Research on the promotion of new energy vehicles based on multi-source heterogeneous data: consumer and manufacturer perspectives

Bing Sun1 · Zhuofang Ju1

Received: 21 December 2021 / Accepted: 15 November 2022 / Published online: 19 November 2022 © The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2022

Abstract
Under the background of green development, new energy vehicles, as an important strategic emerging industry, play a crucial role in energy conservation and emission reduction. In the post-epidemic era, steadily promoting the promotion of new energy vehicles will be a hot topic. Based on multi-source heterogeneous data, combined with the latent Dirichlet allocation topic model, social network analysis, and econometric methods, this paper explores whether individual purchase decisions and company-level cooperative research and development will promote the promotion of new energy vehicles. The results show that whether it is battery electric vehicles, hybrid electric vehicles or plug-in hybrid electric vehicles, users are more concerned about space dimension, power performance, and design style. Patent collaboration network analysis indicates that new energy vehicle enterprises are establishing close partnerships, which will urge the promotion of new energy vehicles. An interesting test result found that for short-term innovation, new energy vehicles enterprises should invest more patent research and development in battery electric vehicles and hybrid electric vehicles models to better accelerate the promotion of new energy vehicles.

Keywords New energy vehicle · Social network analysis · COVID-19 · Latent Dirichlet allocation topic model

Introduction

New energy vehicles (NEVs) are of great significance to energy conservation and emission reduction and economic development (Cano-Rodríguez et al. 2022; Huang et al. 2022a). With the prominence of energy problems and the progress of electric vehicle technology, all countries are paying attention to the development of NEVs. In China, the automobile industry plays an important role in the national economy. However, the rapid development of traditional cars inevitably brings a series of energy and ecological environmental problems such as energy consumption and environmental pollution. The development of new energy vehicles has become a strategic choice combining economic, social, and ecological goals. New energy vehicles refer to vehicles that use unconventional fuels or new power equipment. This paper focuses on battery electric vehicles (BEVs), hybrid electric vehicles (HEVs), and plug-in hybrid electric vehicles (PHEVs). Since the outbreak of COVID-19 in early 2020, the NEV industry has been hit by an apparent lack of consumer spending power (Li et al. 2021). Specifically, in 2020, NEV sales in China accounted for only 5.4% of total vehicle sales compared to other European countries. It can be predicted that in the post-epidemic era, it is difficult to achieve the goal of 20% of new energy vehicle sales in the development plan of China’s new energy vehicle industry (Sun and Wang 2018). Therefore, under the impact of COVID-19, stabilizing the consumption of the automobile industry has become a top priority for the Chinese government.

Both individual consumers and automobile manufacturers are important participants in the promotion of new energy vehicles. New energy vehicle consumers, as users of new energy vehicles, are also implementers of new energy vehicles. Consumer evaluation is crucial to the steady development of the new energy vehicle industry (Shende 2014). Consumers have a clear understanding of the policy and value of new
energy vehicles, which will promote the promotion of new energy vehicles (Xiong and Wang 2020). In addition, a proper understanding of consumers’ purchase intentions by manufacturers is more conducive to the success of NEV in the market (Wang and Dong 2016). At present, many car clubs and auto manufacturers attach great importance to consumer participation and consumer evaluation of new energy vehicles, and auto manufacturers also hope to carry out targeted research and development production according to consumer evaluation. Therefore, we have reason to believe that consumers’ online evaluations will affect users’ purchase decisions of new energy vehicles. Moreover, manufacturers can understand consumers’ preferences through consumers’ online evaluation and take quick actions to respond to market changes and to accelerate the promotion of new energy vehicles.

For automobile manufacturers, based on the diffusion of innovations theory, through extensive technical cooperation, automobile manufacturers can reduce the cost of high-tech research and development (R&D) and improve the technological innovation ability and competitive advantage (Qi Dong et al. 2017). For example, BEiQi New Energy and Beiqi Foton have cooperated to break through the bottleneck of low-temperature technology for new energy vehicles with short battery life (Cheng et al. 2021). The important way of technical cooperation is patent cooperation. Patent information is of great value to the analysis of the investigated enterprises, and the obtained patent information can find the space for technological progress, so as to accelerate the promotion of new energy vehicles (Sun et al. 2018). An effective way to analyze the promotion of NEVs at the company level is to discover knowledge from existing sources of technical data to drive new technological innovations and bring them to the market as soon as possible (Hewu et al. 2014; Xie and Tian 2015).

In order to ensure the integrity of the research, based on multi-source heterogeneous data, this paper collects multiple data sources, structured and unstructured data, and analyzes the promotion of new energy vehicles. Firstly, this paper uses the latent Dirichlet allocation (LDA) model to collect unstructured texts and analyzes the online evaluation data of new energy vehicles, so as to study the role of consumer decision-making in promoting the promotion of new energy vehicles. Secondly, this paper uses social network analysis (SNA) and an econometric model to analyze the R&D patent cooperation between new energy vehicle companies and discusses the influence of company-level patent cooperation on accelerating the promotion of new energy vehicles. At the same time, the unstructured text and patent are structured to realize the transformation from text, and patent to a conclusion, and form a holistic cognitive picture. The technology roadmap is shown in Fig. 1. As one of the ten key industrial development areas in China in 2025, the new energy vehicle industry has become an important part of China’s automobile industry and economic development. Therefore, we take the consumer evaluation and patent cooperation between companies in the field of new energy vehicles as the research object, which provides some meaningful practical enlightenment for consumers and enterprises in the field of new energy vehicles and is also of great significance to promote the development of the new energy vehicle industry.

