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Technological Feature Analysis of Hybrid Electric Vehicles (HEVs) Makers Based on Patent Data

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Abstract

A hybrid electric vehicle (HEV) is a type of vehicle that combines a conventional internal combustion engine (ICE) propulsion system and an electric propulsion system (hybrid vehicle powertrain) together. HEV becomes widely available after the release of the Toyota Prius in Japan in 1997 and the Honda insight in 1999. Due to HEVs have preferable performance in emission and in fuel economy than the conventional ICE vehicles, in late 2000s HEV has released by many other automakers. HEV which is considered a necessary technological transition from ICE vehicles to pure electric vehicle has gained its popularity all around the world. Consequently, the technological characteristic of major HEVs needs to be analysis to provide over all criteria to evaluate behaviors of major HEVs makers.

The patent is a legal method that protects a set of exclusive rights of assignees or inventors about their technological/intellectual properties. Therefore, the application of patent is universally utilized in the field of HEVs. The patent information includes lots of useful information, such as: filing date, publication date, international patent classification, applicants, inventors, reference literature, claims, abstract of the technology, etc. Moreover, patent data information has a broad coverage and high reliability with high availability and accessibility. As a consequence, patent information or patent statistics is deemed an indicator for the description of technological features of companies.

In this paper, technological features of hybrid electric vehicles (HEVs) makers are analyzed based on the patent information. The patent data related to HEVs are extracted firstly from the WIPO patent database that includes the patent application and publication information of patents all over the world of last decades. Using these results, the patent application trend of HEVs can be easily plotted, the major registered and applied areas can be found, and the main applicants can be confirmed. With the help of the extracted information from patents data, the patent strategy/patent portfolio/technology portfolio can be clarified for the key players in HEVs field. Subsequently, the patents are classified using a technology relevant coordinate. HEVs patents are reported to be classified into different types, namely: 1. Power transmission systems; 2. Battery types; 3. Brake types. Hence, this can be used to construct the technological coordinate. Thus, locations of companies’ technologies can be obtained. Consequently, the difference between companies can be evaluated. Finally, the promising/emerging technology development field can be revealed by the changing trend of the IPCs and technological fields.
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Chapter 1

Introduction

In this chapter, the background information of hybrid electric vehicles and patent data information is first introduced. Subsequently, the literatures related to patent analysis are reviewed to provide an overall concept of patent information related analysis. Last, the structure of the thesis is explained.

1.1 Background information about hybrid electric vehicles (HEVs)

In this section, the background information about hybrid electric vehicles is introduced. The definition of HEV, the merits and the reason why HEV is widely accepted are narrated.

1.1.1 What is HEVs?

A hybrid electric vehicle (HEV) is a kind of vehicle that uses two or more distinct power sources to move the vehicle. Generally, it combines a conventional internal combustion engine (ICE) propulsion system with an electric propulsion system which consists of one or more electric motors. This kind of hybrid vehicle drivetrain is the feature of the hybrid vehicle. Moreover, the
presence of the electric propulsion system is intended to realize better fuel economy and better performance. Moreover, HEV is deemed the transitional technology between ICEVs (internal combustion engine vehicles) and EVs (electric vehicles), which gaining high popularity recently.

### 1.1.2 Brief history of HEVs

Early in 1899, Pieper of Belgium developed a vehicle which has under-seat electric motor and a gasoline engine [1]. One year later, in 1900, the first gasoline-electric hybrid vehicle was developed by Ferdinand Porsche [2]. This hybrid vehicle is named as the Lohner-Porsche Mixte Hybrid and it has the arrangement of two motor-in-wheel-hub with a combustion generator set providing the electric power. In 1905, a hybrid vehicle with an electric motor/generator, batteries, and a small gasoline engine was introduced by Henri Pieper. It used the electric motor to charge its batteries at cruise speed and used both motors to accelerate or climb a hill [3]. Later in 20th century, several other types of hybrid vehicles were invented, however, none of them were successful in commercialization.

