

2023.09 Aalto EMBA

Analyzing the Impact of Declining Used Car Values on Used Car Sales

Kim, Chul Soo

November 2024

2023.09 Aalto EMBA

**중고차 가치 하락이 중고차 판매에
미치는 영향 분석**

김 철 수

November 2024

Executive Summary (English)

In the context of the used car market, the presence of incomplete and inaccurate information, or what is referred to as "information asymmetry," can have a detrimental impact on market efficiency. A decline in the value of used cars may result in financial losses for consumers, which could have a ripple effect across the entire used car market. In light of these considerations, it is imperative to examine the impact of declining used car values and to identify strategies for improving information asymmetry. In particular, George Akerlof, a US economist, has described the used car market as a "lemons market," in which the seller has an incentive to misrepresent the actual condition of the vehicle in order to increase the average sale price. A review of foreign cases, including those in the United States and Europe, reveals that the scale of the used car market is larger than that of the new car market. In 2020, the used car market in South Korea saw 2.59 million transactions, a figure that stands in stark contrast to the 1.7 million transactions recorded in 2019. This surge in activity can be attributed to several factors, including the reluctance of consumers to engage in face-to-face transactions due to the ongoing pandemic and the subsequent shift towards online platforms. The prevalence of direct sales between individuals, which often bypass the involvement of professional dealers, is also a contributing factor. This trend has led to a decline in the popularity of traditional dealerships, with consumers increasingly favoring direct sales.

The primary objective of this study is to examine the impact of declining used car values on the used car market and to identify strategies for reducing information asymmetry in the market. The objective is to analyze the factors affecting the value of used cars, including price, sales area, brand, and model year. This analysis will examine the impact on the used car market and related stakeholders, including demand and supply, and identify strategies to enhance market efficiency and reduce information asymmetry. The goal is to develop effective solutions to improve the efficiency of the used car market and reduce information asymmetry while enhancing consumer trust. The objective is to enhance understanding of the used car market for both sellers and buyers, and to provide transparent and accurate information to facilitate market efficiency and consumer confidence.

To achieve this objective, a comprehensive analysis of the current used car market will be conducted, employing a variety of statistical techniques to examine the patterns of transactions and recent trends. Moreover, we intend to collect and analyze data on the sales of domestic and imported used cars over the past five years. To identify factors affecting the value of used cars, we will employ a range of statistical techniques, including two-way ANOVA, regression analysis, logistic regression analysis and general linear model.

The results of the analysis indicated that the primary factors influencing the value of used cars are brand, vehicle age, transaction location, and mileage. Notably, there was a strong negative correlation between vehicle age and value. Additionally, 56.7% of used car transactions were conducted directly between individuals, while only 43.3% involved professional used car dealers, suggesting a potential for consumer dissatisfaction.

The objective of this research is to enhance the efficiency of the used car market through the establishment of a government-led data repository and the implementation of market reliability measures. Moreover, the strategy entails allowing major corporations to enter the used car market, thereby enhancing market transparency and fostering competition in the secondary market for used cars. These strategies are designed to elevate consumer trust in the used car market. Additionally, the investigation will examine the impact of various factors influencing the value of used cars in different countries.

Executive Summary (Korean)

중고차 시장에서 불완전한 정보와 정보 비대칭은 시장의 효율성을 저하시킬 수 있는 요인으로 작용하고 있다. 중고차 가치 하락은 소비자에게 재정적 손실을 초래할 수 있으며, 이는 중고차 판매 시장 전반에 영향을 미치고 있다. 이에 따라 중고차 가치 하락의 영향을 분석하고 정보 비대칭을 개선할 방법을 모색하는 것이 필요로 하며 특히, 미국 경제학자 조지 애커로프는 중고차 시장을 "레몬 시장"으로 묘사하며, 판매자가 차량의 실제 상태를 알리기 어려운 상황에서 소비자들이 평균 가격을 지불하게 되는 문제를 지적했다. 통상 미국 및 유럽 등 해외 사례를 살펴보다도 중고차 시장의 규모가 신차 시장규모 보다 크다는 사실을 알 수 있다. 한국의 중고차 시장은 2020 년에 259 만 대의 거래가 이루어졌으며, 이는 COVID-19 이후 대중교통 회피와 같은 여러 요인으로 인해 증가했지만 국내 중고차 시장의 거래 유형을 살펴보다도 개인간 직거래 유형이 전문 중고매매업자를 통한 거래보다 높다는 사실은 중고차 시장에 대한 소비자의 불신 및 불만이 상대적으로 작용하여 전문매매업자를 통한 거래를 기피하고 있기 때문이다.

이 연구의 주요 목적은 중고차 가치 하락이 중고차 판매에 미치는 영향을 분석하고, 시장의 정보 비대칭을 개선할 방법을 탐색하는 것이다. 가격, 판매지역, 브랜드, 연식 등 중고차 가치 하락이 미치는 다양한 요인들과 중고차 시장 및 관련 이해관계자, 즉 수요와 공급 참여자에게 미치는 영향을 분석하고, 중고차 시장 효율성을 향상하고 정보 비대칭을 줄이며 소비자 신뢰를 회복하기 위한 제안과 전략을 제공하는 것을 목표로 한다. 이를 통해 중고차 시장에 대한 이해를 높이고, 판매자와 구매자 모두에게 투명하고 정확한 정보를 제공하여 시장 효율성을 향상시키고자 한다.

이를 달성하기 위해, 다양한 통계와 데이터를 활용하여 거래 패턴과 최근 동향을 조사하여 현재 중고차 시장 환경과 특색에 대해 전반적으로 분석했다. 또한, 우리는 지난 5년간 판매된 국내 및 수입 중고차에 대한 데이터를 수집하고 검토하여 경험적 데이터 확장을 통한 통계적으로 분석했다. 중고차 가치에 영향을 미치는 요인을 분석하기 위해 이원 분산 분석(Two-way ANOVA), 회귀 분석(Regression Analysis), 로지스틱 회귀 분석(Logistic Regression Analysis), 일반 선형 모델(General Linear Model) 등 다양한 통계 기법을 활용하여 분석했다.

분석 결과, 중고차 가치에 영향을 미치는 주요 요인은 브랜드, 차량 연식, 거래 지역, 주행 거리 등으로 나타났으며 특히, 차량 연식과 가격 간에는 강한 음의 상관관계가 발견되었다. 또한, 중고차 거래의 56.7%가 개인 간의 직거래로 이루어지는 반면, 전문 중고차 딜러를 통한 거래는 43.3%에 불과하여 소비자들의 불신에 기인한 것으로 나타났다.

본 연구는 중고차 시장의 효율성을 높이기 위해 정부 주도의 데이터베이스 구축과 법적 조치를 통한 시장 신뢰 구축을 제안했다. 또한, 대기업의 중고차 시장 진입을 허용하여 시장의 개방성을 높이고, 중고차 경매 및 거래의 경쟁성을 강화하는 방안을 분석했고 이러한 전략들은 중고차 시장의 투명성을 높이고 소비자 신뢰를 회복하는 데 기여할 것이다. 중고차 가치에 영향을 미치는 다양한 요소들이 한국 이외의 다른 나라에서도 동일한 상관관계를 나타낼 지 대한 탐구도 지속할 것이다. 아울러 AI 딥러닝 (Deep Learning)을 활용한 분석도 병행하여 본 연구에서 나타난 유의미한 결과가 동일하게 나타나는지도 분석할 것이다.

Table of Contents

I. Introduction.....	1
1. Research objective.....	1
2. Research Methods.....	2
II. Literature Review.....	3
1. Current Status of the Used Car Market in South Korea	3
1) Situation of the Used Car Market	3
2) Type of Used car channels in South Korea	6
3) Recent Trends in Used Car Market	8
2. Review of Prior Studies.....	9
1) Analysis of Price Prediction and Influencing Factors for Used Cars	9
2) Empirical Study on Determinants of Used Car Prices in the United States	10
3) A study on the interaction between promotions for New and Used cars.....	11
III. Statistical Analysis	12
1. Data Acquisition Methods.....	12
1) Data Acquisition Process	12
2) Variable Description and Transformation.....	12
2. Analysis Results.....	15
1) Overview of Data Analysis.....	15
2) Correlation Analysis Results	15
3) Two-way ANOVA Result.....	16
4) Regression Analysis Result.....	17
5) Logistic Regression Result.....	19

3. Used Car Price Estimation	20
1) Estimated Marginal Means Calculation.....	20
2) General Linear Model (GLM) Result.....	20
3) Impact of Used Car Sales.....	23
IV. Strategic Suggestions.....	26
1. Government-Level Management of Used Cars.....	26
1) Strategic Management of the Used Car Database (DB).....	26
2) Legislation on Used Car Market Resilience.....	27
2. Complete Openness of the Used Car Market.....	29
1) Complete Openness.....	29
2) Used Car Export Support.....	29
3) Competitive Used Car Trading and Improvement Support.....	30
V. Conclusions and Implications.....	31
1. Summary and Conclusions.....	31
2. Implications.....	35
Reference.....	36
Acknowledgements.....	38

List of Tables

< Table 1 > Automobile Registrations Status.....	3
< Table 2 > Transaction Type of Used Car.....	4
< Table 3 > The status of Registration Numbers and Acquisition Tax Revenue.....	5
< Table 4 > Current e-Commerce Marketplace Status in Used Car Market.....	7
< Table 5 > RMSE Results of the Price Model.....	10
< Table 6 > Descriptive Statistics of the Data	11
< Table 7 > Changes in Market Share of Used and New Cars.....	11
< Table 8 > Data Set.....	15
< Table 9 > Correlation Analysis Results.....	16
< Table 10 > Two-way ANOVA Result.....	17
< Table 11 > Linear Regression Result	18
< Table 12 > Logistic Regression Result.....	19
< Table 13 > General Linear Model Result	21
< Table 14 > GLM Post Hoc Tests Result.....	22
< Table 15 > The status of Automobile Exports	30
< Table 16 > The status of Auctioned Cars	30

List of Figures

< Figure 1 > Supply and Demand Curves in the Used Car Market	24
< Figure 2 > Changes in the Market due to Variations in the Elasticity of Used Car Supply.....	24

I. Introduction

1. Research Objective

The used car market is characterized by imperfect information and asymmetric information imbalance, which diminish market efficiency. Notably, the American economist George Akerlof¹ referred to the used car market as a "lemon market." Sellers can inform buyers about the actual condition of the used cars they are selling (whether they are of good quality or not), but buyers may find it difficult to fully ascertain the true condition of the used cars. The used car market has long been plagued by issues related to information asymmetry, where sellers often possess more information about the vehicle's condition than buyers. This imbalance can lead to inefficiencies in transactions, resulting in consumer distrust and a reluctance to engage in the market.

The objective of this research is to address these challenges and enhance the efficiency of the used car market through several strategic initiatives. The used car market has a significant scale worldwide, with many consumers leaning towards purchasing used cars instead of new ones. As of 2020, the actual transactions of used cars in South Korea reached 2.59 million, increased by 5.2% than the previous year, marking the highest level in the last five years. This growth can be attributed to several factors, including the avoidance of public transportation post-COVID-19, polarization in purchasing power, and delays in new car launches due to semiconductor supply issues. The size of this market is only 0.4 times that of the new car market, indicating a lower level compared to abroad, such as 2.4 times in the U.S. and twice in Germany for their used car markets relative to new car markets. In 2023, the breakdown of transaction types shows that private transactions between individuals accounted for 56.7%, while transactions through professional used car dealers made up 43.3%. This indicates a relative distrust and dissatisfaction consumers have towards used car dealers, leading them to avoid dealer transactions. Additionally, a significant issue in the used car market is the depreciation of used cars, which can cause financial losses for consumers who own them and can impact the broader market for used car sales. Consequently, analyzing the impact of used car depreciation aims to enhance understanding of the used car market and contribute to improving its efficiency by ensuring transparency and accurate information for both sellers and buyers.

The objective of this research is to address these challenges and enhance the efficiency of the used car market through several strategic initiatives. One of the primary strategies proposed is the establishment of a government-led data repository. This repository would serve as a centralized database containing comprehensive information about used cars, including their history, condition, and pricing trends. By providing consumers with access to reliable data, the repository aims to reduce information asymmetry, enabling buyers to make more informed decisions and fostering greater confidence in their purchases. In addition to the data repository, the research advocates for the implementation of market reliability measures. These measures could include regulatory frameworks that ensure transparency in transactions, protect consumers from deceptive practices, and promote ethical behavior among dealers. By enhancing the overall reliability of the market, these measures are expected to build consumer trust and encourage more

¹ George Akerlof(1970), "The Market for 'Lemons': Quality Uncertainty and the Market Mechanism"

transactions. Furthermore, the strategy includes allowing major corporations to enter the used car market. The entry of large, reputable companies could introduce competitive dynamics that benefit consumers, such as improved service quality, better pricing, and enhanced consumer protections. This increased competition is anticipated to drive innovation and efficiency within the market, ultimately leading to a more robust secondary market for used cars. The investigation will also explore the impact of various factors influencing the value of used cars across different countries. By analyzing these factors, the research aims to identify trends and patterns that can inform best practices and strategies for improving the used car market globally. Understanding how different economic, cultural, and regulatory environments affect used car values will provide valuable insights for policymakers and industry stakeholders.