The remainder of this article is organized as follows. The “Literature review” section reviews the relevant literature. The “Method” section describes the data, variables, and model. The “Results and discussion” analyzes the research results. The “Discussion” section is the resulting discussion. The sixth part is the conclusion, limitation, and future research direction.
Literature review

Consumer perspective

According to the theory of planned behavior, experience may lead to changes in perceived behavioral control and influence willingness and behavior, so that consumers’ purchase decisions are conducive to the promotion of new energy vehicles (Xiong et al. 2016). Liu et al. (2020) constructed the influencing factors framework of electric vehicles adoption based on the theory of planned behavior, taking consumer experience as the antecedent of adoption intention. Therefore, understanding and intervening in these consumer decisions may be a key factor in consumer acceptance of electric vehicles (Huang et al. 2021a). In the new energy vehicles user research of the past, most scholars studied NEV user purchase intention influencing factors as the theme, such as Xu and Xu (2010) analyzed the sales staff with a new energy automobile sales experience of survey data, and find the potential influencing factors, including those around the buying behavior of cost, energy consumption, brand influence, external, and internal. All these factors will affect the purchase decision of new energy vehicles. Chen et al. (2019) analyzed the impact of the three customer perceived values of the price, function quality, and service quality of new energy vehicles on the purchase intention of new energy vehicle customers. He et al. (2012) points out that products with good performance will increase consumers’ purchase intention.

Wang et al. (2016) uses the idea of migration to extract emotion polarity from the evaluation data of new energy vehicles and establishes a classification model, which provides a method for manufacturers to quickly grasp the emotional tendencies of consumers. In addition, some scholars have found that the technical performance of NEV plays a decisive role in consumers’ purchase decisions. Previous studies have shown that Asian consumers are equally concerned about the technical and functional features of electric vehicles, and the appearance of the car is also important to them (Goel et al. 2021). Performance considerations for new energy vehicles also play an important role in the purchase decision process (Adamson 2005). Based on the above research, we pay more attention to the study of individual purchase decisions to promote the promotion of new energy vehicles.

Manufacturer perspective

Based on the diffusion of innovations theory, technical factors are one of the most important challenges facing the promotion of new energy vehicles (Liu et al. 2018). Technological advances and improvements in electric vehicles have become an important attraction for electric-vehicle consumers who value innovation (Huang et al. 2021b). Based on this, more and more manufacturers begin to attach importance to R&D cooperation to improve the technological progress of NEVs. R&D collaboration is a typical R&D strategy that manufacturers are increasingly developing to reduce uncertainty and costs and accelerate new product development (Banerjee and Siebert 2017). Partnerships with other manufacturers have proven beneficial, especially for R&D-intensive industries, where the required technology is often beyond the company’s technological base (Bayona et al. 2001). Under such circumstances, technological innovation is challenging, prompting companies to look for partners (Cainelli et al. 2015). Many theoretical studies have also confirmed that technical cooperation has an important impact on the innovation achievements of enterprises (Martínez Ardila et al. 2020). By constructing a network evolution model to simulate the way enterprises choose partners, Baum et al. (2010) conclude that knowledge complementarity plays an irreplaceable role and maybe the real driving force of cooperative alliance. Wenjie et al. (2016) constructed a global low-carbon vehicle technology cooperation innovation network and investigated its overall characteristics through patent data mining.

The research method of promotion of NEVs

Research on the promotion of new energy vehicles should be conducted from an overall perspective. Existing studies are mostly based on questionnaires, policy texts, and literature reviews. For example, (Li et al. 2021) used the latent Dirichlet allocation (LDA) topic model to analyze the policy document of NEV and its impact on the promotion of NEV in each city. Jia and Wu (2018) analyzed articles related to new energy vehicles using the LDA thematic model, indicating that the promotion of new energy vehicles requires further investment in charging, battery and patent portfolio. Hu et al. (2022) took the field of new energy vehicles in the patent database as the data source, identified the technical topics, and used the LDA topic model to analyze the technical topics in the patent text. In order to understand the potential information conducive to the promotion of new energy vehicles more efficiently and quickly, the method of text mining is needed to identify the key information. Text mining technology enables researchers to synthesize information from many unstructured text data and identify topic trends. Topic model is an important tool in text mining. Topic models are useful for organizing, understanding, researching, and summarizing large amounts of textual information in ways which is difficult for human annotation to achieve (Benites-Lazaro et al. 2018). LDA is the most widely used algorithm in the topic model (Blei et al. 2003). The LDA model extracts a
series of topics related to all literatures from the corpus and provides a method of quantitative research on topics. The LDA model is most suitable for processing documents with multiple topics. The online user evaluation of new energy vehicles is an unstructured text and usually contains several key points. In other words, the network user evaluation of the promotion of new energy vehicles includes multiple topics, which proves that the LDA model is reasonable and necessary for the analysis in this paper.