The invention of the regenerative braking system brought HEVs into a new generation. It was invented in 1967 for the American Motors Amitron by AMC [4]. By adopting of the regenerative brake, the vehicle’s kinetic energy is converted into electric energy to charge the battery, rather than wasting it as heat energy as conventional brakes do. Later in 1980s, the regenerative brake concept was further developed by Dacid Arthurs using off-the-shelf components, military surplus, and an Opel GT [5].

Although many efforts had been made to the commercialization of HEVs, HEV becomes widespread only in the late 1990s until the release of the Toyota Prius in Japan in 1997, followed by the Honda Insight in the United States and Japan 1999 [6].

In the year of 2004 Ford and Toyota entered into a licensing agreement which allows Ford to use 20 patents from Toyota related to hybrid technology and licenses Ford’s patents involving its European diesel engines to Toyota. One year later, the first hybrid electric sport utility vehicle (SUV) was released by Ford.
In 2009 Hyundai began to sales its HEVs (Hyundai Elantra LPI Hybrid) in the Korean domestic market. Elantra LPI is a mild hybrid which is the first hybrid utilises advanced lithium polymer (Li-poly) batteries and liquefied petroleum gas (LPG) as a fuel for internal combustion engine [7, 8].

1.1.3 The classification of HEVs

The HEVs can be classified according to the types of powertrain and degree of hybridization. About the types of powertrain, the HEVs can be divided into 3 types, saying parallel hybrids, series hybrid and power-split or series-parallel hybrid. On the other hand, the HEVs can be categorised by the degree of hybridization into micro hybrids, mild hybrids, full hybrids and plug-in hybrid.

The parallel hybrid systems are most commonly produced HEVs at present. In these systems, both an internal combustion engine (ICE) and an electric motor are connected to the transmission. The structure is shown in the following figure. Famous models for this type are: Hondas Insight, Civic, Accord.

![Figure 1.1: Structure of a parallel hybrid electric vehicle](image)

In the series hybrids, only the electric motor drives the drivetrain and a smaller ICE works as a generator to power the electric motor or to recharge the batteries. Figure 1.2 displays the
1.1. Background information about hybrid electric vehicles (HEVs)

Structure of this type of powertrain. Famous model for this type is Toyotas Coaster.

![Figure 1.2: Structure of a series-hybrid vehicle](image)

Power-split hybrids or series-parallel hybrid is a combination of series and parallel hybrids. The main principle behind this system is the decoupling of the power supplied by the engine (or other primary source) from the power demanded by the driver. The structure is shown in Fig. 1.3. The famous models of this type of powertrain are: Toyotas Prius, Nissans Tino.

![Figure 1.3: Structure of a split hybrid vehicle](image)

1.1.4 Merits of HEVs and the reason

HEVs can not only optimize the fuel economy by using efficiency-improving technologies but also can decrease the noise and emissions. HEV runs on twin powered engine (gasoline engine...
and electric motor) that cuts fuel consumption and conserves energy. Moreover, since it requires less fuel to run which means fewer emissions and less dependence on fossil fuels. Shutting down the ICE at idle and restarting it when needed can reduce the idle emission which is widely adopted in many HEVs. Furthermore, since HEVs’ gasoline engines are usually smaller than a comparably sized pure gasoline-burning vehicle, HEVs produce fewer emissions from ICEs. Moreover, some varieties of HEVs use their internal combustion engine to generate electricity by, to either recharge their batteries or to directly power the electric drive motors. As a consequence, HEV gains its popularity in the vehicle market.

1.1.5 Why HEV?

HEV is gaining its popularity during the last decades due to it excellent performance in fuel economy at the same time being environmentally friendly with less emission. Although the existence of conventional and electrical vehicles, HEV which is the transmission technology between them combines the advantages of both ICE and EV.

