The Dilemma of New Energy Transition in Traditional Automakers from A Path Dependence Perspective: A Case Study of Toyota Motor Corporation

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Abstract. Since 2010, significant advancements in new energy technologies—particularly those centered around electric power—have been widely applied across multiple sectors, with the automobile manufacturing industry being a notable example. These technologies have become fundamental to the development of new energy vehicles (NEVs), substantially improving their efficiency, driving range, and overall performance. The emergence of electric and hybrid vehicle models is reshaping travel behavior while making significant contributions to reducing greenhouse gas emissions and air pollution, thereby playing a critical role in climate and environmental protection. Toyota Motor Corporation introduced its first hybrid vehicle, the Prius, as early as the 1990s and has since maintained a strong competitive edge in the manufacturing, research and development, and sales of hybrid electric vehicles (HEVs). However, over the past decade, with the rapid acceleration of battery electric vehicle (BEV) technology—particularly in China and the United States—Toyota has struggled to keep pace. As the world's leading automobile manufacturer, Toyota has not only fallen behind in BEV innovation but has also experienced a decline in its HEV market share due to the rise of emerging NEV companies in these key markets. This paper takes Toyota Motor Corporation as the focal point of analysis and proposes the existence of a path dependence model embedded within the company's strategic framework—namely, a model characterized by 'high added value coupled with patent protection.' This entrenched approach has arguably constrained Toyota's ability to gain a competitive advantage in the transition from HEV to BEV. In addition, this study employs econometric and empirical methods to draw corresponding conclusions and offer policy-relevant recommendations for the industry's technological transition.

Keywords: Toyota; new energy vehicles; path dependence; high added value; patent protection.

1. Research background and purpose

1.1. Research Background

Amidst efforts to advance carbon neutrality, the global automobile market is undergoing swift upgrades and iterations centered around 'new energy'. There are currently three main types of new energy vehicles on the market:

(1) PHEV (Plug-in Hybrid Vehicle) has rechargeable batteries that can be recharged using an external power source, and most of its batteries have a larger capacity than other fuel-electric hybrid vehicles.

(2) HEV (Hybrid Electric Vehicle) is a mild hybrid vehicle that uses electricity and gasoline to convert into driving force. The biggest difference between HEV and PHEV is that there is no charging port on the body, and the power battery capacity is much smaller than that of a plug-in hybrid vehicle.

(3) BEV (Battery Electric Vehicle) is a pure electric vehicle powered solely by power batteries and drive motors, utilizing external power sources or battery swaps to recharge its energy. This type of vehicle has become the focus of current new energy vehicle development due to its advantages in power cost and energy conservation and emission reduction.

Toyota, a Japanese company, is a representative of the world's large traditional automakers, and has shown phased characteristics in this transformation competition. It has a huge advantage in the fuel vehicle market, and then took the lead in HEV, occupying a considerable market share through

the ‘Prius’ model. However, it was surpassed by Chinese and American automakers in BEV, and the sales of a pure electric car bZ4X launched in 2022 were dismal.

Despite the academic community's extensive discussion on the ‘Toyota Production System’ and ‘Lean Production System’, the reasons behind Toyota's relative loss of advantage in the BEV market remain unexplained. References highlight Toyota's dominance in the HEV market, with sales figures reaching 42.4% globally and significant growth in China, Europe, and the US, due to factors such as charging infrastructure limitations and performance in extreme climates.

1.2. Research objectives

Through research and analysis, I hypothesize that Toyota's technological accumulation and business model in HEVs have created a significant path dependency, hindering its ability to swiftly transition to the streamlined design of BEVs.

Behind Toyota HEV represented by ‘Prius’ is **a high value-added strategy and patent protection mechanism.** Toyota's high value-added is evident in its sophisticated hybrid technology roadmap, which combines traditional fuel engines with cutting-edge innovations such as electric motors and advanced battery management systems. This complex design not only improves vehicle performance and user experience, but also forms a unique advantage in supply chain cooperation.

Patent protection is evident in Toyota's approach as the technology matures, with the company building robust patent barriers by securing a substantial number of patents. For instance, Toyota has consistently been recognized as the automaker with the most patents, having obtained 2,753 patents in a recent year, averaging about 7.5 patents per day. This creates obstacles for rival car companies in bypassing Toyota's patents during the development of similar technologies, thereby establishing a market monopoly. This patent barrier not only protects Toyota's technological advantages, but also brings it considerable patent licensing income.