For the manufacturer’s perspective, previous studies mainly focused on direct analysis of patent data, while social network analysis was mainly used to study the evolution of new energy automobile industry. Based on the marked data in the previous stage, Wang et al. (2016) used the idea of migration to extract the emotional polarity of the review data of new energy vehicles and established a classification model, which provided a method for manufacturers to quickly grasp the emotional tendency. Huang et al. (2022a) studied how network topology affects the diffusion of BEV, and the research shows that BEV is still the mainstream model, and PHEV, as a transitional replacement model for CVs, can be effectively guided by network science theory to transform the electric vehicle industry from PHEV to BEV. SNA is an interdisciplinary academic method used in social psychology, sociology, statistics, and graph theory (Sun et al. 2018). Moreover, SNA is extensively used to examine the trend of patent collaboration networks (Moussa and Varsakelis 2017), illustrating collaboration networks between invention institutions and applicant organizations. Also, many scholars used SNA to analyze citation networks (Chang et al. 2009).

From the perspective of research content, previous studies only examined the influencing factors based on consumers’ purchase intention, and a few studies explored user satisfaction with new energy vehicles, ignoring the related research on user evaluation of new energy vehicles. In addition, few previous studies focused on the promotion of new energy vehicles through patent cooperation between manufacturers. From the perspective of research methods, most of the existing studies on the perspective of consumers are based on questionnaires, while few scholars carry out research based on network evaluation, resulting in a lot of valuable information in the evaluation of network users not being mined. For the research from the perspective of manufacturers, previous studies mainly focused on the direct analysis of patent data, and social network analysis was mainly used to study the evolution of the new energy vehicle industry. Few scholars conduct research based on the patent cooperation of new energy vehicle companies. From the perspective of data structure, previous articles on the promotion of new energy vehicles mostly use a single data source, and the research is not complete.

Therefore, this paper makes the following contributions: In this paper, consumers and manufacturers are included in the same research framework to explore the promotion mechanism of new energy vehicles. In this paper, NEV network evaluation is further studied to explore the impact of network evaluation on consumers’ purchase intention, so as to guide manufacturers to produce new energy vehicles targeted at consumers’ preferences and promote the promotion of new energy vehicles. And through the establishment of patent cooperation network analysis between enterprises revealed the potential of China’s new energy vehicle technology innovation. Based on the multi-source heterogeneous data perspective, this paper applies the machine learning LDA model to the study of EV diffusion; this paper uses the LDA model to analyze the online review text of new energy vehicles and uses social network analysis to analyze the patent data. In addition, econometrics is also used to analyze corporate panel data. This paper provides a new research perspective for the promotion of new energy vehicles.

Method

NEV text mining and analysis

In order to understand the potential information of online reviews of new energy vehicles more efficiently and quickly, this study adopts text mining method to identify and analyze the online review information. Text mining refers to the analysis and prediction of text through statistical modeling and other means to obtain the information in the text. The most commonly used text mining methods include clustering analysis and sentiment analysis (Ding et al. 2021). It helps to mine the annotated text for more important information. In this paper, the text mining method is adopted to analyze the network comments of new energy vehicle users. Firstly, the research work in the data collection stage includes selecting the websites to crawl the comments and the starting and ending times of the comments, screening out the comments of new energy vehicle users on the website, and using crawler tools to crawl these comments. Then, the collected comment information is preprocessed, including three steps: data cleaning, text word segmentation, and deleting stopped words.

At present, the research in the field of new energy vehicles in our country still stops at the interpretation of the policy document. Therefore, this paper adopts the LDA classification model to analyze the promotion status of new energy vehicles from the perspective of user purchase decisions.

Latent Dirichlet allocation model

The basic assumption of LDA model is that each document is composed of a mixture of topics with a certain probability, and each topic is also composed of a mixture of features with a certain probability, thus forming a three-layer Bayesian probability model of “document-topic-feature.” The core formula is as follows:
Based on the NEV evaluation text from the Pacific Automobile Network, we use the Jieba package to segment words by Python 3.8 software. We cleaned them up for useless words such as “of,” “is,” and punctuation by adding the stop words list. In the LDA model, perplexity can be understood as the uncertainty degree that the model trained for a document that belongs to a certain topic. The lower the degree of confusion, the better the clustering effect of the model. Afterward, the whole data is divided into 7 topics by the perplexity method, and the top 10 keywords are extracted from each topic.

Social network analysis

Methodology

Gephi is an easy to access, powerful network analysis software; it is based on the Java virtual machine open-source network analysis software. It is mainly used to visualize various networks, complex systems, and layered graphs. Summarizing the above, in this paper, we employed an SNA method and used Gephi to explore the patent collaboration network for new energy vehicles.

