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Analysis of Policy-Induced Technology Competition and Innovation in A-Segment Vehicles

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Abstract:
The research analyzed a technological innovation case in which a policy-induced business environment caused technology competition among automakers. In Korea, two major companies began competing for a dominant share of the A-segment vehicles market via proactive R&D when government policy allowed more car types to be included in the A-segment category. This article examines such a policy-induced technology competition phenomenon by employing an empirical data analysis method and detailed case study. This research contributes to gaining further insight into the management of the innovation with respect to environmentally friendly technologies such as electric cars. We propose the framework of Policy-Induced Technology Competition (PITC) as an appropriate basis for prompting the technology-policy interplay induced within the South Korean automobile market with the aim of promoting a sustainable shift through the industry race for green innovation. The methodology comprises an embedded case study, STATA, SAS, and mixed-effect beta regression. The results indicate that the seemingly counterproductive to environmental stability policy adjustment to include more fuel-exhausting models into a comparatively energy-efficient class of vehicles led to a higher degree of adoption of a green car model. The analysis of the given case on a policy-ignited A-segment vehicle market race in South Korea, covering consumer and manufacturer implications, could serve as a foundation for further policy-making initiatives for sustainable road transportation market adoption and diffusion encouragement. By adding the government-induced layer to the discussion on innovation adoption encouraged by consumer pain and supplier race, we identified a strong relationship between policy and sustainable innovation dissemination in the automobile industry in South Korea. The regression model also showed possible socioeconomic control variables relevant to the region, such as gender, household type, and wealth, for further policymaking for the EFV sector in general.

Keywords: technology competition, innovation, A-segment vehicles.

A 级车政策引发的技术竞争与创新分析

摘要：
该研究分析了一个技术创新案例，其中政策诱导的商业环境引发了汽车制造商之间的技术竞争。在韩国，当政府政策允许更多车型纳入 A 级车类别时，两家大公司开始通过积极的研发来争夺 A 级车市场的主导份额。本文采用实证数据分析方法和详细案例研究来审视这种政策引发的技术竞争现象。这项研究有助于进一步深入了解电动汽车等环保技术的创新管理。我们提出政策诱导技术竞争（PITC）框架，作为促进韩国汽车市场内技术与政策相互作用的适当基础，旨在通过绿色创新的行业竞争促进可持续转变。该方法包括嵌入式案例研究、统计分析软件、SAS 和混合效应贝塔回归。结果表明，看似与环境稳定政策适得其反的政策调整，将更多的燃油消耗车型纳入相对节能的车型中，导致了绿色汽车车型的采用率更高。对韩国政策引发的 A 级汽车市场竞争的特定案例进行分析，涵盖消费者和制造商的影响，可以作为可持续道路运输市场采用和扩散鼓励的进一步政策制定举措的基础。通过在消费者痛苦和供应商竞争所鼓励的创新采用的讨论中添加政府引导的层面，我们发现了韩国汽车行业政策与可持续创新传播之间的密切关系。回归模型还显示了与该地区相关的可能的社会经济控制变量，例如性别、家庭类型和财富，以便为 EFV 部门进一步制定政策。

关键词：技术竞争，创新，A 级车。

1. Introduction

While still relying on non-renewable and environmentally harmful fossil fuels as its major energy source, the transportation sector has been urged to shift to the state of demand (seeking) for alternative solutions to overcome dependency on scarce natural resources and energy insecurity and minimize the irreversible ecological damage caused by the carbon footprint mass of internal combustion engines. Specifically, as of now, greenhouse gas build-up from transportation accounts for more than ⅕ of total carbon pollution, where road traveling vehicles, including all sizes of passenger cars, contribute roughly half of the whole sector-specific contamination - the indicator threatening to soar due to the rising consumption level in the automobile industry (Ritchie, 2020). In response to the ecological vulnerability induced by road transportation, coordinated action across multiple levels of the socioeconomic ecosystem is required to organize a synergetic policy-market infrastructure, the operational objective of which is to introduce and promote fuel-efficient development in the automobile sector. Necessary advancements on both the demand and supply side of the market are essential for encouraging more prompt consumer adoption of the environmentally friendly vehicles (EFV) concept, but also stimulating the fundamental shift in the sustainable road transportation industry from the production angle. The government, then, plays a central role in orchestrating the interplay between sustainable technology and its creation and diffusion in the automotive industry through policies as key external instruments for driving innovation (Rozendaal & Vollebergh, 2021).