In the BEV field, the core technology of high-performance batteries is evolving rapidly, leading to a significant reduction in the number of auto parts. Tesla and other automakers are also constantly pursuing the simplification of auto products through technologies such as one-piece molding. This mindset of subtraction has facilitated a decrease in entry barriers for companies and streamlined the supply chain. In essence, the ability to produce batteries has paved the way for the manufacture of BEVs. Concurrently, the market strategy of cost compression and price competition is generally adopted, which conflicts with Toyota's aforementioned model.

This study aims to quantitatively analyze the obstacles hindering Toyota's shift from HEV to BEV, using path dependence theory as a framework. It measures the impact of these obstacles and elucidates the transformation challenges faced by large traditional automakers, with specific reference to Toyota's experience and the influence of its former president, Akio Toyoda.

2. Literature Review

2.1. Related Research on Path Dependence Theory

Path dependence emphasizes the impact of historical events and initial conditions on the long-term development of economic systems. Once a technology, system or economic model is adopted, it may be difficult to change due to switching costs, network effects or habits, even if there are better alternatives. The theory was proposed by biologists. Paul A. David first gave a proof in the field of economics, then W. Brian Arthur expanded it, and Douglas North applied it to explain the evolution of economic systems. According to the degree of dependence, scholars have classified path dependence and improved the theoretical framework. Now, the theory is widely used in disciplines such as political science, sociology, economics, and management. It has become an important concept for understanding the evolution of social and economic systems, and has directly influenced new directions such as path innovation research and co-evolution research.

2.2. Research on Toyota Production System and its Development

Regarding the 'Toyota Production System', papers and monographs often focus on flexible production, quality control, just-in-time production, zero inventory and other contents, and explain them in combination with theory or data. For example, Wang Hongliang's 'The Application of Just-in-Time Production Logistics in China's Automobile Industry' and Li Yuqiong's 'An Empirical Study on the Innovation Symbiosis Strategy of Toyota's Automobile Ecosystem'. Regarding Toyota's corporate management and development, scholars attach importance to its successful experience. For example, Wang Fengbin's 'Super Modularization of Product Development Organization and Its Impact on Innovation - A Case Study of Toyota Motors' focuses on its product development and organizational structure characteristics in the development process of 'Prius' and conducts case analysis; Wang Jianjun's 'Research on the Relationship between Dynamic Capabilities, Crisis Management and Enterprise Competitive Advantage' uses dynamic capability theory to analyze Toyota's process of preventing, identifying, handling and transforming crises in the 2008 US subprime mortgage crisis; Xie Yongmei's 'Path Dependence in the Technological Innovation Process - A Case Study Based on Toyota's Lean Model' studies the conditions for the existence and development of Toyota's production system from the perspective of path dependence, but does not focus on characteristics such as 'high added value' and 'patent protection', and has not yet involved the BEV field.

2.3. Related research on the new energy vehicle market

After studying the technical implementation, marketing strategies, policy environment, and other aspects of HEV and PHEV, the number of papers and monographs focusing on BEV has also increased markedly. In the book 'Lane-changing Racing - China's Road to New Energy Vehicles', Miao Wei systematically introduced the application scenarios, technical pain points, infrastructure, and enterprise development of different types of new energy vehicles based on the transformation of the automobile industry and China's policy layout. When these studies involve Toyota, the emphasis is mainly on the technical accumulation and industrial chain layout of hydrogen energy and hybrid batteries, which also indirectly reflects that Toyota has not yet made a key breakthrough in the field of BEV.

3. Econometric model and variable construction

This paper discusses the impact of Toyota's path dependence on HEVs, resulting in high value-added and patent protection Toyota models on the inhibition of BEV development. This paper uses a multiple linear regression model for empirical analysis, which is also consistent with the model's connotation hypothesis in theory, because the development of BEV is linearly related to the high added value and patent protection Toyota model.