Data sources

The patent data used in this paper come from the patent retrieval and analysis system built by the State Intellectual Property Office of China (SIPO). Patent refers to the technological progress of the enterprise during the research period, expressed by the number of patent applications for new energy vehicles (including invention patents, utility model patents, design patents). Compared with other indicators, the number of patent applications or approvals can more intuitively and truly reflect the level of innovation. Considering that patent approvals require a certain amount of time for testing and annual fees and lack of stability and certainty, this paper selects relatively stable, reliable, and timely number of patent applications. The original applicant was chosen to obtain the patent relationship for different companies. The authors manually cut and downloaded the data from 2016 to 2020 to ensure data integrity.

Econometric model

Dependent variable

Sales refer to the annual sales of NEVs of the companies during the study period. The data comes from Wind Economic Database (WIND). Sales of new energy vehicles can clearly show the promotion effect of the new energy vehicle market. As consumers’ decision to buy traditional or new energy vehicles affects marketing, it is important to ensure the success of marketing (Liu et al. 2018).

Independent variable

Patent refers to the technological progress of the enterprise during the research period, expressed by the number of patent applications for new energy vehicles (including invention patents, utility model patents, design patents). We used the keyword = (new energy vehicles OR electric vehicles OR hybrid electric vehicles OR plug-in hybrid electric vehicles) from the National Intellectual Property Administration website to collect the NEV patents. Sun et al. (2018) found that the patent pool of new energy vehicles is established to maximize knowledge spillover and technology diffusion.

$Rd$ refers to the firm’s R&D intensity and uses R&D investment in the company’s current year as our control variable.

Control variables

$Fix$ refers to fixed assets investment. Innovation subsidies on new energy vehicles firms and fixed assets investment will promote technological progress (Wang et al. 2021).

$Cha$ refers to an annual number of charging piles during the study period. A sufficient number of charging piles is conducive to the promotion of new energy vehicles (Egnér and Trosvik 2018). In addition, the more convenient the charging device, the more willing consumers are to accept it (Ma et al. 2019).

According to the availability of data, this paper collects data from 26 representative listed companies of new energy vehicles from 2016 to 2020 to construct a regression model. This paper uses LDA topic model analysis of the data extracted from the Pacific Automobile Network and then uses social network analysis of the involved companies. In the process, we found that some companies didn’t have enough data. This article will remove samples of companies that lack too much data. We assume that all variables can promote the sales of new energy vehicles. The specific variables definition is shown in Table 1.

Formula (2) uses panel data model to study the relationship between total sales of new energy vehicles and sales of different models. In the research process, the total sample data were firstly regression, and then BEV, HEV, and PHEV samples were grouped regression according to different NEV models. The influence mechanism of each group of samples was tested separately. $a$ is the intercept term. $\beta_1, \beta_2$ is the coefficient of the independent variable. $\gamma_1, \gamma_2$ is the coefficient of the control variable. $\epsilon_1$ is an error disturbance term.

\[
\ln Sales_{it} = a + \beta_1 Pat_{it} + \beta_2 \ln Rd_{it} + \gamma_1 \ln Fix_{it} + \gamma_2 \ln Cha_{it} + \epsilon_1
\]  

(2)
Result and discussion

The result of the latent Dirichlet allocation model

Table 2 shows the list of hot words for each topic and the probability distribution of the hot words. Divide the entire data into 7 topics, and extract the top 10 keywords from each topic.

In topic 1, keywords such as “space,” “back row,” and “comfortable” reflect the user experience of new energy vehicles in space dimension. It can be seen that users have higher and higher requirements for car space. New energy vehicle enterprises should improve the vehicle space comfort and utilization rate to meet user needs to promote the promotion of new energy vehicles.

In topic 2, keywords such as “appearance,” “design,” and “modelling” reflect the appearance characteristics of new energy vehicles. It can be seen that online comments on the appearance of new energy vehicles tend to be highly satisfactory. The improvement and enhancement of the appearance design of new energy vehicles will enhance the visual enjoyment of users.

In topic 3, keywords such as “back row,” “seat,” and “big” reflect the comfort degree of new energy vehicles. It can be seen that users still attach great importance to the comfort of new energy vehicles, and improving the ease of various models will promote the promotion of new energy vehicles.

In topic 4, keywords such as “configuration,” “lunch,” and “function” reflect the power performance of new energy vehicles.
vehicles. It can be seen that users have high requirements for power when purchasing new energy vehicles. Therefore, from the technical point of view, improving the dynamic performance of new energy vehicles will promote users to make purchase decisions.

In topic 5, keywords such as “trim,” “wrapping,” and “Sound insulation” reflect configuration of new energy vehicles. It can be seen that whether the configuration of new energy vehicles is comprehensive will affect users’ purchase decisions. Therefore, improving the configuration of new energy vehicles can stimulate the promotion of new energy vehicles.

