta_9 log(PT) + \beta_{10} log(LP) + \mu_{it} \quad (1)$$

$$EFDI_{it} = \beta_0 + \beta_1 log(GDP) + \beta_2 log(IT) + \beta_3 log(TE) + \beta_4 log(AE) + \beta_5 log(CX) + \beta_6 log(RL) + \beta_7 log(RI) + \beta_8 log(LI) + \beta_9 log(PT) + \beta_{10} log(LP) + \mu_{it} \quad (2)$$

Table 8. Descriptive Statistics

Variable	N	Mean	Std. Dev	Min	Median	Max
Log_AFDI	300	5.134806	.4883653	4.189655	5.18172	5.872118
Log_EFDI	300	6.353655	.8649133	5.17615	6.088466	8.114325
Log_GDP	300	26.70252	.6605832	25.73083	26.53704	28.65778
Log_IT	300	6.354865	.7645463	5.175678	6.013416	8.158150
Log_TE	300	11.77708	.640141	10.77833	11.64427	13.52328
Log_AE	300	15.02233	.5932955	14.17761	14.87586	16.6852
Log_CX	300	6.60824	2.767285	0	6.5	12
Log_RL	300	11.42141	.53088	9.970713	11.55042	12.66174
Log_RI	300	15.63986	.6162653	14.49218	15.45269	17.11061
Log_LI	300	18.17829	.6500919	17.20116	17.98213	20.22629
Log_PT	300	1.356016	.7330658	0	1.386294	2.564949
Log_LP	300	3.26667	1.366913	1	3	5

3.3. Panel Analysis

In this study, the economic and logistics infrastructure data from 30 states with potential for FDI by major Korean industries were used as independent variables. Additionally, FDI data from the automotive and the electric vehicle industries were used as dependent variables.

The results of the empirical analysis are in Table 9, showing the characteristics of FDI by large Korean companies and FDI by industry. The characteristics of FDI by large Korean companies can be found in port proximity. This is because Korean conglomerates tend to prefer large ports and shipping companies in pursuit of volume size and procurement stability. Thus, they value quality service and the degree of port calls by large shipping companies over the number of adjacent ports (Ryoo Ju-Han, 2011; Ha and Woo, 2022).

The amount of logistics infrastructure investment, the employment of logistics personnel, and the total employment also reflect the characteristics of each industry. The automotive industry had a negative effect at the 1% significance level in infrastructure investment, and no significant effect was found in industrial intensity and transportation employment personnel. However, it showed a positive effect at the 5% significance level in total employment.

The automotive industry forms a large independent industrial complex centering on automobile manufacturers. This is the unique characteristic of the automotive industry, and Kaneko and Nojiri (2008) claimed that the formation of the industrial complex built by Toyota could lead to the birth of a new city and an industrial complex to the extent that it could be called "Toyota City."

Therefore, each region competes for incentives and infrastructure construction to attract the automotive industry. In other words, although the supply and demand of manpower is an important issue, it is more important to build customized infrastructure than to maintain the existing infrastructure for the construction of a large independent industrial complex. In this sense, the significance of corporate taxes and land price was not found, because many investment enterprises received benefits such as reductions in and exemptions for corporate taxes, and free factory land due to regional competition for attracting investment (Suh Jeong-Wook, 2004; Ha and Woo, 2022).

Table 9. Empirical Result

Variable	Model (1) Automotive FDI	Model (2) Electric Vehicle FDI
Log_GDP (GDP)	-0.103 (-0.39)	-0.151 (-0.30)
Log_RL (Road Length)	0.048 (0.77)	-0.038 (-0.31)
Log_PT (Port)	-0.057* (-2.28)	-0.108* (-2.01)
Log_RI (Road Investment)	0.057 (0.48)	0.117 (1.57)
Log_LI (Infrastructure Investment)	-0.161*** (-0.89)	0.795*** (2.24)
Log_IT (Industrial Intensity)	0.954 (2.36)	4.461** (3.67)
Log_TE (Transportation Employment)	0.236 (1.56)	0.738*** (1.61)
Log_AE (Total Employment)	0.448** (1.37)	-1.577* (-2.43)
Log_CX (Corporate Tax)	-0.012 (-0.06)	-0.034 (-0.14)
Log_LP (Land Price)	-0.119 (-0.52)	-0.065 (-0.69)
N	300	300
R-sq	0.457	0.518

The electric vehicle industry had a positive effect at the 1% level of significance for infrastructure investment and transportation employment personnel. Moreover, the electric vehicle industry had a positive effect at the 5% level of significance in industrial intensity. Generally, the automotive industry is aimed at local production and local sales by forming a single industrial complex. However, since connectivity with other industries is an important factor in the battery-centered electric vehicle industry, FDI is in proportion to the impact of the established industrial infrastructure, unlike the traditional automobile industry, which has built up an independent industrial complex (Ryoo Joo-Han, 2011; Hong Jang-Pyo, 2016).