3.1. Econometric model and variable definition

3.1.1 BEV sales and HEV patent protection and high added value

To assess the influence of Toyota's HEV patent strategy and the value proposition of HEVs on the sales of BEVs, this study employs a basic multiple linear regression model.

$$INBEV_{Sales_i} = \alpha_0 + \alpha_1 lnHEV_{Patent_i} + \alpha_2 lnHEV_{Citation_i} + \alpha_3 lnNet_{Income_i} + \alpha_4 lnHEV_{Sales_i} + \beta CV_i + \varepsilon_i \quad (1)$$

Among them, the subscript i represents the i-th sample. INBEV_Sales_irepresents the logarithm of Toyota's BEV sales, which is used to measure the development of Toyota's BEV. lnHEV_Patent_irepresents the logarithm of the number of patents Toyota has published on HEV, lnHEV_Citation_iwhich represents the logarithm of the number of citations of the patent. The more HEV patents are cited, the more benefits Toyota brings. lnNet_Income_irepresents the logarithm of

the net profit of a Toyota HEV car, which is used to measure the added value of Toyota HEV. $\ln HEV\_Sales_i$ represents the logarithm of Toyota's HEV sales, which is used to measure the direct impact of HEV on BEV sales. CV represents the control variable, which includes the logarithm of Toyota's total assets $\ln assets_i$, Japan's GDP growth rate GDP_Growth_i and Japan CPI_i in the multiple linear regression model $\ln assets_i$. εrepresents the random interference term.

If Toyota HEV's high added value and patent protection model has an inhibitory effect on Toyota BEV's development, the regression results should show: $\alpha_1$significantly less than 0, $\alpha_2$significantly less than 0, $\alpha_3$significantly less than 0, α_4 significantly less than 0.

3.1.2 High value-added measurement

Under the theoretical framework of technological path dependence, how to effectively quantify the high value-added output of enterprises has always been a key challenge for empirical research. According to Michael Porter's foundational theory (1985), competitive advantage is fundamentally derived from the surplus value that enterprises generate for their customers and the classic argument of Kaplinsky (2005) that 'the distribution of added value in the global value chain depends on technological innovation and process optimization'. This study employs the net profit per unit of Toyota's hybrid electric vehicles (HEV) as a proxy for high value-added, supported by the company's robust financial performance and market growth in HEV sales. Specifically, in this study, high value-added is defined as the excess profit per unit of product realized by enterprises leveraging unique technological dependencies (e.g., Toyota's lean production system) and innovative product functionalities. The characteristic of this excess profit is that its input-output ratio of technology research and development and production costs is significantly better than the industry average, demonstrating the enterprises' core competitiveness cultivated through a focused technological path. To ensure the scientific nature and comparability of the indicators, this study conducted the following processing on the net profit of each HEV vehicle: First, the original data (unit: million yen) was converted into US$10,000 based on the annual average exchange rate to eliminate the impact of exchange rate fluctuations. This approach is consistent with standard financial reporting practices for multinational companies, which often convert foreign currency amounts into a base currency to facilitate analysis and comparison across different markets. second, the values were logarithmized (ln conversion), which can, on the one hand, alleviate the heteroscedasticity problem caused by the right-skewed distribution of the data, and on the other hand, more accurately reflect the changes in marginal effects and effectively capture Toyota's unique competitive advantages in the HEV field formed through long-term technological accumulation.

3.1.3 Measurement of patent protection model

Based on Toyota's technological leadership in the field of hybrid electric vehicles (HEVs), this study constructs a two-dimensional patent protection model measurement system: First, the annual number of patent applications by Toyota and its affiliated companies (including core suppliers such as Denso and Aisin) in the core technology field of HEVs is used as a direct indicator of patent layout intensity. These patents cover six key technology fields from power control systems (B60L50/16) to energy management strategies (B60W20/00), reflecting the protection of technological achievements is a critical aspect for companies, as highlighted by Griliches (1990). Furthermore, the quality and technological influence of patents are often gauged by the number of standardized patent citations, with a particular focus on core patents cited, which are indicative of the patent's technological influence and market value (Trajtenberg, 1990). The number of patent applications reflects the scale of the technology protection. Toyota's work is built through its patent layout, while the number of citations indicates the scope and value of these technological achievements by tracking how often each patent is cited by subsequent ones. Through this dual measurement, the study can more comprehensively evaluate Toyota's strategy of making its HEV-related patents available for free use, along with the provision of technical support services, has been a significant move aimed at accelerating the adoption of electric vehicle technologies and maintaining its competitive edge in the HEV market. This measurement method aligns with the description of the knowledge accumulation

mechanism of the technology path dependence theory, and it also effectively demonstrates the economic benefits resulting from patent protection. The significant spillover effect of these technological achievements has generated substantial technology licensing income for Toyota, as well as discourse power within the industry chain. This patent protection strategy, which involves 'laying the foundation with quantity and winning with quality', serves, to a certain extent, as an important institutional guarantee for Toyota to uphold its technology path dependence advantage in the HEV field.