In topic 6, keywords such as “fuel consumption,” “hundreds of kilometers,” and “fuel saving” reflect the fuel consumption of new energy vehicles. It can be seen that users still look at the fuel consumption of new energy vehicles, and users usually choose new energy vehicles or value fuel economy than fuel cars.

In topic 7, keywords such as “design,” “center control,” and “trim” reflect the design style of new energy vehicles. Automotive system design is an important part of the car body. Improving car body design will bring better visual enjoyment to users and accelerate the promotion of new energy vehicles.

To sum up, the LDA model classifies the text into seven topics: space dimension, appearance characteristics, comfort degree, power performance, configuration, fuel consumption, and design style. In the next step, we will calculate the topic probability of different types of new energy vehicles.

From the LDA topic model results, we can acquire the probability that different types of new energy vehicles belong to the seven topics. We calculate the topic probability of different types of NEV. As shown in Table 3, the sum of each type of NEV probability on the seven topics is 1. In topic 1, the probability of BEV, HEV, and PHEV was 0.156650817, 0.145172706, and 0.150695731, respectively. In topic 4, the probability of BEV, HEV, and PHEV was 0.1569808, 0.1415047, and 0.1525061, respectively. In topic 7, the probability of BEV, HEV, and PHEV was 0.19157723, 0.18748437, and 0.17895406, respectively. Whether BEV, HEV, or PHEV, users are more concerned about space dimension, power performance, and design style. The three vehicle models should enhance the power performance from the technical point, enhance the space utilization rate from the body structure, and improve the design style from the appearance. This can urge the promotion of new energy vehicles.

The result of the social network analysis

Considering the technological collaboration, Fig. 2 shows the network in each period of analysis. In this paper, each patent-filing company is treated as a network node, and the node size and color depth represent the number of other nodes connected to the node. An edge captures hence interactions between two applicants involved promotion of new energy vehicles. These interactions may take place because the technological invention occurred in collaboration.

According to the relevant patent data selected in this paper, patent applications are all enterprises. This figure shows that enterprise contributes a lot to cooperation in the new energy vehicles field, as the dominant part for participating in collaborative patents. With the development of new energy vehicle industry, enterprises integrate knowledge by acquiring external knowledge from other cooperative enterprises, which are more inclined to convert technological innovation into patents (Zhu et al. 2021). Enterprises conduct patent research and development cooperation to promote the technological progress of new energy vehicles, urge the promotion of new energy vehicles, and occupy market share. The expansion of enterprise networks means the increase of cooperative relations among enterprises, and the accumulation of knowledge inside the network leads to the increase of knowledge and technology spillover among enterprises. In general, this patent collaboration network indicates that NEV enterprises are establishing a close partnership.

The result of the econometric model

According to the result of the “The result of the latent Dirichlet allocation model” and “The result of the social network analysis” sections, after analyzing the promotion of NEVs by individual purchase decision and the promotion of NEVs by patent cooperation of NEV companies we further explore the promotion of NEVs by the patent and R&D investment of NEV companies.

### Table 3  The topic prevalence for different types of new energy vehicle

| Vehicle model | The topic probability distribution of each vehicle model | The sum of topics |
|---------------|-------------------------------------------------------|------------------|
|               | Topic 1       | Topic 2       | Topic 3       | Topic 4       | Topic 5       | Topic 6       | Topic 7       |                  |
| BEV           | 0.156650817  | 0.1341561    | 0.1486017    | 0.1569808    | 0.07276582   | 0.1392675    | 0.19157723    | 1                |
| HEV           | 0.145172706  | 0.134628     | 0.1227469    | 0.1415047    | 0.13688814   | 0.1315752    | 0.18748437    | 1                |
| PHEV          | 0.150695731  | 0.1220672    | 0.1284948    | 0.1525061    | 0.13326798   | 0.1340141    | 0.17895406    | 1                |
As shown in Table 4, the regression coefficient of patent was significant at 0.01 level ($\beta=0.001, P<0.01$). That is, patents promote the promotion of NEVs. The regression coefficient of R&D investment was significant at 0.01 level ($\beta=0.348, P<0.01$). That is, R&D investment accelerates the promotion of NEVs. In addition to the control variables, the regression coefficient of fixed assets investment was significant at 0.01 level ($\beta=0.328, P<0.01$). That is, fixed asset investment accelerates the promotion of NEVs.

According to the previous analysis, NEV is categorized into three types, but the impact mechanism of different types of NEVs on the promotion of NEVs is still unclear. We further explore whether the heterogeneity of the types of NEVs may differ in the promotion of NEVs. As shown in Table 5, it can be seen that the regression coefficient of patent is significant at the level of 0.01 in all three groups. The regression coefficient of R&D investment is significant at the level of 0.05 in BEV and is significant at the level of 0.01 in HEV. For BEV and HEV models, new energy vehicle companies will invest more patents, and R&D investment will better expedite the promotion of NEVs.