Policies serve as the direct representation of the carrot and stick approach to induce industry-wide innovation toward sustainability and audience-level progression of EFVs from niche to mass market degree of technology dissemination. Designed to enforce a combination of rewards and sanctions on the demand and supply sides, policy instruments, such as monetary incentives and direct industry regulations and standards, aim to create an integral shift in the automobile market prompted by an increase in green technology demand among consumers and a subsequent boost in firms' R&D for green production. In other words, government-led sustainable transport innovation programs are primarily directed at making fuel-based vehicles as uneconomical as possible for car owners to promote their switch to EFVs, causing the increased public interest in green road transportation to become profitable enough of an opportunity to take initiative upon while maintaining a lower-risk level of investment through producer-facing financial incentives (Rozendaal & Vollebergh, 2021). Moreover, policies in the form of sustainable red tapes directly prompt the road transportation development by imposing "targets for vehicles' fuel economy or emissions" (Rozendaal & Vollebergh, 2021). As such, government protocols guide the development of necessary environmentally friendly technologies in the automobile manufacturing market not only through immediate regulatory stimuli but also by efficiently using the tight linkage between the consumers and producers.

In this regard, we propose the framework of policy-induced technology competition (PITC) as an appropriate basis for understanding the technology-policy interplay induced within the automobile market with the aim of promoting a sustainable shift through the industry race for green innovation. We illustrate the case of A-segment vehicles, also referred to as light, mini, or compact vehicles, the smallest category of passenger cars, to demonstrate the uptake of the competitive transportation market landscape in pursuit of environmentally friendly product technology innovation largely encouraged by policymaking. To be more precise, the present study focuses on the standard change enforced by the Ministry of Land, Infrastructure

and Transport of South Korea in 2008, which prompted the increase in the allowed engine capacity of light vehicles from 800 cc to 1000 cc and increase in the permitted vehicle size in the given category. This seemingly counterproductive to environmental stability policy adjustment to include more fuel-exhausting models into a comparatively energy-efficient class of vehicles led to a higher chance of capturing both social welfare and user benefits. We examine the given official government initiative through the methods of an embedded case study to argue that the modification of the already existing engine standard for the A-segment category is a direct representation of a successful PITC model taking place, which led to higher demand for light vehicles, prompting industry-wide response in the form of competition for capturing the surge in customers' interest with subsequent higher sustainability efficiency in the road transportation market. We further propose that the illustrated framework may serve as not only feasible but also a well-functioning method for a wider general application and enforcement of green technology initiatives in the transportation area, leading to higher innovation diffusion both on the industry and public ends.

2. Background and Literature Review

Referred to as the A-segment according to the European Commission standards, light city cars are recognized as the smallest cars in the passenger class with characteristics such as low engine capacity and compact size designed specifically for short-term limited metropolitan maneuvers. Leaving "the exact market definition [of categorization] … open" in terms of detailed engineering specifications, the EEC segmentation is suitable for characterizing city vehicles manufactured and promoted not only as urban welfare boosters but also as one of the classes of EFVs (Moriarty & Honnery, 1999). This is due to the argument that mini cars have high fuel economy because the size and engine of the vehicle have a positive linear relationship with the emissions produced (Kolk & Tsang, 2017). As such, A-segment cars can be referred to as sustainable transportation compared with larger vehicles and those with higher petrol or diesel consumption. The European approach to city car categories also allows a more precise outlook on the policy revision problem by providing a significantly less restrictive blueprint in contrast to the South Korean vehicle standard represented in the study. Despite setting firmer limitations on the industry and car manufacturers and prompting higher competitiveness in the automobile market, the standard for light vehicles before 2008 emphasized radical sustainable pursuits in road transportation and ignored market pain on both demand and supply sides, which resulted in the factual monopoly of General Motors' mini car model (Jugandonga, 2005). Moreover, such a rigid government segmentation led to predominant consumer dissatisfaction with light passenger vehicles, which are generally recognized as "small and weak" (Lee, 1997), which immediately turned A-segment cars into a business sector "with low sales and low profits" that the manufacturers did not deem cost-effective and lucrative enough to pursue (Kim, 2021).