Finally, for the employment population, the automotive industry showed a positive effect at the 5% significance level, while the electric vehicle industry showed a negative effect at the 10% significance level. Although manpower in the production line is important in the automotive sector, the electric vehicle industry comprehensively values a culture centered around labor, positive work attitudes, and cities near universities in light of human resources (i.e., personnel) with a college degree or higher and the stability of securing long-term manpower (Ryoo, Joo-Han 2011; Ha and Woo, 2022).

4. Optimal Location Selection and Distribution Plan

4.1. Research Procedures and Methods

If the electric vehicle plant under construction by Hyundai Motors is completed, the Korean automotive industry will produce about one million units in the US. However, if it does not meet the threshold of 1.5 million units, which is the demand for Korean cars in the US, there is a high possibility of having to respond to various trade regulations in the long run (Ha Young-Kyou and Woo Su-Han, 2020).

This study argued that local demand should be replaced by local production to address long-term risks. In addition, many automakers are also expected to engage in US FDI to preoccupy the electric vehicle supply chain and resolve risks. Therefore, this chapter intends to derive the optimal location on the premise that 500,000-unit production plants will be established in addition to the existing production base.

This analysis used Excel and QM for Windows; the procedures and assumptions for analysis are as follows. First, using linear programming, this analysis discusses how to distribute a total of 1.5 million units at minimum cost, including 1 million units already in operation (about 650,000 units in Alabama and 350,000 units in Georgia). Second, the new plant selects a new place, not a place with existing infrastructure. This is to win support from many regions in the event of a trade dispute between Korea and the US. Third, three candidate regions are selected with high levels of infrastructure investment and transportation employment. Fourth, the regions that have to distribute 1.5 million finished vehicles are 30 states in the US, which account for about 90% of the total population of the US. Fifth, sales volume is proportional to the population of the region. Sixth, this study examines with the sales logistics costs include administrative cost from the production plant to the center of each region and does not discuss the issues after the first arrival. Seventh, the sales logistics costs in this analysis are based on the average estimates of three carriers transporting finished vehicles. Finally, this analysis excludes procurement logistics costs assuming local production and sales.

4.2. Optimum Location Selection Using Linear Programming

4.2.1. Structural Definitions (Model Symbols, Objective Functions, Constraints)

This section describes the model symbols, objective functions, and constraints that can be defined in the analysis. The symbols defined in this study are as follows:

a) Model Symbol

i1	Alabama (350,000 Units)
i2	Georgia (650,000 Units)
i3	Location Candidate
Fi	Production (Constraint)
J	City
Jj	city j ∈ J
X_{ij}	Transportation Volume

The objective functions and constraints of this analysis are as follows. The objective function is an equation that represents the value that minimizes the distribution cost of finished vehicles in 30 regions, based on the output of two existing plants and one candidate site, and the structural definition is as shown in Equation (3). Additionally, the supply constraints of this analysis are divided into 350,000 units in Alabama, 650,000 units in Georgia, and 500,000 units in new plants, and the structural definition is as shown in Equation (4).

b) Objective Function

$$\min \sum_{i=1}^{3} \sum_{j=1}^{30} C_{ij} X_{ij} \quad (3)$$

c) Constraints

$$\begin{aligned} Alabama&: \sum_{j=1}^{30} \mathrm{X1}_j \le 650{,}000 \\ Georgia&: \sum_{j=a}^{30} \mathrm{X2}_j \le 350{,}000 \\ New\ EV\ Plant&: \sum_{j=1}^{30} \mathrm{X3}_j \le 500{,}000 \end{aligned} \quad (4)$$

4.2.2. Analysis Results

As in the aforementioned hypothesis, in this analysis, three US states (California, Illinois, and Texas) with huge infrastructure investment and high transportation employment were selected as candidates by reflecting the panel analysis results. These three regions not only reflect the panel analysis results but also have great access from the home country. Those three cities are also represented the west, middle land, and south of the US, respectively, meaning that they can be the optimal candidate sites from the perspective of automobile supply chain. The distribution costs by region calculated using linear programming are as follows:

Table 10. Distribution of Finished Vehicles (Unit: $)

Alabama, Georgia, California	Alabama, Georgia, Illinois	Alabama, Georgia, Texas
720,281,848	879,028,859	829,956,179

According to the analysis, California had the lowest distribution cost of USD 720,281,848 and Illinois had the highest distribution cost of USD 879,028,859 among the three candidate sites. This could be caused by differences in the population of the candidate sites. The population of California is about 39.53 million, and that of Texas is about 29.14 million. When production is consumed near the production site, the distribution cost was the lowest because long-distance transportation is not required. Although it cannot be concluded that sales volume is proportional to the population, the results of previous studies emphasize the importance of locations near demand (Sturgeon et al., 2008; Colovic and Mayrhofer, 2011; Ha Young-Kyou and Woo Su-Han; 2021).

5. Conclusions

5.1. Summary of the Results

The supply chain in the manufacturing industry is rapidly changing due to the US–China trade war and COVID-19. The existing supply chain is a cost-oriented supply chain centered on China. However, the supply chain is moving towards solidarity among allies, with the occasional emphasis placed on efficiency and sustainability rather than on cost.

This study stressed the necessity of FDI in the automotive industry and its proximity to the consumption market, referring to the formation and change of the global supply chain.

First, the results of the panel analysis reflect the characteristics of each industry. Since the automotive industry itself forms a large industrial complex, FDI has been based on the population and aggregation of the same industry rather than the scale of economics, logistics, and infrastructure factors. However, the FDI factors in the electric vehicle industry reveal the opposite characteristics of the traditional automotive sector. This is because major parts such as the engine and transmission—considered the basis of the automotive industry—are replaced by parts from the electric and electronic industries. Therefore, the supply chain of the automotive industry will likely develop by reflecting the characteristics of the electric and electronic industries, and hence, the research method should also change according to how each industry is developing.

Second, investment factors of the automotive industry were inconsistent with those of the electric vehicle industry, thereby implying a paradigm shift in the entire automotive sector and the need for additional related studies. Automobile manufacturers have led the automotive industry as core players in the field. However, the replacement of the main components and changes in location and investment factors indicate that battery companies can become new core players in the electric vehicle sector in the future. In this regard, current automobile manufacturers need to consider supply chain competition between countries and investment measures, and strategies to dominate the supply chain within the same industry.

Third, using linear programming, the analysis derived the minimum distribution cost in the two existing places and one new location by selecting three locations (California, Texas, and Illinois) as candidate sites. The results showed that California had the lowest distribution cost because local production was absorbed into local consumption based on the state's population. Proximity to the consumption market has been also emphasized in existing studies. However, considering the support of neighboring infrastructure, as well as long-term state support, Texas could be an alternative, given that it has the second lowest distribution costs.

5.2. Implications and Limitations

This study has academic, practical, and policy implications. As for academic implications, in general, studies on FDI have mostly used methods such as the gravity model, panel analysis, and AHP; moreover, linear programming has been employed for storage and distribution. This study presented the optimal investment plan by using panel analysis and linear programming.

Second, the methodology presented in this study can be applied to other industries. At this time when the global supply chain is constantly unraveling and reorganizing itself, this study analyzed both the influential factors in the formation of a new supply chain and the optimal location thereof. Thus, it can provide methodological implications to be applied to further studies in the future.

Additionally, from the standpoint of companies and governments responding to trade regulations and supply chain reorganization, this study can be a reference when reviewing local expansion. The trend of expanding and establishing new electric vehicle plants is expected to spread not only across the US but also into other regions, including Europe and Asia, with existing automobile markets. Thus, a review of the motivation for and ways of entering overseas markets by referring to the findings of this study would provide valuable and comprehensive guidelines for operating and managing the automobile supply chain, which is the imminent issue facing the industry and the government alike.

Finally, the linear programming presented in this study is not a realistic review factor that can determine the part that is not judged as a policy review or economic influence factor.

The limitations of this study are as follows. First, this study was conducted on the assumption of complete localization of electric vehicle plants. Therefore, it determined the optimal location by using only distribution costs. If the reorganization of the supply chain is outlined and COVID-19 is stabilized, it will be possible to estimate the scale and cost of procurement logistics. Therefore, follow-up studies using mixed-integer programming and adding procurement logistics costs will also be possible. Second, this study compared and analyzed the investment factors of the automotive and electric vehicle industries. This attempt can be considered an analysis of the near future. This research would be more interesting if the software industry is added and analyzed by taking into consideration the development of autonomous vehicles in the long term.

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