Table 4 The regression results

| lnSales | Coef  | Std. Err | t value | P>|t| | 95% Conf Interval |
|---------|-------|----------|---------|-------|------------------|
| Patent  | 0.001*** | 0.000     | 4.810   | 0.000 | 0.001            | 0.002           |
| lnRd    | 0.348*** | 0.081     | 4.280   | 0.000 | 0.188            | 0.508           |
| lnFix   | 0.328*** | 0.083     | 3.950   | 0.000 | 0.164            | 0.491           |
| lnCha   | 0.313   | 0.222     | 1.410   | 0.160 | −0.125           | 0.752           |
| Constant| −9.238  | 4.002     | −2.310  | 0.022 | −17.130          | −1.346          |

*, ***, and *** denote the significance levels of 10%, 5%, and 1%, respectively

Table 5 The regression results were grouped according to NEV heterogeneity

|          | BEV        | HEV        | PHEV       |
|----------|------------|------------|------------|
| Patent   | 0.001**(2.170) | 0.002*****(3.370) | 0.002*****(3.170) |
| lnRd     | 0.311**(2.510) | 0.570***(4.470)  | 0.015(0.090)  |
| lnFix    | 0.502**(4.09)  | 0.194(1.450)   | 0.061(0.350)  |
| lnCha    | 0.173(0.54)    | 0.482(1.330)   | 0.297(0.660)  |
| Constant | −10.814      | −13.372      | 5.359       |

The numbers in parentheses are t statistics
*, **, and *** denote the significance levels of 10%, 5%, and 1%, respectively

Discussion

Theoretical contributions

In this study, consumers and manufacturers are included in the same research framework to explore the promotion mechanism of new energy vehicles and electric vehicle diffusion and contribute to the literature. This study adopts the LDA model to analyze the promotion of new energy vehicles and electric vehicle diffusion. The results of the analysis show that whether it is BEV, HEV, or PHEV, consumers are more concerned about space size, power performance, and design style. This finding supports evidence from previous observations, and consumer evaluation enhances their sense of control and can increase adoption intention (Yu et al. 2005).

Similarly, this study uses Gephi software to conduct a social network analysis of patents of new energy vehicle companies. The analysis of the patent cooperation network shows that new energy vehicle enterprises are establishing close cooperative relations, and the development of the patent cooperation network is stable. Therefore, patent cooperation between manufacturers will be conducive to promoting the promotion of new energy vehicles. Therefore, this study is consistent with previous studies (refer to Sun et al. (2018).

This study further explores the role of new energy vehicle enterprises’ patents and R&D investment in promoting the development of new energy vehicles. An interesting test result is that, for short-term innovation, NEV enterprises should invest more patent research and development in BEV and HEV models.
to better accelerate the promotion of NEVs. This finding supports evidence from previous observations (Huang et al. 2022b). It is proved that the patent and R&D investment of new energy vehicle enterprises can promote electric vehicle diffusion.

Managerial implications

The study offers several important management implications. First, in view of the findings of this paper, users pay more attention to spatial dimension, power, and design style in terms of the influence of personal purchase decisions. Therefore, it is necessary to improve the power performance of HEV, BEV, and PHEV technologically, improve the space utilization rate from the body structure, and improve the design style from the appearance, so as to promote the promotion of new energy vehicles; this implication is consistent with Jia and Wu (2018). According to the market demand for new energy vehicle products, enterprises should implement targeted mode transformation. New energy vehicle enterprises should use information technology, big data, and other ways to obtain more consumer preferences, understand consumers’ needs and preferences in the new energy vehicle market, start from consumers’ purchase decisions, transform and upgrade new energy vehicle products, improve vehicle performance, and provide consumers with more appropriate products.

Secondly, from the perspective of patent cooperation and R&D investment at the company level, new energy vehicle enterprises and policy practitioners should jointly promote the innovation and research and development of new energy vehicles, and provide adequate financial support. Enterprises should increase investment in innovative human resources, attract more high-level technical talents into the market by broadening channels for talent introduction, and promote patent cooperation and R&D.

In addition, enterprises should expand research and development cooperation channels with other new energy vehicle companies to break technical barriers. Specifically, enterprises should expand the breadth and depth of technology based on technological positioning, promote patent research and development, and accelerate the promotion of new energy vehicles. Policy practitioners should increase investment in the research and development of new energy vehicles and promote innovation and research and development of new energy vehicle enterprises.

Conclusion and policy implications

The results of the study have implications for consumer and manufacturer decision-making. Although there are more and more energy-saving technologies for new energy vehicles (Han et al. 2017), the promotion of new energy vehicles is not ideal due to the impact of the epidemic. The results of this study emphasize the importance of consumer evaluation and company R&D cooperation to promote new energy vehicles.

This study makes several contributions to the literature. In this paper, consumers and manufacturers are included in the same research framework to explore the promotion mechanism of new energy vehicles. In this paper, NEV network evaluation is further studied to explore the impact of network evaluation on consumers’ purchase intention, so as to guide manufacturers to produce new energy vehicles targeted at consumers’ preferences and promote the promotion of new energy vehicles. And through the establishment of patent cooperation network analysis between enterprises revealed the potential of China’s new energy vehicle technology innovation. Based on the multi-source heterogeneous data perspective, this paper applies the machine learning LDA model to the study of EV diffusion; this paper uses the LDA model to analyze the online review text of new energy vehicles and uses social network analysis to analyze the patent data. In addition, econometrics is also used to analyze corporate panel data. This paper provides a new research perspective for the promotion of new energy vehicles.