This is despite various incentives that failed to provide enough stimuli to the demand side. Among such "exceptional benefits" to encourage demand for small vehicles were not only direct purchase-related incentives, such as lower tax, insurance, and licensing costs, but also usage-related expenses: public parking and highway tolls fee discounts (Song, 1995). Such monetary measures went along with the empirically tested view that making the purchase and ownership of an EFV less costly could solely boost its diffusion. For instance, an analysis of hybrid car sales in the US revealed that most customer-oriented incentives associated with monetary benefits, such as tax deductions or exemptions for hybrid car owners, as well as usage-related bonuses in the form of parking and HOV lane accessibility, were proven to have increased hybrid vehicle ownership in the region from 0.05% to 2.15% (Beresteanu & Li, 2011). In particular, two studies have reported that tax benefits (Gallagher & Muehlegger, 2011) and tax refunds on the purchase (Chandra et al., 2010) that could be applied immediately to a consumer were revealed to serve as the main factor for the EFV purchase. According to customer surveys on motivation for automobile purchase, policies providing privileges, including exemption for congestion fees, alongside public campaigns for social awareness of accurate consumer information for potential EFV owners, were important contributors to hybrid vehicle adoption (Ozaki & Sevastyanova, 2011). Moreover, in Canada, monetary incentives were indicated to have the speed of diffusion of EFVs, as an innovative product measure, is heavily impacted by incentivizing policies that directly create the appeal of the product for potential consumers. As a result, the overall implication for policymakers before 2008 consisted of a perspective that primarily focusing on making A-segment car ownership inexpensive could drive up sales. However, according to the Ministry of Land, Infrastructure and Transport (2007), the sales of compact cars in South Korea remained lower than 7% of the total automobile industry sales despite continuous improvement in the economic impetus provided to the auto owners.

In contrast to the direct stimulus-response model, an economic factor such as the increase in the cost of gasoline was specifically found to have a high correlation with the growing market share of EFVs (Beresteanu & Li, 2011). It was further identified that gasoline prices were the most visible signal for drivers considering fuel economy that is directly related to the sales of green cars (Chandra et al., 2010). This could imply that socioeconomic environments and conditions could also be critical factors to account for alongside general monetary benefits when attempting to enhance A-segment vehicle diffusion. To indicate essential socioeconomic variables that are potentially correlated

with high volumes of sales of A-segment vehicles and further focus on potential government policies in South Korea in addition to direct general stimuli, it is important to refer to pre-existing conditions in Europe, where the sales of compact vehicles are the highest globally. In particular, it was found that Western European consumers prefer small, simple, and affordable cars because of the population trend of single households, where medium or large individual transportation is not necessary (Voelk, 2020). Moreover, in Italy, it is permitted to drive compact minicars without obtaining a legal driver's license, making A-segment car purchases surge among young drivers (Tampa Bay Times, 2003). Finally, in South Korea specifically, by 2007, research conducted by the Ministry of Land, Infrastructure and Transport (2007) had shown that A-segment cars were owned by households with at least two cars, showing that compact vehicles' drivers in the country were unlikely to be in the low-income category heavily dependent exclusively on financial gains related to the car model. As such, policy measures needed to account not only for financial impetus but also other socioeconomic variables when pumping up the demand for and adoption of compact vehicles.

Both the demand and supply sides play key roles in the transition of the road transportation industry to successful diffusion of sustainable solutions, but the increase in adoption of low-emission vehicles is largely ineffective with the lack of growth in the supply of solutions "to accommodate additional demand" (Rozendaal & Vollebergh, 2021). As a result, the supply side of the car market can be identified as the primary force in the joint market transition to EFVs. However, government regulations and other policies can rarely promote environmental innovation through the stimulus-response model directed at the supply side only. That is because social welfare is, then, prioritized above actual user benefits, significantly reducing their willingness to adopt the innovation (Kemp, 2000). Therefore, technology competition in this sense is argued to be strongly correlated with the demand side, where the race between the car manufacturers is prompted by the idea of introducing the most "socially desirable shape" of solution that is driven by demand for more sustainable options (Kemp, 2000). Applying the outlined argument presented by Kemp on the innovation policy implications, the phenomenon of light passenger vehicle production and diffusion slump could be largely explained through the prism of the imbalance of the government effort in controlling the producer against boosting the consumer interest. This imbalance was primarily caused by prioritizing tight fuel economy limits via implementing the engine standard of 800 cc over car buyers' concern over the complete performance of the compact vehicle. The stimulus-response model carried out by the government before 2008 in pursuit of innovation failed to recognize the driving force of a sustainable technology race, disregarding socioeconomic peculiarities related to EFV adoption in the specific region and not meeting car owners' call for the vehicle productivity. As the automobile audience inferred that the stated engine capacity was "too weak" to support adequate operation and the guideline inherently defeated productive levels of consumer demand from within the root (Lee, 1997), the supply side was short of stimuli for market competition and was essentially stiffened with restraining policies giving a natural leeway to GM's A-segment-specific monopoly in the light vehicle market.