In summary, this research seeks to enhance the efficiency and transparency of the used car market through strategic initiatives that build consumer trust, improve access to information, and foster competition. By addressing the underlying issues of information asymmetry and market reliability, the study aims to create a more favorable environment for both buyers and sellers in the used car market.

2. Research Methods

The purpose of this study is to analyze in detail the impact of depreciation on the value of used cars and its effect on used car sales. By identifying the factors that influence the depreciation of used cars, the aim is to thoroughly examine how these factors affect sales. Additionally, it seeks to understand what elements consumers consider when making purchasing decisions in the used car market. The study intends to clarify through verified research findings how depreciation impacts used car prices and sales volume. Ultimately, it aims to provide strategic recommendations for the future of the used car market.

This study aims to employ quantitative research methods to conduct a detailed analysis of the impact of used car depreciation on used car sales. This study will collect empirical data on used cars sold over the past five years (56,350 cases) and validate the findings of previous studies that examined the effects of used car depreciation by comparing them with this data. Specifically, this study will statistically analyze the factors affecting used car depreciation and explore the correlations among these variables. Through this analysis, we seek to theoretically verify the impact of used car value decline on used car sales. Additionally, this study aims to provide strategic recommendations to enhance the efficiency of the used car market.

This study is composed of a total of five chapters. The introduction presents the background and significance of the research and provides an overview of the research methods. The second chapter examines the used car market and aims to analyze previous studies. The third chapter seeks to analyze various factors influencing the value of used cars using statistical techniques. Additionally, a pricing estimation formula for used cars will be presented utilizing these statistical methods. The fourth chapter will explore strategic recommendations to enhance the efficiency of the used car market. The final chapter presents conclusions and discussions and aims to propose a direction for the used car market.

II. Literature Review

1. Current Status of the Used Car Market in South Korea

As of 2023, the domestic used car market in South Korea is estimated at 2.43 million units. Over the past five years, it has experienced a compound annual growth rate (CAGR) of $\Delta 0.1\%$. This decline, notable except for the atypical surge in 2020 attributed to factors such as the pandemic-induced aversion to public transport, polarization of purchasing power, and supply chain issues pertaining to automotive semiconductors, reflects a period of market stagnation². The size of the used car market is only 0.4 times that of the new car market, significantly lower when compared to global figures—2.4 times that of the U.S. market³ and twice that of Germany's used car market (as of 2019). Furthermore, an analysis of transaction types in 2023 reveals that private sales between individuals comprise 56.7% of total transactions, while trades involving professional used car dealers account for 43.3%. This preference for direct transactions is primarily driven by consumer distrust towards market transparency and quality, arising from issues such as subpar vehicle performance and condition, undisclosed accident history, unsatisfactory pricing, as well as deceptive or bait listings⁴.

1) Situation of the Used Car Market

To examine the current state of the used car market, one must first consider the statistics regarding automobile registrations. The data on the number of vehicles registered annually, provided by the Ministry of Land, Infrastructure and Transport, is presented in the following table. According to the statistics from the Ministry, the compound annual growth rate (CAGR) of new vehicle registrations over the past five years is $\Delta 2.6\%$, indicating a decline. It is observed that the rate of change has fluctuated annually, ranging from a minimum decrease of $\Delta 9.0\%$ to a maximum increase of 6.1% .

< Table 1 > Automobile Registrations Status (Unit: Number of Vehicles)

Year		2019	2020	2021	2022	2023	CAGR
Domestic	Sales units	1,524,218	1,607,892	1,429,384	1,376,769	1,457,799	$\Delta 4.4\%$
	vs last year	$\Delta 0.8\%$	+5.5%	$\Delta 11.1\%$	$\Delta 3.7\%$	+5.9%	
Imported	Sales units	280,218	307,851	313,828	315,376	301,762	+7.7%
	vs last year	$\Delta 5.9\%$	+9.9%	+1.9%	+0.5%	$\Delta 4.3\%$	
Sum	Sales units	1,811,504	1,922,370	1,748,979	1,697,135	1,764,275	$\Delta 2.6\%$
	vs last year	$\Delta 1.7\%$	+6.1%	$\Delta 9.0\%$	$\Delta 3.0\%$	+4.0%	

※ Source: Automobile Registration Status (MLIT, Ministry of Land, Infrastructure and Transport)

² Philip Kotler, "Marketing Management" (1967), categorized the product life cycle into five stages: New Product Development, Introduction, Growth, Maturity, and Decline.

³ Bureau of Transportation Statistics in USA

⁴ Korea Consumer Agency (2021), Survey on the Actual Conditions of Used Car Transactions

As of 2023, the number of registered domestic vehicles stands at 1.46 million units, reflecting a decrease of 4.4% compared to 2019. In contrast, the number of imported vehicles has risen slightly to approximately 300,000, marking an increase of 7.7% over the same period. The lackluster sales of domestic vehicles are contributing to poor performance in the domestic used car market. Since new car sales began to decline notably in 2021, there has been a subsequent decrease in the volume of used car transactions, as well as a reduction in the number of dealerships and employees within the sector.

Next, we will examine the annual transaction statistics for used cars. The data presented in Table 2 indicates that the actual number of used cars traded in 2023 is 2.4 million⁵, with a real business transaction count of 1,054,947, which represents a decrease of 2.1% compared to last year's figure of 1,077,101. Conversely, transactions between individuals have increased by 5.1% year-on-year, totaling 1,379,216. While it may appear that the business transactions have a greater volume than individual transactions in the yearly transaction type data, it is essential to consider that business transactions are counted twice when they involve the purchase and subsequent sale of the used cars. Furthermore, even when examining the five-year Compound Annual Growth Rate (CAGR), it is evident that the proportion of individual transactions is higher than that of business transactions. This disparity can be attributed to factors such as 'poor vehicle performance and condition (47.4%)', 'undisclosed accident history (11.4%)', 'price dissatisfaction (7.2%)', and 'false or bait listings (4.5%)', which reflect a lack of transparency in transactions and reliability concerning quality⁶. The Ministry of Land, Infrastructure and Transport (MLIT) categorizes automobile registration transfer data into classifications such as dealer sales, individual sales, gifts, inheritances, court-ordered transfers, and others. In this context, business transactions refer to cases where a used car dealer purchases a vehicle for resale to consumers. On the other hand, individual sales denote transactions occurring between the seller and buyer in the used car market. In order to assess the scale of the used car market, we will examine the annual registration status and the payment status of acquisition taxes. When a used car is transferred, a local tax known as the acquisition tax must be paid, and local tax statistical reports will be referenced to estimate the size of the used car market. New registration⁷ refers to the initial registration of a vehicle manufactured domestically or imported into the automobile registration ledger. The type of registration applicable during the sale of used cars pertains to the transfer registration category.

< Table 2 > Transaction Type of Used Car (Unit: Number of Vehicles)

Year		2019	2020	2021	2022	2023
Business Transaction	Transaction for Purchase (a)	1,078,084	1,178,781	1,220,919	1,201,896	1,213,448
	Transaction for Sale (b)	1,045,240	1,107,241	1,146,465	1,052,189	1,032,505

⁵ The total number of previously registered vehicles is 3.8 million. Excluding the formal transaction numbers involving dealer purchases and inter-dealer transfers, the actual transaction count is 2,434,163 vehicles.

⁶ Korea Consumer Agency (2021), Survey on the Status of Used Car Transactions

⁷ The causes of vehicle registration are categorized into four types: new acquisition, transfer, inheritance, and others (Local Tax Statistics Annual).

	Transaction for Dealer (c)	157,458	186,786	190,812	211,687	190,458
	Transaction for referral (d)	46,566	31,679	29,390	24,912	22,442
	Sum (A=a+b+c+d)	2,327,348	2,504,487	2,587,586	2,490,684	2,458,853
Individual Transaction	P2P (e)	1,293,805	1,375,811	1,288,722	1,239,031	1,308,380
	Inheritance, Litigation (f)	74,018	72,522	68,193	72,739	70,836
	Sum (B=e+f)	1,367,823	1,448,333	1,356,915	1,311,770	1,379,216
Total Transaction (Sum C=A+B)		3,695,171	3,952,820	3,944,501	3,802,454	3,838,069
Real Transaction (D=b+d+e+f)		2,459,629	2,587,253	2,532,770	2,388,871	2,434,163
Real Business Transaction (F=b+d)		1,091,806	1,138,920	1,175,855	1,077,101	1,054,947
Change rate of	C	Δ2.0%	+7.0%	Δ0.2%	Δ3.6%	+0.9%
	D	Δ2.6%	+5.2%	Δ2.1%	Δ5.7%	+1.9%
	F	Δ1.0%	+4.3%	+3.2%	Δ8.4%	Δ2.1%
	B	Δ3.9%	+5.9%	Δ6.3%	Δ3.3%	+5.1%

※ Source: Ministry of Land, Infrastructure and Transport (MLIT)

Among the figures presented in Table 3, those related to the trade of used cars include the number of vehicle transfer registrations and the revenue data from acquisition taxes. Based on this data, it is possible to estimate the trading volume of used cars and new cars through the number of new registrations, transfer registrations, and acquisition tax amounts in the automotive market.

< Table 3 > The Status of Registration Numbers and Acquisition Tax Revenue (Unit: One Billion Won)

Year		2017	2018	2019	2020	2021
Registration (New Car)	Acquisition Tax Payment (#)	1,702	1,722	1,788	1,953	1,828
	Acquisition Tax Payment Amount	2,964	3,124	3,206	3,863	3,904
	Estimated New Car Sales Amount	47,044	49,584	50,892	61,323	61,961
	New Car Sales Amount (Per Unit)	27.64	28.80	28.46	31.40	33.89
Registration (Used Car)	Acquisition Tax Payment (#)	2,144	2,149	2,108	2,281	2,336
	Acquisition Tax Payment Amount	1,102	1,242	1,249	1,369	1,503
	Estimated Used Car Sales Amount	17,493	19,720	19,825	21,736	23,856
	Used Car Sales Amount (Per Unit)	8.16	9.18	9.40	9.53	10.21
Used Car Market Size (Compared to New Cars)		0.37	0.40	0.39	0.35	0.39

※Source: Ministry of the Interior and Safety, Local Tax Statistical Yearbook (2021)

As of 2023, the estimated market size of used cars derived from the acquisition tax amounts related to transfers and new registrations (based on a practical acquisition tax payment rate of 6.3%⁸) is approximated to be 0.4 times that of the new car market. Some data suggests that the used car market is 1.4 times larger than the new car market (according to data from the Korea Consumer Agency); however, this is attributed to a misunderstanding of the practice where the purchase and sale (revenue) by dealers in business transactions are double registered, which erroneously inflates the number of used car transactions.

The estimated size of the used car market is approximately 0.35 to 0.40 times that of the new car market. Meanwhile, Opinion News reported that the market size of the used car sector was about 20 trillion won⁹, based on the transfer registrations of 3.95 million used cars in 2020. According to Carisyou Data, a company specializing in automotive data analysis, the estimate for the used car market size in 2020 is about 25 trillion won, assuming an average cost of 10 million won per used car. Many market research and media organizations often overstate the market estimates due to misconceptions arising from the double counting of transactions in the purchase and sale of used cars, as reflected in the statistics on the number of used car registrations.

2) Types of Used Car Channels in South Korea

The Marketing Mix¹⁰, often referred to as the 4Ps, consists of Product, Price, Place, and Promotion, which are core elements of a marketing strategy. Among these, "Place" pertains to the strategies related to distribution channels through which products reach consumers. The distribution channels for used cars can be analyzed in various ways.

The first method is Direct Selling. This refers to individuals who own used cars selling them through online platforms or personal websites. This approach constitutes a significant portion of used car transactions, particularly those between private parties. Given the limited number of transactions, the determination of a fair price between buyers and sellers is of utmost importance.

The second method is Indirect Selling. This approach involves selling used cars through intermediaries such as used car dealers or online used car trading platforms. Used car dealers purchase vehicles and resell them to other consumers, while trading platforms offer intermediary services that connect sellers and buyers. In this way, they facilitate the buying and selling process of used cars. A representative example of this is SK Encar, which originated as an internal venture of the SK Group. In its early stages, SK Encar significantly contributed to enhancing the trustworthiness of online platforms and promoting online transactions through the introduction of a quality assurance program, as well as providing various information such as inventory details, accident histories, and warranties. Offering a diverse range of used car models and price information has become a key competitive advantage.

⁸ Yoon Jong-cheol (2022), A study of the improvement of acquisition tax on used cars, calculated the market size based on a 7% acquisition tax rate. The author estimated the effective acquisition tax payment rate to be 6.3%, after deducting local taxes.