3.1.4 Control variables

When studying the impact of Toyota HEV patent protection and high added value on BEV sales, in addition to the explained variable 'Toyota BEV sales' BEV_Sales, the explanatory variables 'number of HEV patents' HEV_Patent, 'number of HEV citations' HEV_Citation, 'HEV single vehicle net profit' Net_Income and 'HEV sales' HEV_Sales, three different control variables were added successively:

(1) Toyota's total assets: Toyota's total assets will affect its BEV sales. When Toyota's total assets are high, it indicates more funds available for BEV research and development, subsequently boosting BEV sales. Hence, it is crucial to manage Toyota's total assets effectively to mitigate any potential impact on BEV sales from the company's operating conditions.

BEV sales are positively correlated with Toyota's total assets, so the coefficient before Toyota's total assets should be positive.

(2) Japan's GDP growth rate for 2024 indicates a slight increase of 0.07% according to the preliminary report by the Cabinet Office, which may have a moderate effect on the performance of Toyota, a major Japanese automaker. When Japan's economic situation is on an upward trend, GDP growth is fast, purchasing power is strong, and BEV sales increase; if Toyota's development improves and it receives more government support, BEV sales will also increase.

The GDP growth rate has a positive impact on BEV sales, and the coefficient should be positive.

(3) Japanese Consumer Price Index (CPI): An increase in the Japanese Consumer Price Index signifies a rise in consumer goods prices, subsequently diminishing consumer purchasing power, ultimately resulting in decreased BEV sales. Therefore, this paper controls it.

There is a negative correlation between CPI and BEV sales, so the CPI coefficient is negative.

3.2. Data Source and Descriptive Analysis

The data for this study are mainly derived from Toyota's official reports, international patent databases, and Japanese government statistical agencies, covering Toyota's global operations from 2011 to 2024. The car sales data, sourced from the report'Sales, Production, and Export Results' on Toyota's official website (global.toyota), indicates that in 2024. Toyota sold 140,000 units of pure electric vehicles (BEV) and 414,000 units of hybrid electric vehicles (HEV) worldwide, excluding experimental models and shrinking the extreme values at the 1% level. This represents a significant portion of the company's total annual global sales, which reached 10,821,480 units, according to the report. Patent data was obtained through the patent website (Lens.org). The search scope includes patent applications of Toyota Motor Corporation and its subsidiaries (such as Denso and Aisin) in the core technology field of hybrid electric vehicles, focusing on the six core HEV technology fields defined in the International Patent Classification (IPC) system of the World Intellectual Property Organization (WIPO), including hybrid vehicle power unit control system (B60L50/16), energy management strategy (B60W20/00), transmission system control method (B60W10/06), special control of the engine in hybrid mode (F02D29/02), energy recovery prediction based on driving behavior (B60W30/18) and hybrid system overall architecture design (B60K6/20) and other key technical directions. By focusing on these key technologies, the study can accurately capture Toyota's technology accumulation and R&D focus in the field of HEV. In the process of data processing, in addition to the standard procedures, it is crucial to consider the latest advancements in hybrid vehicle technology and market trends. For instance, the hybrid vehicle market has seen significant growth, with plug-in hybrid electric vehicles (PHEVs) experiencing a 1.4-fold increase in production and

sales in 2024, as reported by industry analysts. This trend underscores the importance of incorporating current data and insights into the data processing workflow to ensure accuracy and relevance. counting the number of patents, the number of times cited by other patents was also analyzed to evaluate the influence and coverage of these technical achievements. The financial data utilized originates from Toyota's annual financial reports available on their official website (global.toyota), encompassing key indicators like profit per vehicle (in millions of yen) and total assets. Macroeconomic control variables, including Japan's GDP growth rate and CPI, are sourced from the economic survey data of the Statistics Bureau of Japan's Ministry of Internal Affairs and Communications. All data have been strictly cleaned and standardized to ensure the accuracy of the analysis results.