Despite some debates regarding the relationship between innovation and the competitive market structure, the general viewpoint favors the argument that a monopolistic market does not provide enough profit incentive for the single supplier to innovate due to the higher cost of embarking upon the research and development process and insufficient payoff of selling the new product. It is commonly proposed that not only does the producer have lower stimulus to invest in innovative processes and generate breakthrough technologies to lead the market, but also greatly discourages new entrants due to the steep entry barriers stifling radical innovation (Boldrin & Levine, 2008). Moreover, when specifically focusing on the development and production of a new technology, such as EFVs, the monopoly is even less capable of providing consumers with a "socially desirable good", which is critical in regard to successful environmental transformation in the industry (Boldrin & Levine, 2004). As such, the competitive market landscape is proven to be advantageous for sales, productivity, and pressure to innovate (Carlin et al., 2004). Furthermore, the preceding research identified the importance of market demand in combination with competition power on the evident presence of innovative efforts to "increase the chances of market innovation improving the firm performance" (Anning-Dorson, 2017). Here, we argue that the framework of policy-induced technology competition is especially detrimental to capturing the necessary shift in 2008 in the policy instruments in the A-segment market in South Korea and describe the nature of the competition underlined. Although both collaboration-specific and competition-oriented government tactics are proposed to be favorable forces for innovation encouragement for the promotion and development of EFVs (OECD, 1996), it is emphasized that instead of spurring higher inequality, policy-induced coordinated market rivalry may enhance innovation and productivity on higher levels (Aghion et al., 2021). Moreover, balanced and ethical market competition is considered to be "the main driver of innovation" as it encourages firms to implement more efficient processes and strive for advantageous renovations and technological breakthroughs to meet customers' needs and gain competitive advantage (PricewaterhouseCoopers, 2011). In this sense, the necessary "balanced-strong" competition can be identified as cooperative (Park et al., 2014). This collaborative characteristic of a still competitive market is essential for information dissemination and

interaction to achieve prompt technology adoption by the producer and consumer and rewarding technology innovation performance for environmental and socioeconomic welfare overall. Accordingly, we demonstrate how sustainable development in the EFV sector is dependent on policy instruments, such as standards and incentives, to encourage the "widespread diffusion of environmental technologies" in the form of environmentally friendly A-segment cars cyclically through the technology competition for the consumer interest.

3. Methodology

This research employs both qualitative case study and empirical data analysis to determine the interaction between government policy and technological innovation.

3.1. Embedded Single Case Study

To argue that the technology-policy synergy targeting the demand and supply sides prompted the development of a heightened competitive landscape in the market, we used an empirical research method of case study with elements of quantitative and qualitative analysis, showcasing regulatory- and incentive-based involvement in the establishment of a successful PITC model in the automobile industry marching toward the green agenda. As a representative example of the synergy effect between the policies and industry response in the form of a race for delivering the most efficient segment solution, the case study approach places the theoretical complex framework of policy-induced technology competition in the real-life setting of the A-segment vehicles sector to uncover the development of an EFV product shaped according to the consumer needs and global sustainability goals.

To be more specific, the embedded single case research design on the issue of PITC was used to highlight the significance of guiding and stimulating both the producers and consumers with regard to boosting the industry contest for innovation. The two subunits of analysis, demand and supply narratives, served as the dual-perspective foundation for exploring and analyzing the synergetic automobile market reaction and the environment evoked by the shift in the policy instruments in 2008 in a compound manner. This research attempts to illustrate efficient sustainable technological innovation by exploring causal relationships between regulatory impetus and environmental technology race, designing the concept of PITC, and showcasing its forward-looking implications for the general development of EFVs through an explanatory case study. As such, the in-depth multifaceted analysis of technology-policy interplay in the compact car market practically demonstrates the A-segment vehicle market growth after the policy review to devise a novice theoretical framework of PITC and concurrently pinpoint it as an exemplary prototype of the framework produced and its direct effects on the advancement of the EFV sector.

3.2. Data Sources and Data Description

Through the selected method of a case study, the triangulation of data was attainable via the use of primary sources on quantitative and qualitative indices relevant to the market shift within the compact car market in South Korea. The timeframe from the early 1990s to late 2000s was selected to capture the pertinent period of the industry segment pre-, interim, and post-engine standard revision to form a complex examination of the recession and stagnation of the A-segment vehicle market before 2008 and the design and implementation of PITC for sustainable development and competition-based expansion in effect and the aftermath of enactment. Original records, including government reports on the 2008 enactment published by the Ministry of Land, Infrastructure and Transport, newspaper articles documenting real-time events in the specified timeframe administered by leading official South Korean broadcasting accounts, such as MBC News and The Hankyoreh, and corporate statements issued by competing automobile manufacturers, were studied throughout the research to provide concurrent context for the practical implementation of PITC and ensure precision for the quantitative analysis. Moreover, the materials from automobile owners' blogs and forums were used to systematically review consumer attitudes toward competing car models. To describe the framework of PITC as a functional and viable model for EFV development through industrial competition as a whole, secondary literature in the form of research articles on the rationale, description, and effects of policy changes on the consumer and supplier behavior in other regional markets, such as the US, was utilized.