⁹ Source: Opinion News (<http://www.opinionnews.co.kr>)

¹⁰ E.Jerome McCarthy, Basic Marketing: A Managerial Approach

The third sales method is the Multi-Channel Approach. This involves operating a used car specialty store that allows for direct transactions with customers, combining direct and indirect sales by employing various distribution channels. An example of this is a used car trading complex, where used car dealers and trading companies gather to sell vehicles. This method signifies running a direct sales store while simultaneously conducting online transactions through a used car trading platform. All operations related to used cars can be handled in one location, equipped with sales companies, maintenance providers, automotive finance firms, and other ancillary facilities within a physically large trading complex¹¹. Notably, the emphasis is on high volume sales at low profit margins, making efficient inventory management and turnover rates critical elements.

The fourth method is Co-Selling. This approach involves gathering used cars from various sellers in one location for sale, as exemplified by recent used car auction sites. Sellers can register information about the used cars and provide it to consumers, who then benefit from the ability to compare various used car options before making a purchase. This method allows consumers to select from a diverse range of used cars while also enabling sellers to engage in bulk sales (Turnkey) effectively¹².

The fifth method is the e-Commerce Marketplace Approach. This entails selling used cars through online e-commerce marketplaces, typically via specialized websites or apps that provide information about used cars. Buyers are offered the ability to search for and purchase used cars online, facilitating a platform that connects buyers and sellers for smooth transactions in the used car market. Financial institutions indirectly involved in the used car market emphasize transaction transparency by providing intermediary platforms. As the necessity for installment financing in the used car market increases, finance companies under groups such as KB Car (KB ‘chachacha’) are creating and offering their own used car distribution platforms. Additionally, mobile intermediary platforms for used cars, utilizing apps and primarily driven by venture companies, are also becoming widespread in the market.

< Table 4 > Current e-Commerce Marketplace Status in Used Car Market

Company	Main Services	Company	Main Services
Encar	Used Car Information Providing Platform for Selling My Car	Car Manager	Exclusive National Inventory Sharing for Used Car Dealers
K Car	Direct Used Car Information and Store, Selling Information Platform	Hey Dealer	Online Used Car Purchasing Platform
KB Chachacha	Used Car Trading and Financial Information Provision Platform	Molden Car	Used Car Specialty Shopping Mall
Bobae Dream	Used Car and Automotive Shopping Mall	Auto Dealer	Korea Association Used Car Official Shopping Mall
Hyundai Motor	Certified Used Car Providing Used Car Valuations and Financial Information	Eacar	A platform for sharing information of transferring used car, rentacar, and lease car

※Source: Summary Excerpt from Each Company's Website

¹¹ Song Kyuman (1997), A Study on the Current Status of Used Car Dealership Architecture in Korea and Improvement Measures

¹² Kim Cheol-jung (2024) states that the required funds in corporate accounting are calculated as (Sales Revenue - Operating Profit - Depreciation Expense) x Operating Cycle.

The addition of online and mobile elements to the used car distribution model mitigates, to some extent, the information asymmetry and opacity that have characterized the traditional used car market, despite the existence of price differences between wholesale and retail transactions.

3) Recent Trends in the Used Car Market

The entry of major automobile manufacturers, such as Hyundai and Kia, into the used car market has transpired. Unlike the complete opening of used car sales in countries like the United States and Europe, the domestic used car market in Korea has been designated as a 'business sector suitable for small and medium enterprises' since 2013, preventing large corporations like Hyundai and Kia from participating. Subsequently, in February 2019, the designation was lifted, allowing large companies to engage in used car sales; however, due to opposition from used car associations, this process was delayed. It was not until the Ministry of Small and Medium Enterprises and Startups led a resolution through the 'Small Business Adjustment Review Council' on April 28, 2022, that it became feasible for large corporations to enter the used car market. Initially, Hyundai and Kia aimed to selectively purchase certified used cars and convert them into products of impeccable quality at direct maintenance centers before marketing them as certified used cars. However, they shifted to outsourcing the entire product commercialization process to external companies, collaborating with these firms on the development and operation of content for their certified used car operational platforms. This strategic pivot represents a financial strategy aimed at improving the high-cost structure in the early stages of the business (sourcing from expert interviews).

As of February 2023, Hyundai Motor Company's certified used car inventory consists of 780 vehicles. Kia Motors, which launched slightly later, has 605 vehicles in advertisement. Combining the inventories from both companies, the total number of certified used cars stands at 1,385. Considering the number of vehicles undergoing the commercialization process, it is estimated that they hold approximately 2,000 units in sales inventory. Assuming a monthly inventory turnover rate of 70%, the maximum potential number of certified used cars that Hyundai and Kia can sell monthly is estimated to be around 1,400 units. According to the Korea Automobile Manufacturers Association (KAMA), the projected combined market share for five automobile manufacturers, including Hyundai and Kia, Renault, Ssangyong, and GM Korea, is estimated to be between 7.5% and 12.9% by 2026¹³.

The second point to consider is the trends among big sized car rental companies such as Lotte Rental and SK Rent-a-car. As of December 2022, these companies owned a total of 1,212,902 vehicles¹⁴ for business purposes. The rental business companies are selling their vehicles, which are either returned early or are reaching the end of their rental period, at prices significantly higher than the residual value set based on depreciation norms (with a depreciation period of five years using the straight-line method, as referenced in each company's financial statements). To facilitate large-scale sales, they either utilize external auction houses for consignment selling or establish their own auction venues for direct sales. These companies also create proprietary systems for certified used car sales, aiming to maximize retail prices from auction sale prices, which are often set at wholesale levels. Among the vehicles returned mid-term or at maturity, some

¹³ Maeil Economic Daily (March 2022), Can Hyundai's entry into the used car market transform the lemon market?

¹⁴ Reference material from the National Rental Car Mutual Association

are repurposed as short-term rental cars for insurance purposes, while others, particularly popular models abroad, are exported in bulk.

The final point to consider is the entry of installment finance companies into the used car market. Most installment finance companies, including Hyundai Capital, KB Capital, Samsung Card, and Shinhan Card, offer a variety of financial products secured by vehicles. They are selling new and used cars primarily through long-term rentals or operational leases. The return conditionally operational lease product has given rise to the term "car-poor," supplying used cars returned either mid-term or at the end of a contract period of 3 to 5 years for profitability purposes. To hedge against return risks at the end of the contract, agreements are sometimes made with residual value guarantee companies or insurance through reinsurers. However, in order to minimize the operational costs associated with residual value guarantees and insurance premiums, they occasionally take on the residual value risk directly. This practice is based on statistical data indicating that the residual value of returned vehicles is typically lower than the used car market price, thus posing a lower risk in terms of used car disposal.

2. Review of Prior Studies

This study aims to empirically validate three research studies analyzing the factors and interactions influencing the decline in the value of used cars, based on a dataset of 56,350 cases. The first reference study is "Analysis of Price Prediction and Influencing Factors of Domestic Used Cars" (Jo Soo-jin, 2018). The second is an "Empirical Study on Determinants of Used Car Prices in the United States" (Song Jeong-seok et al., 2020). These studies will provide insights into the factors affecting the depreciation of used car values. Finally, the third study is "Research on the Interaction of Promotions between New and Used Cars" (Jang Kwang-pil, 2010). Through this research, we aim to explore how sales incentives impact used car sales.

1) Analysis of Price Prediction and Influencing Factors for Used Cars ¹⁵

This research proposes a predictive model for used car prices by considering key factors that are anticipated to influence the valuation of used vehicles. These factors include basic information (such as model year, mileage, engine displacement, color, etc.) and pricing information (new car prices and used prices). The specific analytical techniques employed in this study are Stepwise linear regression, Random Forest, Gradient Boosting, Support Vector Machine, Extreme Gradient Boosting, and Neural Networks, with the predictive power assessed using RMSE (Root Mean Square Error). The study identifies the following factors as significant in impacting the value of used cars compared to new cars: usage period (Car Age), mileage (Mileage), warranty information (Warranty), maximum torque (Max_torque), and fuel efficiency (Km/l), listed in order of importance. The study relies on data gathered from Bobaedream¹⁶, which introduces a subjective bias that lowers the credibility of the information collected by the responsible party. There are limitations in the data analysis, including confusion between the terms "distance" and

¹⁵ Jo Sujin (2018), "Korean Used Car Price Prediction and Analysis of Influencing Factors,"

¹⁶ Bobaedream is a reliable car trading platform that offers various features, including not only used car transactions but also insurance information and a user community(<https://m.bobaedream.co.kr/>).

"mileage." To address this, the research aims to expand the focus from domestic vehicles to imported cars and verify fundamental and pricing information through Two-way ANOVA. Among various variables such as manufacturer, color, car age, engine displacement, transmission type, warranty information, fuel type, vehicle specifications, options, and new car prices, the analysis will emphasize aspects that are most significantly considered by customers when purchasing used cars, as identified in a survey conducted by the Korea Consumer Agency in 2021. These aspects include used car price, brand, car age, and mileage, reflecting customer preferences in order of importance.

< Table 5 > RMSE Results of the Price Model (Summary Excerpt)

	Train RMSE (model 1)	Test RMSE (model 2)
Random Forest	0.0348	0.0790

2) Empirical Study on Determinants of Used Car Prices in the United States ¹⁷

This study utilizes transaction records of used cars sold across 50 states in the United States in 2017, obtained from the used car trading platform Kaggle, comprising approximately 800,000 observations. It examines the influences on used car prices through various factors, including the sale price, year of manufacture, transaction region, mileage, and manufacturer. The research compares and analyzes the used car prices of major automotive brands sold in the U.S. used car market in 2017, alongside the prices of used Hyundai vehicles in South Korea. The analysis reveals that as per capita income in the sales region increases, the used car prices for Hyundai and Kia decrease, whereas for the comparison models, a rise in per capita income correlates with an increase in used car prices. The decline in used car prices for Hyundai with increasing mileage is less pronounced compared to Acura, Audi, BMW, Infiniti, Kia, Lexus, and Toyota; however, when compared with Honda, Isuzu, Mazda, Mitsubishi, and Subaru, the reduction in price related to mileage increases does not significantly differ¹⁸.

It is shown that the used car prices of all manufacturers, including Hyundai, decline with increasing mileage. The increase in used car prices relative to the age of the car is more substantial for brands like Acura, Audi, BMW, Honda, Infiniti, Kia, Lexus, Mazda, Mitsubishi, and Subaru, whereas Isuzu and Toyota exhibit an increase that is not significantly different from that of Hyundai. Furthermore, the results indicate that for all comparison automotive companies, the prices of used cars rise as the model year becomes more recent. This study reaffirms that, similar to South Korea, factors such as price, year of manufacture, mileage, manufacturer, and transaction region play significant roles in the U.S. market. However, it acknowledges limitations in the research conducted in the U.S. context, which may not align with domestic market conditions. Consequently, this study aims to identify the factors influencing used car value through regression analysis, establishing the priority and directionality of each factor.

¹⁷ Song Jeongseok et al. (2020), "Empirical Study on the Determinants of Used Car Prices in the U.S.," Journal of Logistics

¹⁸ This study analyzed ten vehicle models as comparative subjects: Acura, Audi, BMW, Honda, Infiniti, Lexus, Mazda, Mitsubishi, Subaru, and Toyota.

< Table 6 > Descriptive Statistics of the Data (Summary Excerpt)

	average	Standard Deviation	Minimum value	Maximum value
Pricing (\$ K)	9.775	0.512	7.313	12.257
Year	7.607	0.001	7.600	7.609
Income per capita	10.757	0.186	10.131	11.582

3) A study on the interaction between promotions for new and used cars ¹⁹

This study establishes a model that considers new and used cars as substitutes, rather than complements, in a market where they compete with each other. It reflects the idea that pricing and promotions for new cars will impact future sales through the used car market. This approach departs from previous research, which focused on competition among new cars within the new car market, under the assumption that the cross-elasticity between new and used cars of the same model is high, and it sets up a model (notated as BUN model: Brand-Primary/New vs. Used-Secondary).

In this study, it is assumed that consumers consider not only new cars but also used cars when they wish to purchase a vehicle. Key variables such as price, sales agent incentive, interest rates, and mileage have been incorporated into the analysis. The research begins with the rational assumption that the pricing and promotion of new cars influence the sale of used cars, recognizing a competitive relationship between the new and used car markets. It posits that the pricing and promotion strategies for new cars can have both direct and indirect effects on the value of used cars, and furthermore, if the price of new cars decreases or if incentives make purchasing new cars more attractive, the value of used cars may decline.

< Table 7 > Changes in Market Share of Used and New Cars

Changes in Market Share(M/S) Due to Initial Discounts on Used Car Prices (Summary Excerpt)		
Used Car Price Reduction	Change in M/S of New Car	Change in M/S of Used Car
Δ\$1,000	Δ3.34%	+21.8%
Δ\$1,500	Δ5.16%	+34.3%
Δ\$2,000	Δ7.07%	+48.0%

The pricing strategies and promotions in the new car market significantly influence consumer purchasing decisions. When prices for new cars decrease or aggressive promotions are offered, more consumers may opt for new cars over used ones. This shift can lead to reduced demand in the used car market and subsequently depreciation in the value of used cars. Furthermore, the pricing and promotional activities in the new car market can impact the used car market and act as a determinant for used car values. The significance of this study lies in its analysis of the fluctuations in new car market share and used car market share due to reductions in used car prices, examining these trends through the lens of substitute goods.