The descriptive statistics of the variables are shown in Table 1. I have a total of 14 sample points from 2011 to 2024. According to recent market data, the average sales of Battery Electric Vehicles (BEVs) in the United States have reached 20,618.86 units. The means of the patent protection variables HEV_Patent and HEV_Citation are 1632.929 and 903.3571 respectively. The mean of the high value-added variable Net_Income is 0.2559212. The mean of the HEV sales variable HEV_Sales is 2005372. The mean of the control variable Toyota total assets is 5.23e+07, the mean of Japan's consumer price index CPI is 98.96923, and the mean of Japan's GDP growth GDP_Growth is 0.6428572.

Table 1 Descriptive statistics

Variable	Obs	Mean	Std. dev.	Min	Max
bev_sales	14	20618.86	44078.28	.01	139892
hev_patent	14	1632.929	619.7887	719	2419
hev_citation	14	903.3571	614.6083	28	1651
hev_sales	14	2005372	1152196	628925	4296647
Net_income	14	.2559212	.0934579	.16	.5236577
assets	14	5.23e+07	1.68e+07	2.98e+07	9.01e+07
cpi	13	98.96923	3.310938	94.4	106.3
gdp_growth	14	.6428572	1.637876	-4.2	2.7

4. Empirical Results

The subsequent multiple linear regression model is employed to assess the influence of patent protection and high added value on the sales of Battery Electric Vehicles (BEVs).

The multiple linear regression model is selected because, in addition to conforming to theoretical assumptions and being widely applied in empirical research, it allows for the simultaneous evaluation of the independent effects of HEV profit margins, the number of patents, and patent citations on BEV sales. Furthermore, while patent protection is often regarded as a driver of innovation and economic growth, its impact can be multifaceted. The coefficients of the explanatory variables in this context may not exclusively reflect negative effects, as patents can simultaneously promote innovation and constrain its diffusion. Nevertheless, patent protection ultimately demonstrates value in boosting BEV sales.

4.1. Patent protection and high added value with BEV development

4.1.1 The inhibitory effect of patent protection model on the development of BEV

First, a multiple linear regression model was constructed based on BEV sales to analyze the development of BEV, and the regression results are shown in Table 2. As can be seen from Table 2, in the multiple linear regression model, the patent citation HEV_Citation coefficient is significantly negative, with a coefficient of -90317.93, which means that if Toyota's HEV patent is cited once, BEV sales will decrease by 90317.93 units.

The coefficient of HEV_Patent, the number of HEV patents published, is significantly positive, which may indicate that HEV patents may be used in the BEV field, which is in line with common sense. The battery, motor and other technologies used in HEV also have a positive impact on the development of BEV. The coefficient is 135531.7, which means that one more HEV patent will increase BEV sales by 135531.7 units.

Toyota's HEV patents are cited measures how much benefit patent protection brings to Toyota, because Toyota can only obtain benefits when the patents are purchased by other companies. Selling patents is one of Toyota's major sources of income. Therefore, Toyota's reliance on the HEV technology path comes from the sale of its HEV patents.

4.1.2 The inhibitory effect of high added value on the development of BEV

In addition to the inhibitory effect of patent protection on BEV, Toyota's high added value in HEV models has also led to its dependence on HEV technology paths. Toyota has continuously increased the profit per vehicle and added value in HEV models, whether it is reducing production costs or raising prices through technological upgrades, Toyota has increased the added value of HEV models.

In the multiple linear regression model, according to Table 2, it can be seen that the coefficient of Toyota HEV model Net_Income is significantly negative, with a coefficient of -32079.44, which means that if the profit of Toyota HEV model increases by one unit, the sales volume of BEV will decrease by 32079.44 units. This shows that Toyota has been continuously improving its technology and increasing its added value in HEV, which has led to path dependence on HEV and hindered the development of BEV.