For emphasizing the critical aspect of consumer interest in the paradigm of technology competition in the light vehicle market and identifying socio-economic factors that should be considered in policy-making for innovation diffusion, quantitative data on the market for A-segment vehicles was collected from the Statistics Office of Korea and Opinet database, covering 16 provinces in South Korea for a period from 1999 to 2011 of pre-, interim, and post- engine standard revision. According to the CARISYOU Data Research Institute, small cars in general are associated with young female drivers. Moreover, our analysis of preceding literature revealed that the demand for EFVs could be a product of relevant socioeconomic factors, such as the number of household members, income level, gasoline price, and age distribution, rather than solely financial impetus provided to the consumers in the form of tax deduction and usage benefits. As a result, the percentage of the 20–34-year-old population, gender ratio of male to female population, gas price, gross regional domestic product (GRDP) per capita, single-person household rate, and employment rate were selected as relevant socioeconomic control variables to determine their effect on the adoption rate of compact cars in South Korea, represented by a dependent variable of A-segment vehicle rate from vehicle registration data

obtained from the Statistics Office of Korea (Table 1). When unavailable, intermediate values of in-between years were assumed using linear interpolation for the single-person household variable. To implement the beta regression model discussed further, the dataset is primarily represented in the form of proportions.

Table 1. Dataset variables, origin, and descriptive statistics (Developed by the authors)

Variable	Data	Unit	Mean	Median	Variance
A_seg_vehicle	% of registered A-segment cars	%	8.479	8.156	3.968
gasprice	Annual gasoline price	100 won/liter	14.858	14.725	4.276
yo2034	Rate of age between 20 and 34 years old	%	31.081	30.832	20.370
gender	Male population divided by female population	Binary			
grdp	Gross regional domestic product to the local population	Billion won/1000 people	18.159	15.895	57.371
household	Single-household rate	%	6.798	6.694	2.520
employ	Female employment rate	%	46.684	47.600	19.347

3.3. Statistical Model

To examine potential control factors that influence the demand for A-segment vehicles, a nonlinear maximum-likelihood regression method based on beta distribution is used. According to preceding research on extended beta regression models accounting for random effects, the mixed-effect beta regression was identified as a tool for considering the dependency in longitudinal data by allowing participant-specific effects (Zimprich, 2010). Because independent variables frequently depart from approximate normality, beta distribution, advantageous due to its flexibility, can be expressed in either unimodal, uniform, symmetrical, or skewed bimodal shapes. Compared with the linear mixed model, the model accounts for and fits the given data in a more precise and apt manner identified by Akaike's Information Criterion (AIC) and Bayesian Information Criterion (BIC) (Smithson & Verkuilen, 2006). As such, a statistical analysis, employing a cross-sectional and longitudinal examination with time-series data of registration and socioeconomic variables described in Table 1, was conducted based on the control variables, using the mixed-effect beta regression to analyze the South Korean A-segment vehicle market.

The dependent variable denoted as y is distributed in a U shape because of the change in the government policy in 2008. Dummy variables X1, X2, and X1X2 were constructed to express the phenomenon. The basic form is as follows:

$$y = \beta_0 + (\beta_1 + \beta_2 X_2) X_1 \quad (1)$$

where y is the proportion of A-segment vehicles, X1 is the number of years in the time frame, X2 is the indicator variable that has a value of 0 or 1 depending on before (0) or after (1) 2008, and X1X2 is the product of X1 and X2.

As a result, if X2 is 1, the equation can be derived as follows:

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_1 \quad (2)$$

If X2 is 0, the equation can be derived as follows:

$$y = \beta_0 + \beta_1 X_1 \quad (3)$$

The coefficients β1 and β2 are the penetration rates formatted as slopes. To express the phenomenon of the sales slump of compact vehicles before 2008 and the policy-induced surge after 2008, β1 is expected to be negative, and β2 is expected to be positive. Accordingly, the absolute value of β2 must be greater than that of β1. According to the aforementioned theory, we constructed several models for the proportion of sales of A-segment vehicles representing the demand. The models include time variables and other socioeconomic factors that may affect the dependent variable y represented in Table 1. The STATA program was used to obtain the initial coefficient, and the SAS program was used to conduct mixed-effect beta regression. The fitness of the model was measured using AIC and BIC values.