¹⁹Jang Gwang-pil (2010), A Study on the Interaction of Promotions between New Cars and Used Cars

Although there are limitations regarding the data, the analysis seeks to determine if there is a correlation between the two variables and whether any factors other than price reductions influence market share changes. Therefore, this research aims to model the relationship between the independents and the binary outcome of used car sales to identify which factors have a significant impact, utilizing logistic regression analysis to predict the likelihood of used car sales under varying circumstances.

III. Statistical Analysis

1. Data acquisition methods

1) Data acquisition process

The subject of this study is the domestic and imported used cars sold in the last five years, totaling 56,350 cases. Cars without sales price information among domestic vehicles and those with significant data loss among imported vehicles were excluded from the analysis. Vehicles with a mileage of less than 2,000 km may be classified as new and were thus excluded, while those with a mileage exceeding 300,000 km were likely to contain erroneous information and were also excluded.

Data for 31 vehicle models with fewer than 10 actual transactions, as well as used cars with transaction prices exceeding 100 million KRW, were excluded from the analysis due to absolute skewness and kurtosis values that are difficult to accept as conforming to a normal distribution²⁰. During the estimation of means (multiple regression analysis, GLM), the volume of data concerning car age was extensive, necessitating a reduction to the most recent five years for analysis (19,186 cases). Based on the preceding research analysis and the results of a survey on the current state of used cars, factors presumed to influence used car value were identified as used car prices, mileage, car age, brand name, and vehicle type. Data was collected through information from complete vehicle used car databases, used car-related associations, and financing company loan information.

2) Variable Description and Transformation

The purpose of this study is to identify the variables that affect the depreciation of used cars and to analyze the factors influencing used car prices, as well as to confirm their impact on sales volume. Among the 56,350 data entries collected, the maximum price of used cars is 99 million won, attributed to the Mercedes EQS model, while the minimum price is associated with a 2009 Kia Pride model. For the analysis of vehicle types, we categorized them into passenger cars, vans, commercial vehicles, RVs, and vans.

²⁰ Park Jeong-yeol (2024) applied the criterion established by Moon Su-baek (2009), which states that to verify whether a distribution follows a normal distribution, the absolute value of skewness must be less than or equal to 3.0 and the absolute value of kurtosis must be less than or equal to 8.0. Consequently, a total of 1,089 cases were excluded.

The data were converted into 17 region codes, and 63 brands were divided into domestic and imported vehicles. Based on sales volume, the brands were classified into three groups. Group 1 (10 brands) consists of popular models from Hyundai-Kia, GM Korea, KG Mobility (formerly Ssangyong), Renault Korea, Mercedes, BMW, Audi, Volkswagen, and Land Rover. Group 2 (11 brands) includes Porsche, Mini, Volvo²¹, Ford, Jeep, Lexus, Jaguar, Toyota, Peugeot, Tesla, and Cadillac, while the remaining vehicle types are classified into Group 3 (9 brands).

① Used car price

The primary challenge in handling the dependent variable in the analysis lies in constraining the prices of used cars to upper and lower limits, ensuring that the results are not distorted by other factors affecting different makes and models. Due to the characteristics of used cars, such as modified vehicles or those with enhanced performance, certain special variables may not be fully captured, and thus, their qualities may inadvertently affect price representation. While the empirical data validates the prices of used vehicles, there is no method to ascertain the production year and discount rate applicable at the time of sale for the specific vehicle type. Consequently, standard price lists for each brand were utilized. This approach mirrors the methodology employed in prior research addressing the price determinants of specific products.

② Car age

One of the most important determinants of vehicle pricing is the car age. This variable can represent the wear and tear on the vehicle, and therefore, as the age of the vehicle increases, a decrease in price is anticipated. This intuitive assumption is supported by existing literature, notably the study by Kihm and Vance (2016)²², which confirmed a statistically significant negative relationship between vehicle prices and age. In this study, rather than calculating car age based on the month of May, we established the reference date as the end of December each year, using empirical data from the last five years of sales to classify the ages of used vehicles.

③ Car Mileage

The mileage of a vehicle is used as another variable reflecting the aging of the vehicle. It is anticipated that as the mileage increases, the wear and tear on the vehicle intensifies, leading to a decrease in its value; thus, it shows a negative correlation with vehicle prices. Mileage less than 2,000 km is excluded as it may be perceived as the distance covered for customer delivery, while mileage exceeding 300,000 km is excluded due to the infrequency of used car transactions at that level. The reason for establishing an upper limit on mileage is due to the significant deviation in the absolute values of skewness and kurtosis, making it impossible to assign statistical significance based on a normal distribution.

²¹ Volvo should be included in Group 1 due to its rising popularity; however, considering the data collected from 2006, it is more appropriate to classify it in Group 2 accordingly.

²² Kihm, A. And Vance, C. (2016), p8

④ Body Type

The types of vehicles were categorized into seven distinct classifications—passenger cars, vans, commercial vehicles, freight vehicles, RVs, vans, and others—based on the Automobile Management Act and the Local Tax Act. In cases where distinguishing the vehicle type was challenging, the model name was used to separately identify vans and freight vehicles, as well as RVs and vans. Sedans and passenger cars were consolidated into the sedan category, while pickups and SUVs/off-road vehicles were grouped under RVs. Additionally, MPVs/vans and cargo vans were integrated into the VAN category. A small number of vehicles labeled as other types, which comprised less than 0.5% of the total observations, were deemed too difficult to analyze and subsequently removed from the dataset.

⑤ Car Brand

The brand of a car is a significant factor in determining the price of used cars, as highlighted in previous studies. This analysis distinguishes between domestic and imported vehicles, and also categorizes vehicles produced abroad, such as those by Korea GM and Renault Samsung, as domestic due to consumer perceptions that consider these brands as local. Should it be demonstrated that the country of origin of the manufacturer has a statistically significant impact on used car prices compared to other nations, it would imply that, in circumstances where customer preferences and perceptions remain unchanged, automobiles from manufacturers in specific countries possess higher brand value. The possibility of multicollinearity in the analysis suggests that the examined brands may focus on more expensive vehicle types, leading to increased standard errors in the correlation between brands and vehicle types by country of origin. Based on this premise, research²³ findings have indicated expectations that brands from traditionally recognized countries (such as Germany, Japan, the United States, and the United Kingdom) hold higher average value than brands from other countries of origin.

⑥ others (Color, Promotion, and etc)

In addition to technical characteristics, there are a variety of factors that can influence vehicle value. For instance, the color of a car has been shown to play a role in used car valuation. According to Axalta's 2022 Global Automotive Color Popularity Report, the most popular color worldwide is white, accounting for 34% of the market share, followed by black (19%) and gray (19%). Silver vehicles represent 8% of the total, with blue vehicles also comprising the same percentage. Other colors each hold a share of 5% or less. While we considered adding the color variable based on the Axalta report and expert interviews, the domestic market predominantly consists of black, white, and gray vehicles, with other colors present in minimal quantities (less than 5%), which limits the statistical significance. Therefore, these factors were excluded from this analysis. However, we included the sales incentive rate for sales representatives, which plays a crucial role in promotions, consistent with prior research.

²³ Prieto, M., Caemmerer (2015), "Using a hedonic price model to test prospect theory Assertion", *Journal of Retailing and consumer Service*, p22.

2. Analysis Results

1) Overview of Data Analysis

A correlation analysis, two-way ANOVA, regression analysis, and logistic regression were applied using the JAMOOVI tool to analyze empirical data on factors affecting the value of used cars. In particular, the analysis aimed to identify relationships among various factors impacting used car value, examining the linear relationships between variables. A strong positive correlation would indicate a favorable influence on value, while a negative correlation would suggest a likely detrimental effect. To this end, various factors were analyzed through correlation analysis. To identify the specific factors influencing used car value and to check for statistically significant differences in the interactions between independent and dependent variables, the two-way ANOVA technique was employed. The regression analysis aimed to model the relationship between each independent variable and the dependent variable, identifying the factors that significantly influence the value of used cars, as well as assessing the magnitude (prioritization) and directionality of these influences. Additionally, logistic regression was utilized to model the relationship between independent variables and the binary outcome of whether the used car is sold or not, aiming to ascertain which factors significantly influence the likelihood of sale.

< Table 8 > Data Set

	Year	Area	Price (₩ M)	Car age	Mileage	Brand	Incentive
N	56350	56350	56350	56350	56350	56350	56350
Missing	0	0	0	0	0	0	0.00
Mean	2022	9.24	25.0	2017	76349	1.3	1.33
Median	2022	10.0	20.0	2017	67000	1.0	1.00
Standard Deviation	1.24	3.61	18.3	2.88	51891	0.457	1.74
Minimum	2020	1	1.5	2006	2004	1	0.00
Maximum	2024	17	99.9	2024	270000	2	13.00
Skewness	0.0529	-0.169	1.41	-0.352	0.895	0.886	2.60
std. error skewness	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103	0.0103
Kurtosis	-1.07	-0.458	1.83	-0.357	0.507	-1.22	8.54
std. error Kurtosis	0.0206	0.0206	0.0206	0.0206	0.0206	0.0206	0.0206

2) Correlation Analysis Results

Correlation analysis was utilized to understand the relationships among various factors that influence the value of used cars. the correlations among various factors affecting the value of used cars were examined, and the linear relationships between these variables were identified, based on existing research and empirical data. As shown in <Table 9>, the correlation coefficients (Pearson's r) among the factors influencing used car value—such as year, region, price, car age, mileage, brand (domestic/import vehicles), and sales agent incentives—are all positive, indicating a significant correlation. Notably, a strong quantitative linear relationship is observed between the price of used cars and sales agent incentives ($r=.213$,

p<.001) as well as the year (r=.151, p<.001). In terms of car age, a pronounced quantitative linear relationship is found with vehicle price (r=.504, p<.001) and year (r=.437, p<.001), while a weaker linear relationship is present with sales agents incentive (r=.133, p<.001). Additionally, a clear quantitative linear relationship is noted between domestic and imported vehicles in relation to vehicle price (r=.568, p<.001), while a weak quantitative correlation is observed for sales agent incentives (r=.136, p<.001).

< Table 9 > Correlation Analysis Results

		Price (₩ M)	Year	Car age	Incentive	Brand
Price	Pearson's r	-	0.151***		0.213***	
	df	-	56348		56348	
	p-value	-	<.001		<.001	
Year	Pearson's r	0.151***	-			
	df	56348	-			
	p-value	<.001	-			
Car age	Pearson's r	0.504***	0.437***	-	0.133***	
	df	56302	56302	-	56302	
	p-value	<.001	<.001	-	<.001	
Incentive	Pearson's r	0.213***	0.060***	0.133***	-	
	df	56348	56348	56302	-	
	p-value	<.001	<.001	<.001	-	
Brand	Pearson's r	0.568***	0.030***	0.092***	0.136***	-
	df	56348	56348	56302	56348	-
	p-value	<.001	<.001	<.001	<.001	-

* note *p <.05, **p<.01, ***P<.001

Based on the magnitude of the correlation coefficient (Pearson's r), a quantitative linear correlation was observed in used car prices with respect to brand, car age, sales representative incentives, and reference month in that order. This indicates that used car prices are significantly influenced by brand and car age, which is supported by verified statistical data and aligns with the findings of previous studies.

3) Two-way ANOVA Result

The two-way ANOVA was utilized to examine the relationship and statistical significance between the independent and dependent variables. This study employed a two-way ANOVA methodology to identify the factors influencing the value of used cars, examining the interactions among vehicle price, car age, and brand to determine whether statistically significant differences exist. The results from Levene's test for homogeneity of variances indicated a p-value of P<.001, confirming that there were no issues with the assumption of equal variances. The two-way ANOVA results demonstrated that both car age (F=1506, p<.001) and brand (F=431, p<.001) had significant main effects on vehicle price. Furthermore, an interaction effect between car age and brand was also observed in the data (F=109, p<.001).