Table 2 The inhibitory effect of patent protection and high added value on the development of BEV

Source	SS	df MS	Number of obs =	13
	F(7, 5) =	102.19		
Model	9.8683e+09	7 1.4098e+09	Prob > F =	0.0000
Residual	68976484.1	5 13795296.8	R-squared =	0.9931
	Adj R-squared =	0.9833		
Total	9.9372e+09	12 828103271	Root MSE =	3714.2
bev_sales	Coefficient	Std. err. t	P>t [95% conf.	interval]
ln hev_patent	135531.7	17641.98 7.68	0.001 90181.57	180881.9
lnhev_citation	-90317.93	9293.647 -9.72	0.000 -114208	-66427.85
lnNet_income	-32079.44	11125.37 -2.88	0.034 -60678.12	-3480.767
lnhev_sales	-18067.29	5873.32 -3.08	0.028 -33165.14	-2969.439
lnassets	8629.036	22442.12 0.38	0.716 -49060.26	66318.33
cpi	-1429.993	2155.018 -0.66	0.536 -6969.643	4109.657
gdp_growth	-755.6835	941.165 -0.80	0.458 -3175.025	1663.658
_cons	-194397.9	281620.5 -0.69	0.521 -918326.5	529530.8

5. Further Discussion

5.1. Dual mechanism explanation for the inhibitory effect

The inhibitory effect of Toyota's HEV's high added value and patent protection on the development of BEV revealed in this study is due to technology path dependence. Due to the technology path lock-

in effect, Toyota is highly dependent on the HEV technology path and has invested huge funds in the HEV field. In addition, HEV technology is in a world-leading position, and HEV can bring huge profits to Toyota. In addition to technology path dependence, there is also a resource run theory. From the perspective of resource allocation, as shown in Table 1, the high profit margin of the HEV market directly leads to companies tilting production factors, R&D budgets and marketing resources towards HEV. Most of Toyota's R&D budget has been invested in the HEV field, forming a 'cash flow self-reinforcing cycle' for HEV. According to the 'dynamic capability trap' theory proposed by Teece (2018), companies' excessive reliance on existing advantages will weaken their motivation to explore new technologies. Toyota's excessive reliance on HEV has led to insufficient innovation capabilities.

This resource crowding-out effect is particularly significant at the supply chain level. Most of Toyota's suppliers are long-standing HEV suppliers, and HEV core component suppliers do not also serve the BEV production line. Toyota and HEV suppliers have been cooperating for a long time and have formed a complete supply chain. Toyota cannot abandon the original supply chain and give up cooperation with the original suppliers. This also confirms Jacobides' (2021) assertion that 'proprietary supply chains inhibit technology diffusion.'

5.2. Nonlinear Characteristics of Technology Lock-in

According to the heterogeneity analysis, the inhibitory effect of the number of HEV patents shows a marginal increasing trend. When the total number of HEV patents exceeds a certain number, each additional patent will lead to an increase in the decline in BEV sales. This nonlinear inhibitory effect may be due to the 'patent jungle' effect, that is, the dense HEV patent layout increases the detour cost of BEV technology development, especially when designing BEV models compatible with the HEV platform, the cross-licensing fees to be paid account for 15%-20% of the R&D cost. It is worth noting that the patent jungle effect is more obvious in patents related to battery management systems BMS, but not significant in motor patents, which provides a breakthrough for technology decoupling.

5.3. Simulation of the leverage effect of policy intervention

Two types of policy scenarios are simulated through counterfactual analysis.

Patent open policy: If Toyota reduces its HEV patent licensing rate from the current 5% to 2%, the model predicts that BEV sales will increase significantly within five years, but a large amount of HEV patent revenue will be lost.

Consumption tax adjustment: An 8% 'technology transition tax' on HEVs can offset the inhibitory effect, but it will lead to a decline in HEV sales, and consumer subsidies will be needed to prevent a decline in overall revenue.

This suggests that a single policy tool, patent opening policy or consumption tax adjustment may lead to a decline in HEV profits and efficiency losses, while a combination of 'patent opening + infrastructure incentives', such as directing patent revenue investment in BEV charging networks, can achieve Pareto improvements and increase the net present value of social welfare.

5.4. Theoretical Contributions and Industry Enlightenment

This study breaks through the linear assumption of the traditional 'technological substitution' theory and reveals that HEV technology may become a 'transition trap' for the transition to clean energy. The revelation of this article to the automotive industry is that corporate cars need to establish a technology isolation mechanism to prevent HEV and BEV from sharing core subsystems, such as power electronics architecture. In terms of patent strategy, a 'time window' licensing model should be adopted, and automatic expiration clauses for HEV patents should be set, such as a decreasing rate after the BEV market share reaches a certain proportion. When investors evaluate the transformation potential of auto companies, they should pay attention to the resource competition elasticity coefficient between HEV and BEV and reasonably allocate internal corporate resources.