4. Results and Discussion

4.1. Key Factors Driving A-Segment Vehicle Adoption in South Korea

Several models were constructed to compare the fit to the A-segment vehicle market phenomenon in South Korea based on time variables representing the policy change. Before making the models, the variables had to be confirmed by measuring the significance of the coefficients and their effects. First, tests were conducted with the control and time variables using the STATA program (Table 2).

Table 2. Coefficients and significance of the control variables (Developed by the authors)

Variable	Coefficient	St. Error	z	P>|z|
gasprice	-0.723	4.689	-0.15	0.877
yo2034	-4.594	0.623	-7.15	0.000
gender	1.812	0.950	1.91	0.056
grdp	0.016	0.166	0.09	0.925
household	7.116	1.271	5.60	0.000

Continuation of Table 2				
employ	2.671	0.294	9.09	0.000

These results were calculated using only one variable with time variables X1 and X1X2 respectively. The significant variables were yo2034, household, and employment rate with P values less than 0.05. The household and employment rate variables had positive effects on the dependent variable of the A-segment vehicle rate, whereas the yo2034 variable had a negative effect. These coefficient values changed marginally depending on the combination.

The analysis was performed with different combinations of variables using the STATA program. The models were constructed only when every variable was significant. Trials were conducted including time variable X1 only and both X1 and X1X2. The location submodels, which included a random effect, were changed with different combinations of variables, while the dispersion submodel remained constant for model simplification. The models included time variables that implied the policy change and control variables that implied the characteristics of the region. Five best-performing models in the order of the goodness of fit, where smaller AIC and BIC values could represent the phenomenon of a higher adoption rate of A-segment vehicles depending on the policy change, are demonstrated in Table 3.

Table 3. Top five regression models according to the goodness of the fit (Developed by the authors)

Model	Location sub model	Dispersion submodel
M14	(β0 + b0) + (β1 + b1)X1 + β2* X1X2 + β3*yo2034 + β4*gender + β5*employ	γ0
M6	(β0 + b0) + (β1+ b1)X1 + β2*yo2034 + β3*household + β4*employ	γ0
M12	(β0 + b0) + (β1+ b1)X1 + β2*X1X2 + β3* yo2034 + β4*employ	γ0
M3	(β0 + b0) + (β1+ b1)X1 + β2* yo2034 + β3*employ	γ0
M18	(β0 + b0) + (β1+ b1)X1 + β2* X1X2 + β3*gender + β4*grdp + β5*household + β6*employ	γ0

The *employment* variable was included in all five models: it had a positive and significant impact on A-segment vehicle penetration, which means that the increased use of A-segment cars correlated with higher employment rates. However, the *yo2034* variable had a negative and significant impact on the market. The age of 20 to 34 years was selected as a control variable to check young people's choice for their first car according to the hypothesis made after reviewing the European market. Our model result suggests that young people do not select the A-segment vehicle as their first car, in contrast to European countries such as Italy. The GDPR variable in Model 5 is also significant and negative. The *gender* and *household* variables both have a positive and significant impact on the compact vehicle market segment. However, the *household* variable in Model 2 had a negative and significant coefficient. This means that the A-segment vehicle adoption rate is high for female drivers, who form a single-person household.

4.2. Technology Race for Producing Socially Desirable A-Segment Cars

The engine standard adjustment from 800 to 1000 cc, enforced by the Ministry of Land, Infrastructure and Transport of South Korea in 2008, supported by the already prevailing monetary benefits for the auto owners, prompted the transition of the compact vehicle segment into a more demanded car model and created a window of profit for the supply side. To demonstrate the effect of the policy incentive for A-segment vehicles with the 1000-cc engine size threshold on the compact car market, the sales data on two major automobile models, General Motors' Matiz with an engine size of 796 cc launched in 1999 and the newly standardized A-segment Kia Morning with a 999-cc motor released in 2004, were compared along the designated time frame (Figure 1). This graph shows the positive effect on Kia Morning sales and negative effect on Matiz sales due to the policy revision. After Kia Morning was classified as an A-segment vehicle, its sales grew steeply, while General Motors' Matiz sales also surged since 2009 due to the launch of a new model called Matiz Creative with an engine size of 995 cc (Green Car Congress, 2009). In total, it can be observed that the demand for A-segment vehicles increased since 2007 as the anticipated and then executed enactment accelerated the compact car appeal for drivers and allowed the leeway to the industry sector transformation into cost-effective and lucrative enough to pursue.