< Table 10 > Two-way ANOVA Result

ANOVA-Price

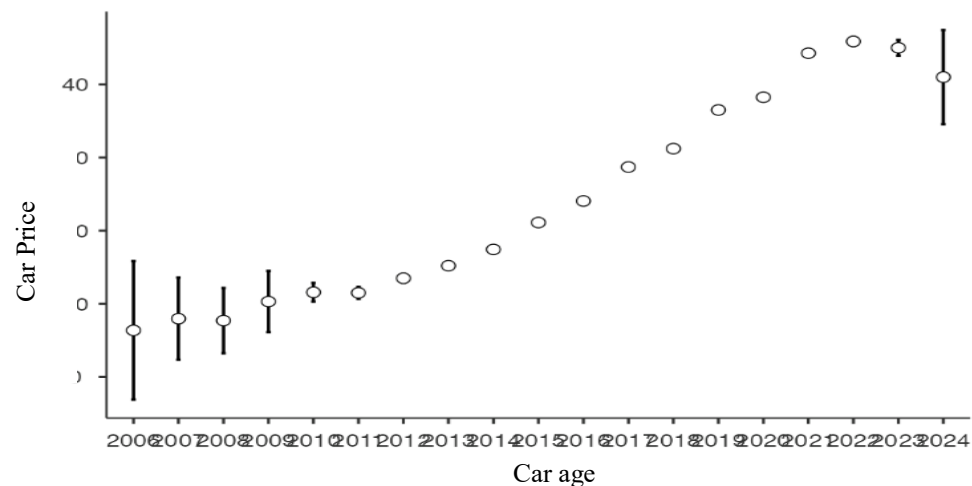
	Sum of Squares	df	Mean Square	F	P
Car age	4.05E+06	18	225174	1506	<.001
Brand (Domestic/Imported)	64460	1	64460	431	<.001
Car age*Brand(Domestic/Imported)	292605	18	16256	109	<.001
Residuals	8.41E+06	56266	150		

Assumption Checks

(Homogeneity of Variance Test (Levene's))

F	df1	df2	P
411	37	56266	<.001

Estimated Marginal Means



Post-hoc analysis using Scheffé's method revealed that domestic vehicles had a price that was 16 points lower compared to imported vehicles ($t=-20.8$, $p<.001$). This finding suggests a higher correlation with car age for newer models, while older models do not exhibit a significant price difference. The results of the two-way ANOVA indicate that both the brand and the model year significantly affect the prices of used cars. Notably, as the model year increases, there is a negative correlation with vehicle depreciation and a decrease in consumer preference, which further impacts vehicle pricing.

4) Regression Analysis Result

Regression analysis was utilized to confirm the influence (magnitude) and directionality among the various factors. This study models the relationships among variables affecting used car prices, including

the year, car age, vehicle type, brand, region, and sales agent incentives. It identifies factors that influence the value of used cars and determines whether these factors have statistically significant effects, as well as their magnitude (priority) and direction.

To examine multicollinearity among the independent variables, the Variance Inflation Factor (VIF) was assessed. Results indicated that all VIF values for the independent variables ranged from 1.00 to 1.27, all below 10, suggesting no issues with multicollinearity. The multiple regression analysis revealed that the independent variables, including the year, car age, vehicle type, brand, region, and sales agent incentives, accounted for 54.1% of the variance in used car prices. Significant effects were observed for year ($t=-25.159$, $p<.001$), car age ($t=149.381$, $p<.001$), brand ($t=175.565$, $p<.001$), region ($t=-7.697$, $p<.001$), and sales agent incentives ($t=28.610$, $p<.001$). Conversely, vehicle type ($t=.242$, $p=.808$) was found to have no significant impact. In terms of the priority (magnitude) of the dependent variables, the ranking was as follows: brand ($\beta=.514$), car age ($\beta=.479$), sales agent incentives ($\beta=.083$), region ($\beta=-.022$), and year ($\beta=-.079$).

< Table 11 > Linear Regression Result

Model Fit Measures

Model	R	R ²	Adjusted R ²	Overall Model Test			
				F	df1	df2	P
1	0.735	0.541	0.541	11049	6	56297	<.001

Model Coefficients - Price

Predictor	Estimate	SE	t	P	stand. Estimate
intercept	-3758.161	85.6978	-43.83	<.001	
Year	-1.18151	0.0470	-25.159	<.001	-0.0798
Car age	3.04553	0.0240	149.381	<.001	0.4799
Code of Car Type	0.00070	0.0287	0.242	<.001	7.04e-4
Brand (Domestic/Imported)	20.57009	0.1172	175.565	<.001	0.5145
Code of Area	-0.11128	0.0146	-7.697	<.001	-0.0220
Incentive	0.87395	0.0305	28.61	<.001	0.0831

Assumption Checks

Collinearity Statistics

F	VIF	Tolerance
Year	1.23	0.810
Car age	1.27	0.790
Code of Car Type	1.03	0.968
Brand (Domestic/Imported)	1.05	0.950
Code of Area	1.00	0.996
Incentive	1.03	0.966

5) Logistic Regression Result

Logistic regression was utilized to analyze the factors influencing sales. In cases where the value of used cars impacts their sales (with variations in inventory turnover rates across different vehicle models), a logistic regression analysis was conducted to model the relationship between the independent variables and the binary outcome of whether a used car is sold. This analysis aimed to identify which factors significantly influence the likelihood of sale.

< Table 12 > Logistic Regression Result

Model Fit Measures

Model	Deviance	R ² CS	R ² N	X ²	Overall Model Test	
					df	P
1	16590	0.171	0.448	10591	5	<.001

Model Coefficients -Impact of Sales

Predictor	Estimate	SE	Z	P
intercept	-104.3235	93.29912	-1.118	0.263
Price	-0.0275	0.00119	-23.086	<.001
Mileage	-5.42e-6	4.63e-7	-11.715	<.001
Year	0.0415	0.01598	2.598	0.009
Brand (Domestic/Imported)				
2-1	19.9682	87.52523	0.228	0.820
Code of Car Type	0.2379	0.0102	23.327	<.001

Assumption Checks

Collinearity Statistics

F	VIF	Tolerance
Price	1.32	0.759
Mileage	1.29	0.777
Year	1.01	0.986
Brand (Domestic/Imported)	1.00	1.000
Code of Car Type	1.02	0.979

Prediction

Classification Table

Observed	Predicted		% correct	Accuracy
	Fast moving	Slow moving		
Fast moving	52598	75	99.9	0.936
Slow moving	3522	155	4.22	

Note The cut off value is set to 0.5

The presence of multicollinearity among the independent variables was examined through the Variance Inflation Factor (VIF) index. The VIF values for the independent variables ranged from 1.00 to 1.32, all of which were below 10, indicating no issues with multicollinearity. The model fit was assessed, revealing that $X^2=10591$ ($df=5$, $p<.001$), Cox & Snell $R^2=.171$, and Nagelkerke $R^2=.448$, confirming the significance of the model. Among the four independent variables, vehicle price ($p<.001$), mileage ($p<.001$), and vehicle type ($p<.001$) significantly influenced used car sales, whereas the base year ($p=.009$) and brand ($p=.820$) variables did not significantly affect sales.

In terms of sales influence, 52,598 out of 52,673 cases belonging to fast-moving vehicle types were correctly classified (99.9%), while only 155 out of 3,677 cases in slow-moving vehicle types were accurately classified. Overall, out of 56,350 cases, 52,753 classifications were accurate, resulting in an overall classification accuracy of 93.6%.

3. Used Car Price Estimation

1) Estimated Marginal Means Calculation

The correlation analysis among factors affecting the value of used cars, two-way ANOVA, regression analysis, and logistic regression analysis was conducted. Validation through prior research and empirical data indicated that existing studies are indeed effective. Additionally, it was revealed that sales agent incentives, which had not been discussed in previous research, also influence the value of used cars. This study aims to statistically estimate the vehicle prices of used cars by utilizing Estimated Marginal Means. The explanatory power of the dependent variable affecting vehicle value, as determined by regression analysis, was found to be 54.1%²⁴, allowing for the calculation of estimated means through this variable.

Assuming a linear relationship between the dependent and independent variables, as well as a normal distribution, the method of estimating means will apply the General Linear Model.

2) General Linear Model (GLM) Result

To estimate the future value of used cars, a multiple regression analysis (General Linear Model, GLM) was utilized. The GLM was conducted based on the nominal variables of car age and brand, alongside the continuous variable of sales agent incentives, which influence the prices of used cars. Due to the vast amount of data, the analysis was limited to the most recent five years, encompassing 19,186 cases. The results of the Levene's test for homogeneity of variances indicated a significance level of $P<.001$, thus demonstrating no issues with homoscedasticity. Among the independent variables impacting prices, brand ($F=5531$, $p<.001$), car age ($F=189.56$, $p<.001$), and sales agent incentives ($F=241.2$, $p<.001$) were found to have a significant main effect. Additionally, an interaction effect between brand and car age was observed ($F=4.40$, $p<.001$).

²⁴ The adjusted R^2 value from the linear regression analysis is 0.541.

When analyzing car age by year, the results showed 2020 ($t=7.039$, $p<.001$), 2021 ($t=24.485$, $p<.001$), 2022 ($t=21.415$, $p<.001$), 2023 ($t=12.897$, $p<.001$), and 2024 ($t=2.381$, $p<.05$). The lower reliability for 2024 can be attributed to the data being limited to cases until March 2024. In terms of priority among the dependent variables, brand ($\beta=1.414$) was ranked highest, followed by car age, which varied by year ($\beta=.502$, based on the year 2022), and finally sales agent incentives ($\beta=.087$).

< Table 13 > General Linear Model Result

Model Results

Info	
Estimate	Linear model fit by OLS
Call	Price ~ 1 + Brand + Car age + Brand (Group1/Group2/Group3) + Incentive
R-squared	0.435
Adj. R-squared	0.435

ANOVA Omnibus Tests

	SS	df	F	P	η^2p
Model	3.19e+6	13	1137.39	<.001	0.435
Brand (Domestics/Imported)	1.19e+6	1	5531.73	<.001	0.224
Car age	204394	5	189.56	<.001	0.047
Brand(Group1, Group2, Group3)	106750	1	495.02	<.001	0.025
Incentive	51975	1	241.02	<.001	0.012
Brand (Domestic/Imported) *Car Age	4742	5	4.40	<.001	0.001
Residuals	4.14e+6	19186			
Total	7.33E+06	19199			

Fixed Effects parameter Estimate

Names	Estimate	95% Confidence interval		t	p
		Lower	Upper		
(intercept)	-12.661	-13.074	-12.248	-60.037	<.001
Brand (Domestics/Imported)	27.623	26.895	28.351	74.376	<.001
Car age1	2.274	1.641	2.908	7.039	<.001
Car age2	8.924	3.209	9.638	24.485	<.001
Car age3	9.800	8.903	10.697	21.415	<.001
Car age4	9.750	8.268	11.232	12.897	<.001
Car age5	6.875	1.216	12.535	2.381	0.017
Brand(Group1, Group2, Group3)	-8.794	-9.569	-8.020	-22.249	<.001
Incentive	0.730	0.638	0.822	15.525	<.001
Brand*Brand(Domestic/Imported)*Car age1	-1.281	-2.236	-0.198	-2.318	0.020
Brand*Brand(Domestic/Imported)*Car age2	-2.609	-3.788	-1.430	-4.338	<.001
Brand*Brand(Domestic/Imported)*Car age3	-1.145	-2.867	0.577	-1.303	0.193
Brand*Brand(Domestic/Imported)*Car age4	-3.193	-5.870	-0.516	-2.338	0.019
Brand*Brand(Domestic/Imported)*Car age5	-2.407	-17.884	13.069	-0.305	0.760

The results of the post-hoc tests for vehicle model year validation indicate that the vehicle prices significantly correlate negatively with age, with the following results for model years: 2020 ($t=-5.913$, $p<.001$), 2021 ($t=-25.325$, $p<.001$), 2022 ($t=-20.995$, $p<.001$), 2023 ($t=-11.937$, $p<.001$), and 2024 ($t=-1.437$, $p=.705$). This suggests that as the vehicle model year increases, the price decreases, and the explanatory power also increases. Additionally, the results from the post-hoc tests concerning brand differences ($t=-19.1$, $p<.001$) reveal that domestic vehicles have prices that are, on average, 25.9 points lower than imported vehicles.

< Table 14 > GLM Post Hoc Tests result

Post Hoc Tests

Post Hoc Tests - Car age

Comparison			Difference	SE	t	df	Pturkey
Car age		Car age					
2019	-	2020	-1.834	0.276	-5.913	19186	<.001
2019	-	2021	-7.619	0.301	-25.325	19186	<.001
2019	-	2022	-9.227	0.440	-20.995	19186	<.001
2019	-	2023	-0.815	0.683	-11.937	19186	<.001
2019	-	2024	-5.671	3.948	-1.437	19186	0.705
2020	-	2021	-5.985	0.323	-18.557	19186	<.001
2020	-	2022	-7.594	0.455	-16.699	19186	<.001
2020	-	2023	-6.520	0.693	-9.409	19186	0.911
2020	-	2024	-4.038	3.950	-1.022	19186	0.008
2021	-	2022	-1.608	0.470	-3.422	19186	0.974
2021	-	2023	-0.534	0.703	-0.760	19186	0.996
2021	-	2024	1.948	3.951	0.493	19186	0.733
2022	-	2023	1.074	0.772	1.391	19186	0.733
2022	-	2024	3.556	3.964	0.897	19186	0.947
2023	-	2024	2.482	3.999	0.621	19186	0.999

Post Hoc Tests – Brand

Comparison			Difference	SE	t	df	Pturkey
Domestic		Imported					
1	-	2	-25.9	1.350	-19.1	19186	<.001

Ultimately, the price of a used car, as represented in multiple regression analysis (GML), is expressed by the following formula: Used Car Price = $-12.661 + 27.623$ (Brand: Domestic = 1, Imported = 2) + {2.274 (2020 model) or 8.8924 (2021 model) or 9.800 (2022 model) or 750 (2023 model) or 6.875 (2024 model)} - 8.794 (Reflecting inventory depletion by brand).