The main findings of this study are as follows. First, Whether BEV, HEV, or PHEV, consumers are more concerned about space size, power performance, and design style. Second, the analysis of the patent cooperation network shows that the new energy vehicle enterprises are establishing a close cooperation relationship, and the patent cooperation network is developing stably. Therefore, patent cooperation between manufacturers will be conducive to promoting the promotion of new energy vehicles. Finally, for short-term innovation, new energy vehicle enterprises should invest more patent research and development in BEV and HEV models to accelerate the promotion of new energy vehicles.

There are still some limitations in this study, and our research can be extended to several directions. Firstly, based on the evaluation text of new energy vehicle websites, we only selected one of the most famous automobile websites in China. It would be interesting to add evaluation text from other sites. Second, we only analyze the influence of patent cooperation and R&D investment. Another interesting direction for future research is to consider the overall mechanism of influence.

Author contribution The manuscript was approved by all authors for publication. Bing Sun and Zhuofang Ju conceived and designed the study. Zhuofang Ju performed the experiments and wrote the paper. Bing Sun reviewed and edited the manuscript.

Funding This work was supported by the National Natural Science Foundation of China “MLP-based knowledge-intensive industry leading technology formation mechanism and promotion policy research” [grant number 71774035]. This work was supported by the National Natural Science Foundation of China “Research on the formation mechanism, crack path and strategy system of the knowledge-intensive industry’s dominant technology lock-in: Based on the path constitution theory” [grant number 72274044] and Heilongjiang Province Natural Science Foundation project “research on identification and establishment of knowledge-intensive industry leading technology” [grant number LH2020G005].
References