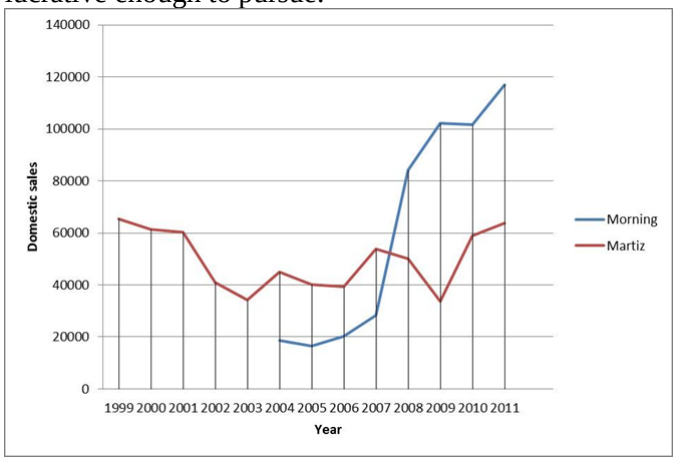

Figure 1. Sales data for GM Matiz and Kia Morning 1999-2011 (Developed by the authors)

Kia adopted engine downsizing from its previous

models and opted to develop a A-segment car with three-cylinder engine, higher power per cylinder, and less fuel consumption known as the Morning model. A relatively higher energy economy was possible due to the lighter weight of the vehicle and high-temperature materials. In the engine head and block, high-pressure cast aluminum was used, which allowed the manufacturer to reduce the mass of the motor to as low as 82.4 kg for the vehicle to be categorized under the compact light category (Caroom, 2021). The main components of the engine head and block were assembled in one body in a solid frame structure to eliminate excessive details and parts and minimize the assembling cost. The remaining engine parts also used advanced lightweight materials for durability and performance, and the crank shaft had an offset design to reduce noise and vibration. Both the fuel efficiency and power of the engine were significantly improved, which were two major concerns identified among the consumers formerly dissatisfied with the complete performance of the car at the expense of environmental benefits before the standard enactment. Kia was able to sell over 54,500 Morning units within 6 months after the initial release, while continuous technological improvements and simpler design increased the car's fuel efficiency by 8% (Park, 2018). As a result, Kia, with its energy-economic engine transformation, managed to achieve the highest power performance and fuel economy in the A-segment vehicle class, which allowed the company to continue innovative processes and introduce a new turbo engine with 110 horsepower and 14 kg-m torque (Yoon, 2017).

On the other hand, General Motors' Korea (GM Korea) first decided to increase its Matiz engine size to compete in the 1000-cc category. However, its net effect was rather harmful to fuel efficiency and cost, which repeatedly prompted drivers' unwillingness to opt for other car models. Eventually, having implemented the engine downsizing similarly to Kia, GM Korea could improve the fuel consumption performance and significantly subdue the weight and cost of the model. Despite continuous and persistent research and development, GM Matiz lost its dominance in the A-segment market share in South Korea in 2008 due to intense competition induced by Kia Morning's ability to seize the demand and satisfy market pain points. Moreover, the drop in the sales could be explained by the failure of GM to ensure the delivery of continuous technological innovation during critical customer inflow. Betting against the fuel efficiency trend, the automaker preferred to resume the engine upsizing of Matiz to ensure its higher power over Kia Morning (Kim, 2017). This change led to increased vehicle weight and deprived the model of its greenness due to a higher level of energy consumption. As the global economic crisis struck in 2008, fuel prices soared, and despite numerous total performance advantages of the Matiz model, the relatively lighter Kia Morning with a three-piston gasoline-efficient engine immediately took over the major market share. Following this competitive strike, GM Korea took upon the challenge by developing and launching the new Matiz model, known as Spark, with improved fuel economy and reduced vehicle weight, which allowed the supplier to reclaim the dominant position in the compact vehicle segment. Therefore, the competitors continued to deliver major sustainable technological breakthroughs for the light automobile market by upgrading their respective models until the 2020s and expanding the segment with new editions, such as Kia Ray.

5. Implications for a Sustainable Transportation Transition

The extended multifaceted analysis of the A-segment vehicle niche policy-driven transition to a competitive market landscape for capturing the surge in customers' interest aimed to design and demonstrate how the framework of a PITC could encourage higher sustainability efficiency in the road transportation market. It was identified that the standard change with existing financial incentives prompted the race for environmentally friendly product innovation between General Motors and Kia to capture both green welfare and user benefits with a higher A-segment vehicle penetration rate after 2008. Moreover, we found that the rate of diffusion of compact vehicles in South Korea was significantly dependent on several socioeconomic factors, such as the rate of single households, gender, employment, and age ratio in a specific region. The results indicate that the seemingly counterproductive to environmental stability policy adjustment to include more fuel-exhausting models into a comparatively energy-efficient class of vehicles led to a higher degree of adoption of a car model formerly weak in performance. In general, we can argue that government policy has a positive effect not only on compact fuel-efficient cars but also on the diffusion of EFVs, such as hybrid, hydrogen, and electric vehicles. Although it is proposed that the immediate PITC framework can be applicable to the diffusion and further inducement of market development of green personal transportation, the results of the high correlation are largely based on the South Korean auto market and the nation-specific consumer side, which is intricately tied to domestic socioeconomic values. Further advanced research is suggested to draw the potential variations in public perception of similar incentives and the supply side response to producer-directed constrictions in extrinsic markets. The results, however, firmly demonstrate that the framework of PITC has had a productive effect on the initial and further development and adoption of A-segment cars and is generally recommended to be replicated for efficient integration of sustainable innovation through competition.