Estimation of Used Car Prices Using GLM

$$\text{Used Car Price} = -12.661 + 27.623 (\text{Brand: Domestic}=1, \text{Imported}=2) + \{2.274 (2020 \text{ model}) \text{ or } 8.8924 (2021 \text{ model}) \text{ or } 9.800 (2022 \text{ model}) \text{ or } 750 (2023 \text{ model}) \text{ or } 6.875 (2024 \text{ model})\} - 8.794 (\text{Stock depletion reflected for each brand})$$

3) Impact of Used Car Sales

The fundamental determinants of the market price for used automobiles are the demand and supply for those vehicles. Unlike the supply of new cars, the supply of used cars can be considered fixed (inelastic) regardless of price. This is because, at any given point in time, the specifications and model year of a specific used car are characteristics that are already established and hence not influenced by the price. From an economic perspective, in this case, the 'ex ante' supply curve is represented as a vertical line, indicative of a typical inelastic supply curve.

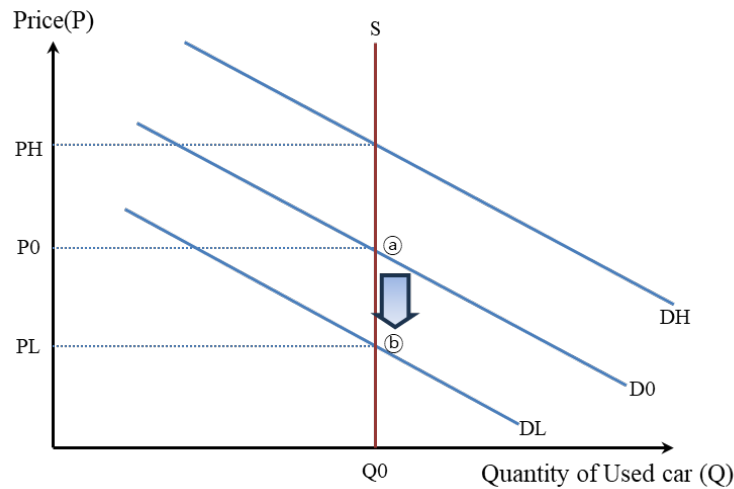
However, in rare instances where the supply curve for used cars might exhibit the typical upward-sloping shape of a general supply curve, one could propose that if there are multiple used cars with identical characteristics—such as brand, model year, and mileage—and the price for these cars rises, then sellers possessing inventory of such cars may seek to sell more of them. If such scenarios can indeed occur in reality, the 'ex ante' supply curve would resemble a general upward-sloping (elastic) demand curve. Nevertheless, in practical terms, the likelihood of numerous used cars being present with identical variables like brand, model year, and mileage is extremely low, resulting in a stable supply quantity that is not affected by price changes; thus, a vertical supply curve can be considered.

This vertical supply curve can be illustrated as S in Figure 1. In contrast, the demand for used cars typically takes the form of a downward-sloping 'ex ante' demand curve, which can be represented as D0 in Figure 1. This downward sloping demand curve reflects the basic characteristic of demand functions²⁵: when conditions are equal, lower prices will lead to a higher quantity demanded for the given commodity. Based on the downward-sloping demand curve and the vertical supply curve discussed so far, which indicates a fixed supply, it can be inferred that the price in the used car market is determined by the parallel shifts of the demand curve. For instance, if the demand curve shifts rightward from D0 to DH as illustrated in Figure 1, the price increases from P0 to PH.

Conversely, if the demand curve shifts leftward from D0 to DL, the price decreases from P0 to PL. It is evident that the decline in the value of used cars does not influence the supply curve but instead detracts from market efficiency. The value of used cars exhibits a negative correlation over time. Therefore, we can infer that the market size and efficiency (㉔, P0 x Q0) contract over time (㉕, PL x QL).

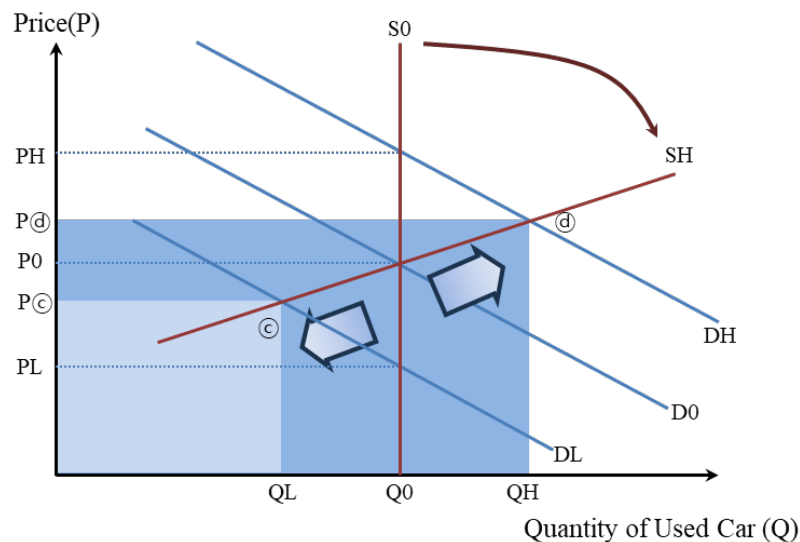
²⁵ Kim Minseong (2023), Lecture Notes on Demand and Supply Elasticity, p28 ~ p35

< Figure 1 > Supply and Demand Curves in the Used Car Market



The inelastic supply of the used car market affects the degree of change in supply quantity in response to price fluctuations. If the inelasticity of supply can be altered to be more elastic, the efficiency of the used car market could increase. As illustrated in Figure 2, changes are depicted when the inelastic supply curve is adjusted elastically. Under an elastic supply condition compared to an inelastic market, it can be inferred that the price in the used car market is determined by the parallel shift in supply quantity. For example, if the supply curve changes elastically from S_0 to S_H in Figure 2, the price increases from P_0 to P_{d} , thus significantly enhancing market efficiency ($P_{\text{d}} \times Q_H$) compared to the existing market conditions.

< Figure 2 > Changes in the Market due to Variations in the Elasticity of Used Car Supply



From the preceding discussion, it can be inferred that used car prices are determined by factors related to used car supply and demand. Notably, the impact of supply elasticity appears to be greater than that of

demand. To alter the elasticity of used car supply, changes in market entry barriers and competition structure are necessary in the domestic market. The domestic used car market has been designated as a suitable sector for small and medium enterprises, preventing large corporations such as manufacturers and rental car companies from entering the market. This has led to limited competition, and the supply market dominated by small businesses has faced structural issues due to constrained supply levels. By easing market entry, the elasticity of used car supply can be enhanced through competition from large corporations.

Secondly, changes in government regulations and policies related to used cars can influence the supply elasticity due to impacts on suppliers' production activities and cost structures. To overcome the asymmetry of used car information, it is essential to establish a government-led used car database (DB) and implement legislation aimed at building market trust. More detailed discussion will be provided in Chapter 4 concerning strategic recommendations.

IV. Strategic Suggestions

The quantitative analysis of used car values demonstrated through empirical data analysis that factors such as brand, car age, sales agent incentives, and preferred vehicle types significantly influence used car prices. Based on this finding, strategic recommendations will be proposed to address the information asymmetry within the used car market and to alleviate consumer dissatisfaction.

The first aspect is the management of used cars at the government level. The used car market is often categorized as a lemon market, where the reliability of data is not guaranteed. Various information related to used cars possesses characteristics of public goods, necessitating systematic management by the government and the provision of such information to consumers upon request. This also necessitates the legal formalization of these measures.

The second point is the complete opening of the used car market. Even looking at the case in the United States, the used car market is notably more active compared to the new car market²⁶. Although it is difficult to ascertain the exact size of the domestic used car market due to the lack of organizations that compile and manage related data, based on the acquisition tax payment standards, it appears to be at a level of about 0.4 times that of overseas examples, indicating high potential for future development. The used car market is not limited to the current retail market; it also encompasses used car exports, used car auctions, and the recycling market involving scrapped vehicles. Rather than the argument that the entry of large companies into the used car market would lead to the bankruptcy of small used car firms, market opening could lead to market expansion, thereby increasing the overall size of the used car market and enhancing its economic impact.

The third aspect is the support for competitive transactions and environmental improvements in the used car market. The number of competitive transactions in the used car auction market has been steadily increasing. This indicates a rise in both the supply and demand for used car transactions, and thus should be institutionalized to promote further growth. If we expand used car auction venues into automotive complex cultural facilities, similar to international examples, and endow them with new value, the economic ripple effect will be significantly magnified. A more detailed examination is as follows.

1. Government-Level Management of Used Cars

1) Strategic Management of the Used Car Database (DB)

The used car market possesses the characteristics of a public good, and as its size and importance have increased, the necessity for a systematic database (DB) management for national used car oversight has become significant. Firstly, establishing a systematic used car DB would enhance market transparency. Among the key variables affecting used car values, crucial information on sensitive items

²⁶ U.S. Bureau of Transportation Statistics (2019), the used car market is estimated to be 2.4 times larger than the new car market.

such as used car prices, mileage, car age, and manufacturer is essential. Fortunately, the Korea Insurance Development Institute, although offering it as a paid service, manages the accident history from various insurance companies and provides this data as a DB, which is highly informative. Moreover, it is feasible to mandate local governments to collect and record mileage, car age, and maintenance history during the registration transfer and acquisition tax payment processes, effectively creating a comprehensive database. This initiative could help overcome one of the major issues in the used car market, which is information asymmetry, thereby enhancing the transparency of the used car market.

Secondly, the used car database will enhance market efficiency. When consumers make purchasing decisions based on reliable information and sellers determine prices corresponding to the actual value of the used cars, it leads to the establishment of sale and purchase prices that accurately reflect true value, thereby increasing market elasticity and efficiency. This could dispel the phenomenon wherein the used car market has been referred to as a "lemon market."

Thirdly, it aids in monitoring the national used car market. By collecting and analyzing data on used car sales, price trends, and popular vehicle models, one can identify trends and changes within the used car market. The acquisition cost at the time of previous registration is referenced against actual transaction prices, and if market prices become known and manageable, it could lead to increased revenue from taxes, as well as the resolution of disputes arising from tax collection. If this can be expanded to 2.4 times the current capacity in the United States, additional tax revenue related to used cars could grow approximately sixfold (2.4 times ÷ 0.4 times). This would contribute to national policymaking and provide a foundation for the healthy development of the used car market.

The systematic management of a comprehensive used car database plays a crucial role in preventing crimes related to used vehicles. It is essential for tracking and identifying potentially dangerous used cars, such as stolen or altered vehicles. By effectively managing data concerning vehicle identity verification and ownership transfer, such a system serves as an effective measure to prevent and respond to crimes associated with used cars.

Furthermore, it can provide information necessary for establishing and regulating a national used car policy, which has strong characteristics of a public good. By assessing and analyzing the current status, challenges, and scale of the used car market, the government and relevant agencies can formulate policies required to regulate and manage the used car market and implement them promptly.

2) Legislation on Used Car Market Resilience

One of the biggest complaints among consumers in the used car market is the prevalence of false and bait listings²⁷. This issue has been highlighted as a significant problem within the used car market and a hindrance to its development. To eliminate false and bait listings and promote the activation and trustworthiness of the used car market in our country, it is essential to establish regulatory measures such as punitive damages and mandatory penalties. An urgent area for review is the establishment of measures to enhance the transparency of transactions in the used car market by eradicating illegal activities by dealers

²⁷ Korea Consumer Agency (2021), Survey on the State of Used Car Transactions.

and improving the mechanisms that enhance transaction transparency. To facilitate these institutional improvements, we must examine the roles of the trading counterparts—dealers, sales personnel, and consumers—as outlined below.

Improvements to the system for enhancing transparency in the used car market are necessary, including the introduction of separate dedicated license plates for purchasing and selling vehicles, which would provide benefits such as transaction transparency and tax reductions for dealers²⁸. Additionally, regulations imposing penalties for non-compliance with mandatory used car defect warranty insurance should be established. For exemplary businesses, incentives like future tax benefits should be introduced to encourage voluntary improvements led by the market.

The second point is the strengthening of management for sales personnel. This includes the implementation of a mandatory certification system for sales personnel to combat fraud, forgery, flooding, and the sale of stolen vehicles. To become a sales personnel in the used car industry, it is necessary to establish a system for a used car sales certification that grants sales rights only to those who have completed specific training and passed an examination, similar to the qualifications required for debt collectors and insurance sales representatives. The government must also make efforts to fundamentally block individuals with criminal records from obtaining this certification by requiring a criminal record check prior to its issuance, as provided by the National Police Agency.