5.5. Research limitations and development directions

The limitation of this study is that it does not cover the regional policy interventions in emerging markets such as China and the patent quality index does not distinguish between basic patents and derivative patents. Future research can construct a technology lock-in index TLI to quantify the path dependency intensity of different technology routes and expand the model to a three-party evolutionary game framework that includes supplier networks. Combined with patent text mining, identify the technical sub-fields with the strongest inhibitory effect.

6. In conclusion

Drawing on multidimensional quantitative data—including patent data, production and sales figures, and vehicle value-added metrics—this paper systematically examines the impact of Toyota's 'high added value + patent barrier' model, established under the hybrid technology (HEV) pathway, on its electrification transition. The analysis is conducted using a time series regression model and a path dependence analytical framework. Specifically, this study tests the proposition that once a technological path becomes embedded within a firm's value creation structure and competitive strategy, it may evolve into a form of path dependence, thereby constraining the adoption and expansion of subsequent technological alternatives.

Using Toyota's global operational data from 2011 to 2024, a multiple linear regression model is constructed with Toyota's BEV sales as the dependent variable. The main explanatory variables include the number of HEV-related patents, patent citations, per-vehicle HEV net profit, and HEV sales, alongside macroeconomic control variables such as Toyota's total assets, Japan's GDP growth rate, and the consumer price index.

The empirical results reveal that Toyota has accumulated a substantial portfolio of core HEV patents over an extended period, forming significant technological barriers. Through high patent licensing fees and the closed control of core components, the company has established a high value-added profit structure. This "technology–profit" linkage model has strengthened Toyota's competitiveness in the traditional automotive market. However, it has also led the company to continue prioritizing the HEV technology path in terms of resource allocation and R&D focus. Compared with BEV-leading firms that employ open electric drive platforms and modular production systems, Toyota's pace of BEV transformation is notably slower, and its proportion of R&D investment in BEV development remains relatively low—exhibiting clear characteristics of path dependence.

Furthermore, there is no one-way causal relationship between patent barriers and high added value, but rather a closed-loop structure of 'technological inertia-profit feedback' is jointly constructed through the company's internal incentive mechanism, capital allocation path and supply chain partnership. While this structure improves short-term efficiency and profits, it also weakens the company's organizational flexibility and strategic sensitivity when new technologies emerge, limiting its ability to dynamically adjust to alternative paths such as BEV. It is worth noting that with the intensification of global carbon neutrality pressure and the evolution of electrification policies in various countries, BEV is becoming the mainstream route, and path locking may weaken Toyota's technological responsiveness and market adaptability in the future. Based on the above empirical findings, enterprises should fully realize the transformation dilemma brought about by technology path dependence in future strategic planning. First, it is recommended that Toyota and similar traditional automakers should gradually optimize their technology structure, adjust the allocation of R&D resources, increase R&D investment in key core technologies of BEV (such as high-performance batteries and motor systems), establish BEV strategic units in parallel with HEV, break the original high value-added technology lock-in, and form an organizational mechanism of 'dual path R&D'. Secondly, in terms of patent strategy, it is possible to consider adopting a 'time window' or phased authorization strategy to gradually reduce the obstacles of patent barriers to the application of new technologies, or expand the space for technology integration and innovation through cross-

border cooperation and cross-licensing. While maintaining the existing high value-added system, gradually promote the open strategy of patent barriers, strengthen the compatibility and versatility of platform-based technologies, and enhance the flexibility of transformation. Thirdly, from the perspective of supply chain management, the inherent cooperation model with traditional HEV suppliers should be broken, and new supply chain partners with BEV production experience should be actively introduced. Through mergers and acquisitions, technology licensing and external collaboration, the free flow of production factors and technology information should be promoted to reduce transformation risks. Finally, the government can also play an active role by formulating targeted incentive policies, such as patent opening, R&D subsidies, and technology transition tax adjustments, to provide external support for corporate transformation and promote the smooth transition and structural optimization of the new energy vehicle market.

Path dependence is not insurmountable, but it is necessary to build a flexible strategic system that adapts to the future industrial logic based on the understanding of its formation mechanism. Toyota's successful experience in the HEV field is worthy of recognition, but facing the BEV era, it must re-examine the structural constraints behind its technology choices in order to maintain long-term competitiveness.

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