From the viewpoint of demand, the case analysis in this study showed that policy incentives impact the diffusion of A-segment vehicles as a subclass of EFVs. That is, there are positive and significant control

variables in the case of the South Korean A-segment vehicle market, such as female employment rate and single-person household rate. To bring about effective penetration of sustainable transportation into the traditional automobile market, a support policy that targets such specific customer segments is necessary alongside the prevailing fiscal and monetary measures discussed. This focus of a PITC framework could ensure the inflow of new consumers into the market, interested not only in the standard cost-saving benefits related to the purchase of an EFV but also group-specific advantages critical for early adopters of green innovation in transportation. Consequently, the growing demand for a wider selection of EFVs could serve as a signal for the automobile manufacturers and increase the supply of vehicles, which in turn brought up more reluctant buyers and improved the greenness of the car industry. Despite that, the standard adjustment could not be as impactful for the market transformation without already prevailing consumer-oriented monetary stimuli. This means that the framework of PITC for sustainable development in the car market must foremost encourage the cost effectiveness of the purchase and ownership of a new green product to attract environmentally conscious and price-sensitive consumers. For them, guarantee of highway toll discount, insurance premium exemption, free public parking space, subsidies, tax exemption, reduction, and refund are valuable policy tools for boosting the initial cost efficiency of the market segment.

From the supply perspective, we demonstrated how policy-induced industrial competition can expedite innovation among technology firms. This contrasts with the case of the pre-2008 timeframe when stringent regulations stiffened the growth of the light vehicle segment in South Korea as the manufacturers found the low rate of demand and rigorous guidelines on the production of compact cars to be overly stringent and not cost-effective to invest in. It can be observed that policy makers are able to set such a reasonable, efficient standard for a product category, at which multiple manufacturers can compete for improved designs with higher functionality and lower cost, which could eventually lead to overall performance improvements throughout the industry and higher satisfaction rates among the consumers. Finally, such a competitive landscape in the automobile industry creates opportunities for producing innovation for environmental and social welfare through active innovative processes for capturing the largest market share. Overall, the symbiotic relationship between policy, demand, and supply sides, which form the policy-induced technology competition for sustainable growth, prompted by direct incentives and guidelines, is essential for a successful introduction of EFVs into the general individual road transportation market, as demonstrated by the case of A-segment vehicles in South Korea.

6. Conclusions and Limitations

The present article provides an in-depth multifaceted case analysis of A-segment vehicle penetration and growth in the South Korean automobile market before and after 2008, which signifies the year of the engine and sizing standard adjustment for the given car category. By analyzing the development of the demand and supply side alongside the designated timeframe of the enactment, we argued that the modification of the already existing engine standard for the A-segment category is an exemplary case of a successful PITC model in action, where the monetary incentives created demand for compact cars among the cost-sensitive and environmentally aware public. This effectively prompted an industry-wide response in the form of technology competition between Kia and General Motors for capturing the upward-going trend in customers' interest with consequent higher sustainability in the market segment. Drawing upon predating research on the role of competition in generating and amplifying innovation, we established the predominant aspect of technology race in the green transformation of the transportation sector. By adding the government-induced layer in the form of public inducement and manufacturer penalties and their effect on the innovation adoption encouraged by consumer pain and supplier race to deliver the best product fit, we were able to identify and test the relationship between policy and sustainable innovation dissemination in the automobile industry in South Korea. In addition, by constructing a regression model with possible socioeconomic control variables relevant to the region, we identified new potential focus points of gender, household type, and wealth for further policymaking in the EFV sector in general. In general, the analysis of the given case on a policy-ignited A-segment vehicle market race in South Korea, covering the consumer and manufacturer implications, could serve as a foundation for further policy-making initiatives for market adoption and diffusion encouragement of sustainable road transportation.

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Authors' Contributions

Joosung Lee conducted this research, including the case study, and wrote the manuscript. Elena Kazakova conducted the literature analysis and policy research. Jihoon Kim conducted the data analysis.

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