Lastly, it is essential to provide consumers with safety mechanisms for complaint resolution and condition verification when conducting used car transactions. To achieve this, the approach of granting customers a certain period of right²⁹ to dispute when purchasing products on installment should also be applied to used car purchases. By allowing customers to drive the vehicle for a certain period before finalizing the purchase, they can gain a more accurate understanding of the vehicle's performance and condition, which is expected to reduce consumer disputes arising from quality complaints. This service was first implemented by the Czech used car platform Carvago and is now being offered in several countries, including the United States. The service allows for a test drive within one week and enables customers to return the vehicle during the usage period if there are defects or if they simply change their minds. The introduction of this service domestically can help prevent low trust and coercive sales practices that commonly arise in used car transactions, thereby contributing to the revitalization of the used car market. Additionally, to enhance the quality assurance and maintenance reliability of used cars, it is necessary to mandate that maintenance is conducted at service centers of a certain grade or higher, and to introduce a maintenance real-name system³⁰. This would ensure that in cases of the sale of quality-compromised vehicles, such as flood-damaged cars or those with defects, the maintenance service providers also share the corresponding responsibility through the implementation of a maintenance real-name system.

²⁸ Choi Kyung-ho (2023), Legislative Evaluation of the Used Car Performance and Condition Inspection Liability Insurance System Under the Automobile Management Act.

²⁹ Right to defense the right of objection refers to the legal authority that allows one to temporarily impede the exercise of a claim (Civil Code Article 536).

³⁰ Automobile repair shops are classified into four categories: certified repair facilities (Grade 1), specialized repair companies (Grade 2), general repair businesses (Grade 3), and non-rated repair shops (Grade 4).

2. Complete Openness of the Used Car Market

1) Complete Openness

The domestic used car market has been restricted to large enterprises since 2013, designated as a "small and medium-sized enterprise (SME) favorable industry," contrasting with the complete opening of used car markets in overseas countries such as the United States and Europe. Although this designation was lifted in February 2019, allowing large companies to enter the used car sales industry, their entry has been delayed due to opposition from used car organizations. Consequently, it was only through the "Business Adjustment Recommendation Resolution" established by the 'Small and Medium Business Policy Committee,' led by the Ministry of SMEs and Startups, on April 28, 2022, that large companies were able to enter the used car market. However, as part of collaborative recommendations, the commencement of their used car sales operations has been postponed for a specific period, and the number of vehicles sold is also restricted to a set annual percentage. This has resulted in a restriction of consumer rights, contrary to the original intention of improving used car quality and safety, realistic pricing, service, and a diverse range of options due to the actual market entry of large enterprises. Thus, there is an urgent need for a complete opening of the domestic used car market for finished vehicles, akin to OECD countries. Large automobile manufacturers expand into the used car market not just beyond the new car market but also for used car sales, maintenance, financial services, and accessory sales, aiming for diverse revenue streams. Stabilizing used car prices is essential for maintaining the competitiveness of new vehicles, which is why most automobile manufacturers focus on enhancing the quality and image of used cars. This is also why imported car dealers have implemented certified used car services in the domestic market. However, the difficulties faced by domestic finished vehicles in entering the used car market have led to issues of reverse discrimination compared to imported car dealers. Moreover, the restricted market entry for domestic manufacturers has resulted in the loss of various business opportunities, ultimately diminishing the benefits available to consumers and perpetuating a negative cycle. To prevent this, a complete opening of the used car market for domestic finished vehicles is necessary.

2) Used Car Export Support

According to data from the Korea International Trade Association, as detailed in Table 8 regarding the status of automobile exports, the number of used cars exported in 2023 reached 639,000 units, generating an export value of USD 4.78 billion. This represents an increase of +58% in export volume and +62% in export value compared to 405,000 units and USD 2.95 billion in 2022. Looking at the five-year compound annual growth rate (CAGR), the export volume grew by +36%, while the export value surged by +246%. The average export price per unit also rose to USD 7,500, marking an increase of +154% compared to USD 2,900 in 2019. These figures illustrate a strong upward trend across all metrics of export volume, value, and unit price. In contrast to the domestic used car market, which is currently facing stagnation, the range of vehicles available for export is expanding, with the number of target export countries increasing from 10 in 2019 to a total of 17 as of 2023. This growth can be attributed not only to favorable conditions for exports, such as advantageous exchange rates and low shipping costs, but also to a significant rise in exports to Russia and nearby countries due to the repercussions of the Ukraine conflict. Therefore, to support revenue diversification for used car trading companies in the future, it is essential to provide tax incentives and infrastructure support for the overseas export of used cars.

< Table 15 > The status of Automobile Exports (Unit: Number of Vehicles)

Year	2017	2018	2019	2020	2021	2022	2023
Export Value (\$ B)	9.9	10.8	13.8	12.4	19.7	29.6	47.8
Export Volume (K units)	287.9	360.2	469.9	387.6	467.0	404.7	638.7
Export Unit Price (\$ K)	3.4	3.0	2.9	3.2	4.2	7.3	7.5

※ Source: Export Statistics by Item from the Korea International Trade Association (HS Code 8702, 8703, 8704 in Used car)

3) Competitive Used Car Trading and Improvement Support

The used car market, particularly in the sector of purchasing quality used cars, continues to see an increase in competitive transaction volumes. A typical example of competitive transactions revolves around auctions, characterized by participating sellers and successful bids. From 2021 to 2023, data on auction and public sale numbers reveal an upward trend in both categories, as illustrated in <Table 9>. In 2023 alone, there were 372,436 vehicles listed for auction, of which 244,083 were sold. Platforms such as HeyDealer, Encar.com, Car Moss, and KB Chachacha are actively operating in the online vehicle sale market. It is estimated that around 1.4 million quality used cars were purchased in 2023 (1.21 million from individuals and 190,000 from dealerships), with competitive transactions accounting for approximately 69.4% of the total, through auctions (244,000 vehicles) and online sales (450,000 vehicles). To revitalize the auction market in the future, it is essential to provide various tax supports for auctioned items, as well as to broaden market participation to include general individuals, akin to real estate auctions, while enhancing operational transparency. Looking at the case of Japan³¹, auction houses have been established in a theme park format, serving as cultural spaces. This turns the space into a multifaceted cultural facility rather than merely a site for automobile transactions. The inclusion of play areas for children, customer experience centers, and stores for automotive accessories illustrates how these auction venues operate as shopping destinations for vehicles, providing insights into the current state and future direction of auction houses in Korea.

< Table 16 > The status of Auctioned Cars (Unit: Number of Vehicles)

Period		1H	2H	Sum (1H+2H)	Average (Month)
2021	Number of Entries	150,285	153,867	304,152	25,346
	Number of Successful Bids	104,105	104,896	209,001	17,417
	Bid Success Rate	69.3%	68.2%	68.7%	68.7%
2022	Number of Entries	181,096	190,234	371,330	30,944
	Number of Successful Bids	113,749	109,361	223,110	18,593
	Bid Success Rate	62.8%	57.5%	60.1%	60.1%
2023	Number of Entries	187,351	185,085	372,436	31,036
	Number of Successful Bids	126,491	117,592	244,083	20,340
	Bid Success Rate	67.5%	63.5%	65.5%	65.5%

※ Source: National Automobile Auction Association (<https://www.aaa-korea.com/data>)

³¹ Song Gyu-man (2019), "A Study on the Current Status and Improvement Measures of Used Car Auction Houses in Korea - Focused on Benchmarking Japanese Used Car Auction Houses," Hongik University.

V. Conclusions and Implications

1. Summary and Conclusions

The introduction examined the purpose and methodology of a study on the impact of declining used car value on used car sales. The imperfect information in the used car market and the asymmetry of information reduce market efficiency; notably, the American economist George Akerlof has described the used car market as a "lemon market." However, a review of international cases shows that the market size for used cars is significantly larger than that of new cars, such as being 2.4 times that of the U.S. and twice that of Germany. Additionally, an analysis of transaction types in the domestic used car market reveals that direct transactions between individuals (peer-to-peer transactions) surpass transactions conducted through professional used car dealers (business transactions). This trend indicates a relative distrust and dissatisfaction among consumers regarding the used car market, leading them to avoid transactions with professional dealers. Accordingly, this research aims to analyze the impact of declining used car value and to seek solutions for improving the asymmetry of imperfect information, thereby enhancing understanding of the used car market. The goal is to promote transparency and accurate information provision in the used car sales market for both sellers and buyers, ultimately pursuing methods to enhance market efficiency.

This study utilized empirical data from 56,350 transactions involving both domestic and imported used cars sold over the past five years to analyze the factors contributing to the depreciation of used car values. Various statistical methods were employed to assess these factors and estimate their impact on the market. Furthermore, the research outlines the background, objectives, and methodology of the study, and offers recommendations aimed at recovering consumer trust.

In the second chapter, we thoroughly examined the current state of the used car market through various indicators and data, as well as analyzed previous studies. Looking at the status of the used car market, the Compound Annual Growth Rate (CAGR) for the number of new vehicle registrations over the past five years, according to statistics from the Ministry of Land, Infrastructure, and Transport, has decreased by 2.6%. This decline serves as an important barometer that may signal poor future sales for used cars. By estimating the tax amounts related to vehicle transfers and new registrations, based on a real acquisition tax payment rate of 6.3%, the size of the used car market for 2023 is projected to be 0.4 times that of the new car market. Some sources, such as the Korea Consumer Agency, suggest that the used car market is actually 1.4 times the size of the new car market; however, this interpretation arises from a misunderstanding related to the double counting of transactions by dealers in their buying and selling activities, leading to a misrepresentation of the actual number of used car transactions.

The distribution methods for used cars can be categorized into several types: direct selling between individuals, indirect selling through used car dealers or automobile trading platforms, a multi-channel approach that combines both direct and indirect selling by utilizing various distribution channels through specialized used car stores that transact directly with customers, co-selling where multiple sellers gather their used cars in one location, and the e-commerce marketplace method, which involves selling used cars via online platforms. Historically, as the market transitioned from direct and indirect selling to mixed, co-selling, and e-commerce methods, there remains a discrepancy between wholesale and retail prices in used

car transactions. Nonetheless, these diverse distribution methods serve to alleviate the information asymmetry and opacity that have characterized the traditional used car market. Furthermore, recent entries into the used car market by manufacturers like Hyundai and Kia, as well as auction market participation by rental companies and the provision of used car financial services by installment finance companies, have significantly enhanced customer convenience and increased the transparency of used car transaction information..

Additionally, a review of previous studies examining factors influencing used car values was conducted. The study on predicting and analyzing the prices of domestic used cars (Jo Su-jin, 2018) considered key elements affecting used car values and price determinations, including basic information (such as model year, mileage, engine displacement, and color) and price information (new car prices and used car prices). Various analytical models were employed, including stepwise linear regression, random forests, gradient boosting, support vector machines, extreme gradient boosting, and neural networks. However, while the low reliability of these models presents limitations in achieving accurate price predictions, the research nonetheless offers valuable insights by analyzing used car values across various variables. To advance this study, an expansion to include imported cars was planned, aiming to validate basic information and price information through two-way ANOVA. Among several variables, including manufacturer, color, car age, engine displacement, transmission type, warranty information, fuel type, vehicle specifications, options, and new car prices, the analysis sought to confirm customer preferences based on a survey on the actual conditions of used car transactions (Korea Consumer Agency, 2021), with a focus on factors deemed most significant when purchasing used cars, such as price, brand, car age, and mileage.

The second preceding study examined is an empirical analysis of the factors determining used car prices in the United States (Song Jeong-sik et al., 2020), utilizing transaction records of used vehicles sold across 50 states in the U.S. in 2017 from the used car trading site Kaggle. This research investigated the impact of various elements, including used car prices, year of manufacture, transaction location, mileage, and manufacturer, on the pricing of used cars. It compared and analyzed the used car prices of major automotive manufacturers in the U.S. market with those of Hyundai used cars in Korea. However, this study is limited to cases specific to the U.S. market, which may not align with domestic market conditions. To address this limitation, the present research identified factors influencing used car values through regression analysis, elucidating the prioritization and directional relationships among these factors.

The third preceding study examined is a research on the interaction between promotions of new and used cars (Jang Kwang-pil, 2010). In this study, it was reported that price and promotions significantly influence consumers' purchasing decisions when buying vehicles. If the price of new cars decreases or if aggressive promotions are offered, the number of consumers purchasing new cars increases, resulting in a decline in demand for the used car market and a decrease in the value of used cars. The significance of this study lies in its analysis of the fluctuations in new car market share and used car market share in relation to used car price reductions, approached from the perspective of substitute goods. However, there are limitations in the data regarding the existence of correlation between the two variables and whether other factors beyond price reductions contributed to market share variations. To complement this, the present study aims to identify significant factors impacting the sales of used cars when their value influences sales, by modeling the relationship between independent variables and the binary outcome and utilizing logistic regression analysis to predict the likelihood of used car sales.

In the third chapter, a correlation analysis of factors affecting the value of used cars, two-way ANOVA, regression analysis, and logistic regression to analyze empirical data. Specifically, the analysis sought to establish the correlation among various factors influencing the value of used cars, determine the linear relationships among variables, and identify strong positive correlations indicating a positive influence on value, while negative correlations suggest a higher likelihood of adverse effects. To achieve this, a correlation analysis of various factors was examined. The results indicated that the correlation coefficients (Pearson's r) among the benchmark year, region, vehicle price, car age, mileage, domestic/imported status, and sales agent incentives were all positive, signifying a considered correlation. A quantitative linear correlation was observed between vehicle price and brand, car age, sales agent incentives, and benchmark month, respectively. This confirmed that the price of used cars is significantly influenced by brand and car age, aligning with the findings of existing research.