Adamson KA (2005) Calculating the price trajectory of adoption of fuel cell vehicles. Int J Hydro Energy 30(8):1289–1307
Banerjee T, Siebert R (2017) Dynamic impact of uncertainty on R&D cooperation formation and research performance: evidence from the bio-pharmaceutical industry. Res Policy 46(7):1255–1271
Baum JAC, Cowan R, Jonard N (2010) Network-independent partner selection and the evolution of innovation networks. Manage Sci 56(11):2094–2110
Bayona C, García-Marco T, Huerta E (2001) Firms’ motivations for cooperation R&D: an empirical analysis of Spanish firms. Res Policy 30(8):1289–1307
Benites-Lazaro LL, Giatti L, Giarolla A (2018) Topic modeling method for analyzing social actor discourses on climate change, energy and food security. Energy Res Soc Sci 45:318–330
Blei DM, Ng AY, Jordan MI (2003) Latent dirichlet allocation. J Mach Learn Res 3(Jan):993–1022
Cainelli G, García-Marco T, Huerta E (2001) Firms’ motivations for cooperative R&D: an empirical analysis of Spanish firms. Res Policy 30(8):1289–1307
Benites-Lazaro LL, Giatti L, Giarolla A (2018) Topic modeling method for analyzing social actor discourses on climate change, energy and food security. Energy Res Soc Sci 45:318–330
Blei DM, Ng AY, Jordan MI (2003) Latent dirichlet allocation. J Mach Learn Res 3(Jan):993–1022
Cainelli G, De Marchi V, Grandinetti R (2015) Does the development of environmental innovation require different resources? Evidence from Spanish manufacturing firms. J Clean Prod 94:211–220
Cano-Rodríguez S, Rubio-Varas M, Sesma-Martín D (2022) At the crossroad between green and thirsty: carbon emissions and water consumption of Spanish thermoelectricity generation, 1969–2019. Ecol Econ 195:107363
Chang S-B, Lai K-K, Chang S-M (2009) Exploring technology diffusion and classification of business methods: using the patent citation network. Technol Forecast Soc Chang 76(1):107–117
Chen K, Ren C, Gu R, Zhang P (2019) Exploring purchase intentions of new energy vehicles: from the perspective of frugality and the concept of “mianzi.” J Clean Prod 230:700–708
Cheng L, Liu Y, Lou X, Chen Z, Yang Y (2021) Does technology conglomeration promote innovative outcomes of new energy vehicle enterprises? The moderating effect of divisive faultlines. J Clean Prod 324:120959–126526
Ding Z, Liu R, Yuan H (2021) A text mining-based thematic model for analyzing construction and demolition waste management studies. Environ Sci Pollut Res 28(24):30499–30527
Egnér F, Trosvik L (2018) Electric vehicle adoption in Sweden and the impact of local policy instruments. Energy Policy 121:584–596
Goel P, Sharma N, Mathiyazhagan K, Vimal KEK (2021) Government is trying but consumers are not buying: a barrier analysis for electric vehicle sales in India. Sustain Prod Consump 28:71–90
Han L, Wang S, Zhao D, Li J (2017) The intention to adopt electric vehicles: Driven by functional and non-functional values. Transp Res Part A: Policy Pract 103:185–197
He L, Chen W, Conzelmann G (2012) Impact of vehicle usage on consumer choice of hybrid electric vehicles. Transp Res Part D: Transp Environ 17(3):208–214
Hewu W, Hong SHI, Ping C, Minggao O (2014) Analysis on the progress of energy saving and new energy vehicle industrialization in China based on a database. J Automot Saf Energy 5(03):29
Hu R, Ma W, Lin W, Chen X, Zhong Z, Zeng C (2022) Technology topic identification and trend prediction of new energy vehicle using LDA modeling. Complexity 2022:1076–2787
Huang X, Lin Y, Lim MK, Tseng M-L, Zhou F (2021a) The influence of knowledge management on adoption intention of electric vehicles: perspective on technological knowledge. Ind Manag Data Syst 121(7):1481–1495
Huang X, Lin Y, Zhou F, Lim MK, Chen S (2021b) Agent-based modeling for market acceptance of electric vehicles: evidence from China. Sustain Prod Consump 28:206–217
Huang J, Xiang S, Wu P, Chen X (2022a) How to control China’s energy consumption through technological progress: a spatial heterogeneous investigation. Energy 238:121965
Huang X, Lin Y, Lim MK, Zhou F, Liu F (2022b) Electric vehicle charging station diffusion: an agent-based evolutionary game model in complex networks. Energy 257:124700
Jia S, Wu B (2018) Incorporating LDA based text mining method to explore new energy vehicles in China. IEEE Access 6:64596–64602
Li J, Jiao J, Xu Y, Chen C (2021) Impact of the latent topics of policy documents on the promotion of new energy vehicles: empirical evidence from Chinese cities. Sustain Prod Consump 28:637–647
Liu Z, Hao H, Cheng X, Zhao F (2018) Critical issues of energy efficient and new energy vehicles development in China. Energy Policy 115:92–97
Liu R, Ding Z, Jiang X, Sun J, Jiang Y, Qiang W (2020) How does experience impact the adoption willingness of battery electric vehicles? The role of psychological factors. Environ Sci Pollut Res 27(20):25230–25247
Ma Y, Shi T, Zhang W, Hao Y, Huang J, Lin Y (2019) Comprehensive policy evaluation of NEV development in China, Japan, the United States, and Germany based on the AHP-EW model. J Clean Prod 214:389–402
Martínez Ardila HE, Mora Moreno JE, Camacho Pico JA (2020) Networks of collaborative alliances: the second order interfirm technological distance and innovation performance. J Technol Transf 45(4):1255–1282
Moussa B, Varvakelis NC (2017) International patenting: an application of network analysis. J Econ Asymmetries 15:48–55
Qi Dong J, McCarthy KE, Schoenmakers WWME (2017) How central is too central? Organizing interorganizational collaboration networks for breakthrough innovation. J Prod Innov Manag 34(4):526–554
Shende V (2014) Analysis of research in consumer behavior of automobile passenger car customer. Int J Sci Res Publ 4(2):1–8
Sun S, Wang W (2018) Analysis on the market evolution of new energy vehicle based on population competition model. Transp Res Part D: Transp Environ 65:36–50
Sun H, Geng Y, Hu L, Shi L, Xu T (2018) Measuring China’s new energy vehicle patents: A social network analysis approach. Energy 153:685–693
Wang Z, Dong X (2016) Determinants and policy implications of residents’ new energy vehicle purchases: the evidence from China. Nat Hazards 82(1):155–173
Wang S, Zhang J, Li L (2016) Sentiment Preddiction for Car Review Based on Active Learning. J Shaxiu Univ 39(1):49–55
Wang X, Li Z, Shaikh R, Ranjha AR, Batala LK (2021) Do government subsidies promote financial performance? Fresh evidence from China’s new energy vehicle industry. Sustain Prod Consump 28:142–153
Wenjie C, Deming Z, Siming Z (2016) Collaborative innovation network evolutionary path of low-carbon vehicle technology. Sci Res Manag 37(8):28
Xie Q, Tian ZL (2015) Text analysis of China’s new energy vehicle industry policy. Trans Tech Publ 1073:2499–2502
Xiong Y, Wang L (2020) Policy cognition of potential consumers of new energy vehicles and its sensitivity to purchase willingness. J Clean Prod 261:121032
Xiong YQ, Chen ML, Business SO (2016) Study of the new energy vehicles demand market’s cultivated policy orientation: supply side or demand side. China Popul Resour Environ 26:129–137
Xu GH, Xu F (2010) Impact factors of purchase decision of new energy automobile [J]. China Popul Resour Environ 20(11):91–95
Yu J, Ha I, Choi M, Rho J (2005) Extending the TAM for a t-commerce. Inform Manag 42(7):965-976

Zhu S, Hagedoorn J, Zhang S, Liu F (2021) Effects of technological distance on innovation performance under heterogeneous technological orientations. Technovation 106:102301

Publisher’s note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.