Factors influencing the value of used cars were identified, and to verify the interaction and statistically significant differences between independent and dependent variables, a Two-way ANOVA technique was employed. The results of the Two-way ANOVA indicated that both the age of the vehicle and the brand have a significant main effect on vehicle prices. Additionally, an interaction effect between car age and brand was also observed in the data. This implies that the impact of brand and car age on the price of used cars is statistically significant. It can be specifically noted that as the age of the vehicle increases, depreciation and a decline in consumer preference lead to a negative correlation with the vehicle price.

In regression analysis, the relationships between each independent variable and the dependent variable are modeled to identify the factors influencing the value of used cars. The analysis aims to determine whether these factors have statistically significant impacts, as well as to assess the magnitude (priority) and direction of these influences.

The results of the multiple regression analysis (GLM) indicated that the independent variables, including the base year, car age, vehicle type, brand, region, and sales representative, explain 54.1% of the variance in used car prices, the dependent variable. While the base year, car age, brand, region, and sales representative incentives have shown significant effects, the vehicle type does not appear to have a meaningful impact. In terms of the prioritization of the dependent variables (magnitude), the order is as follows: brand, car age, sales representative incentives, region, and base year.

Furthermore, in cases where the value of used cars affects binary outcomes (sale/non-sale), we aimed to identify which factors have a significant impact on predicting the sale of used cars by modeling the relationship between the independent variables and the binary outcome through logistic regression analysis. The model's fit was confirmed, indicating that its significance was established. Among the four independent variables, the variables of vehicle price, mileage, and vehicle type significantly influenced the sale of used cars, while the year and brand variables did not show significant effects on sales. Of the 52,673 records classified as belonging to high inventory turnover vehicle types (fast-moving), 52,598 were accurately classified (99.9%), while out of 3,677 records associated with low inventory turnover vehicle types (slow-moving), only 155 were accurately classified. In total, out of 56,350 records, 52,753 were correctly classified, resulting in an overall classification accuracy of 93.6%.

Through this analysis, we aimed to statistically estimate the prices of used cars using the Estimated Marginal Means. The regression analysis revealed that the explanatory power of the dependent variables

affecting vehicle value accounted for 54.1%. Under the assumption of a linear relationship between the dependent and independent variables, and assuming a normal distribution, the estimation used a General Linear Model approach. Consequently, the price of used cars, according to the multiple regression analysis (GML), can be expressed by the following formula:

Used Car Price = $-12.661 + 27.623$ (Brand: Domestic=1, Imported=2) + {2.274 (2020 model) or 8.8924 (2021 model) or 9.800 (2022 model) or 750 (2023 model) or 6.875 (2024 model)} - 8.794 (Stock depletion reflected for each brand).

Additionally, we examined the impact of factors influencing the sale of used cars, inspecting the dynamics of supply and demand in the used car market. In terms of supply, it is assumed that the quantity supplied is fixed (inelastic) regardless of price. From an economic perspective, this results in an 'ex-ante' supply curve that takes the form of a vertical line, indicative of a typical inelastic supply curve. The characteristics of used cars—such as brand, model year, and mileage—exhibit various attributes that hinder standardization and uniformity, thus resulting in inelastic supply. Should the supply curve become elastic, the efficiency of the used car market would significantly increase relative to the existing market. This suggests that the price of used cars is determined by factors related to supply and demand, with the elasticity of supply having a greater impact than that of demand.

In the fourth chapter, various recommendations for enhancing the elasticity of the used car supply have been explored. The first is the management of used cars at the government level. The used car market is often categorized as a lemon market, where the reliability of data is not guaranteed. The various information regarding used cars has characteristics of a public good, necessitating systematic management by the government, alongside the provision of relevant information to consumers upon request. This would also require legal measures to be put in place.

The second recommendation is the complete opening of the used car market. Even in the case of the United States, the used car market is significantly more active compared to the new car market. Although the exact scale of the domestic used car market is hard to determine due to the lack of an organization that compiles and manages data, even referencing foreign cases, it is estimated to be at a level of about 0.4 times that of the acquisition tax standards, indicating a high potential for future growth.

The used car market is not limited to sales alone; it also encompasses used car exports, auctions, and recycling markets utilizing scrapped vehicles. Contrary to the argument that the entry of large corporations into the used car market leads to the bankruptcy of small used car dealers, market openness could result in market expansion, thereby increasing the overall size of the used car market. If entry into the used car market is made free, the economic ripple effects could be considerably greater.

The third point concerns the promotion of competitive transactions and environmental improvements in the used car market. The volume of competitive transactions in the used car auction market is continually rising. This reflects an additional supply and demand emergence within used car transactions that should be institutionalized and activated. If the used car auction venues can be expanded and imbued with new values, similar to comprehensive shopping malls abroad, the economic implications will be even more significant.

2. Implications

In this study, we identified factors that affect the value of used cars through a synthesis of prior research and empirical data. Specifically, we examined the impact and importance of various variables, including brand, vehicle age, mileage, dealer incentives, region, vehicle type, and color, on used car values. In particular, our findings indicated that color was not a significant variable in the domestic context. However, based on previous research and key expert opinions, we inferred that it plays an important role in Europe and Southeast Asia. We believe that increasing statistical validity is the optimal strategy to overcome information asymmetry and enhance efficiency in the used car market. This approach can help the market shed its reputation as a "lemon market." The findings of this study offer valuable insights that can help address the issue of information asymmetry and restore consumer confidence.

The primary objective is to address the issue of information asymmetry in the used car market through the application of statistical reliability. The study employs a novel approach to examine and integrate data on factors affecting used car values, thereby providing a more accurate understanding of the factors influencing used car values. This approach effectively addresses the problem of inaccurate information in the used car market, enabling buyers to make informed decisions and avoid fraudulent transactions. The second major benefit is that improved statistical analysis provides buyers and sellers with a more accurate understanding of the market, thereby facilitating a more confident and informed decision-making process. Another objective of this study was to ascertain whether the empirical case analyses and estimations conducted in the domestic context can be similarly applied in other countries. In the future, we intend to collect empirical transaction data from other countries to verify that the various variables retain the same statistical significance through similar analyses. In addition, an analysis utilizing AI deep learning will be conducted to determine whether the significant results observed in this study are replicated.

In conclusion, enhanced statistical analysis and transparency of information represent the essential elements for the more efficient and effective management of the used car market. By leveraging these improvements, market participants can more effectively safeguard consumers and facilitate more reliable transactions.

References

<Domestic Studies>

- Choi Byungheon (1992), "Analysis of Institutional Factors in the Development of China's Used Car Market - Focusing on the Changes and Issues in Used Car Distribution Policies," Kongju National University.
- Choi Kyungho (2023), "Legislative Evaluation of the Responsible Insurance System for Used Car Performance and Condition Inspection under the Automobile Management Act," Ewha Womans University Law Journal, Vol. 28, No. 2.
- Hwang Sangkyu (2017), "Policy Directions for Activating Used Car Trading and Consumer Protection," Korea Transport Institute.
- Jo Sujin (2018), "Korean Used Car Price Prediction and Analysis of Influencing Factors," Ewha Womans University Graduate School.
- Jo Sung Jin (2005), "The Determinants of Used Rental Car prices", Hanyang University.
- Jo Youngjin (2020), "Study on Factors Promoting the Export of Used Cars," Master's Thesis, Incheon University.
- Jang Kwangpil (2010), "Study on the Interaction between Promoting New Cars and Used Cars," University of Seoul.
- Kim Euihyun et al. (2018), "Used Car Sales Platform Utilizing Blockchain and Smart Contracts," Jeonbuk National University.
- Kim Juhong (2022), "Problems of the Korean Used Car Market and the Entry of Large Corporations," Korea Automobile Manufacturers Association Policy Research Institute.
- Kim Taehoon et al. (2022), "Study on Current and Future Residual Value Prediction Based on Driving Information," Korea Institute for Advancement of Technology.
- Min Dalki (2005), "Study on the Economic Valuation of End-of-Life Vehicles," Journal of Environmental Management.
- Song Jeongseok et al. (2020), "Empirical Study on the Determinants of Used Car Prices in the U.S.," Journal of Logistics.
- Song Kyuman (2019), "Study on the Current Situation and Improvement Plans for Korean Used Car Exchanges - Focusing on Benchmarking Japanese Used Car Exchanges," Hongik University.
- Yoon Jongchul (2022), "Study on Improvement Plans for Acquisition Tax on Used Cars," Logos Business Journal, Keimyung University.
- Korea Consumer Agency (2021), "Investigation on the Transactions of Used Cars."
- Ministry of the Interior and Safety (2021), "Local Tax Statistics Annual Report."
- Maeil Business Newspaper, December 8, 2021, "Reviving Used Car Market."
- Maeil Business Newspaper, March 30, 2022, "Hyundai's Entry into the Used Car Market: Could It Transform the Lemon Market?"
- Maeil Business Newspaper, November 2023, "A Turning Point for the Opaque Used Car Market."
- The Skoop (2022), "Culprits of the Used Car Market Downfall".
- Yonhap News, April 2022, "Shedding the Lemon Market Image: The Lowered Barriers in the Used Car Market."
- Yonhap News, November 2023, "Now You Can Trust It: Hyundai's 'Certified Used Car' Launch."

<Foreign Studies >

- Abdulla AlShared (2021), “Used Cars price Prediction and Valuation using Data mining Techniques”, RIT Dubai.
- Akerlof, G. A. (1970). The Market for Lemons: Quality Uncertainty and the Market Mechanism. Quarterly Journal of Economics, 84(3): 488~500p.
- Carl Friedrich (2019), “Determinants of residual Values – Empirical Analysis of price effects in the Used car market”, Internationaler wissenschaftlicher fachverlag.
- Fadzilah Slim (2021), “Used Car price estimation: moving from Linear Regression towards a new s-Curve model”, International Journal of Business and Society.
- George Milunovich (2023), "Forecasting the prices of Used Cars: A comparative analysis of Supervised learning algorithms", Macquarie University.
- Jan Ziackik (2023), “Determinants of Used Car Prices”, Master’s Thesis, Charles University.
- JianChung Gong (2017), “A study on the factors affecting the Value of Used Cars in Panzhuhua Region”, Education and Humanities Research.
- Kihm, A. And Vance, C. (2016), “The determinants of equity transmission between the new and used car markets: A headonic analysis”, Journal of the operational Research society.
- Prieto, M.,Caemmerer (2015), “Using a hedonic price model to test prospect theory Assertion”, Journal of Retailing and consumer service. P22
- Peles, Y. C (1988), “on the depreciation of automobiles”, International journal of Transport Economic, 15(1), p43~54.
- Shujahat Haider Hashmi, Muhammad Asif, and Raja Majid Mehmood(2021), "Using Regression Analysis and Data Mining Techniques for Predicting Used Car Prices".
- Xu Xiao Ying (2024), “Use of Machine Learning to Predict Used Car Prices-Focusing on the Exploration of Important Factors Affecting Used Car Prices”.
- Ziye Lin (2022), "Analysis of Used Car Market in the United States", University of Michigan.

< Reference Site >

- Bureau of Transportation Statistics (BTS): www.bts.gov, (<https://www.bts.gov/content/new-and-used-passenger-car-sales-and-leases-thousands-vehicles>), survey date : 2024.05.04
- Export Statistics by Item from the Korea International Trade Association (HS Code 8702, 8703, 8704 in Used car)
- Federal Trade Commission (FTC): www.ftc.gov
- Ministry of Land, Infrastructure and Transport Public Data (CL M&S Company provided, Car Chart <https://carcharts.carisyou.net/totalChartRoute>)
- Ministry of Land, Infrastructure and Transport Statistics: Vehicle Registration Status – New Registrations, Transfers, Cancellations, etc.
- NADA Used Car Market Report: (<https://www.nada.org/Research/Industry-Analysis/Used-Car-Guide/>)
- National Automobile Auction Association (<http://www.aaa-Korea.com>)
- National Automobile Dealers Association (NADA): www.nada.org
- National RentaCar Association (<http://www.krma.or.kr>)

Acknowledgement

I would like to express my sincerest gratitude to all those who provided invaluable guidance and support throughout this process.

I would like to express my sincerest gratitude to my advisor, Professor Lee Kyung Geun. From the initial planning stages through to the final completion, the provision of meticulous guidance and expert advice was instrumental in ensuring the successful conclusion of this study. The profound knowledge and fervor of the professor provided substantial inspiration, fostering a new perspective and analytical approach to the research.

Furthermore, I would like to express my sincerest gratitude to the joint supervisor, Professor Kim Bo Young, for her guidance and support. During the course of the research, various difficulties were encountered. However, thanks to the timely and effective guidance provided by the two supervisors, the research was successfully completed. The thorough guidance and supervision provided by the two professors contributed significantly to the successful completion of this research project. Had it not been for their invaluable support and direction, the project would have undoubtedly faced greater challenges and delays.

I would like to express my sincerest gratitude to both professors for their unwavering guidance and support throughout this endeavor.