The figure below showed the sales of HEV in the United States. It is shown that the sales started to decrease, however later in the year of 2011 the sales increased again. The decline in sales, between 2008 and 2011 is consistent with overall declines in vehicle sales during the Great Recession. The increase in 2012 can be attributed to economic recovery, increased gasoline prices.

![U.S. HEV Sales by Model](image_url)

Figure 1.4: U.S. HEV sales by model
Since the sales of HEV is increasing, many automakers may want to join the HEV market. In order to join the HEV market one company has to have the knowledge about the technological aspect of HEVs. Thus, the technological features of the major HEV makers should be analysed. Based on this information about technological characteristic of major HEV makers, one company can make decisions to purchase important licenses of HEV patent or to make cooperation with HEV makers. Moreover, there are few previous researches analysing the technological features of major HEV makers based on the patent information. As a consequence, this research would provide a basic technological information about major HEV makers.

1.2 Background information about Patent

Patent information is frequently used innovation indicator since it contains quite meaningful information in the patent documents. Moreover, the information included in the patent documents labelled with very detailed classification code allowing for analysis on specific topics. Furthermore, the accessibility of patent information is easy since one can search the patent database which is open to the public with no charge by major patent office. Thus, the technological field can be analysed based on patent statistics without costly surveys or interviews.

1.2.1 What is patent?

Patents originated in the 15th century and since then governments worldwide have continued to issue patents as means to encourage technological progress by promoting innovation.

Patent is the legal document which contains a set of exclusive rights (to exclude others from making, using, offering for sale, or selling the invention or importing the invention) granted by law to an inventor or assignee for a limited period of time in exchange for detailed public disclosure of the invention when the patent is granted.

\(^1\)Source: HybridCars.com

Notes: Vehicles are listed in order of introduction into the market.
1.2.2 Types of patents

In America, there are three types of patent documents offering different kinds of protection and covering different types of subject matter. The first type is named as the utility patent which is the most common type of patent. This kind of patents is granted for the invention or discovery of a new process, machine, article of manufacture, or composition of matter; or for the improvement of existing ones. The second type of patent is termed as design. This type of patents is granted for a new, original, or ornamental design for an article of manufacture. A third type of patents is a plant patent. These are the most rare of all kinds of patents which are granted for the invention or discovery and reproduction of a new type of plant.

In Japan and China, the industrial property can be divided into several different kinds, namely: patent, utility model, design and trademark.

1.2.3 Patent data and patent analysis

Patent data or patent information comprises all information which has either been published in a patent document or in the filing statistics. Basically, it includes the information as [9]:

- **Technical information** from the description and drawings of the invention;

- **Legal information** from the patent claims defining the scope of the patent and from its legal status;

- **Business-relevant information** from reference data identifying the inventor, date of filing, country of origin, etc.;

- **Public policy-relevant information** from an analysis of filing trends to be used by policymakers, e.g., in national industrial policy strategy.

In particular, this information contains: applicant, inventor, description, claims, priority filing, priority date, filing date, designated states, legal status, citations and references, bibliographic
1.3 Project report organization

Data, document kind codes and country codes. Usually, bibliographic data are widely adopted for analysis, which refers generally to the various data appearing on the front page. And the bibliographic information of a patent record usually includes the following:

1. Title and abstract of the invention. Application number and patent number.
2. Name of the inventor and the applicant of the invention.
3. Date of application, date of publication of this application, and date of issue of the granted patent; date of priority is also included.
4. International patent code (IPC) of the invention.

As discussed by Fleisher et al., patent analysis is a unique management tool for addressing the strategic management of the firm’s technology and product or service development process. Translating patent data into competitive intelligence allows the firm to gauge its current technical competitiveness, to forecast technological trends, and to plan for potential competition based on new technologies [10].

1.3 Project report organization

This project report is organized as: In the first chapter, the background information about HEVs and patents is introduced. Later in the section chapter the motivation of this research, the objectives, literature review, the research questions and the meaning these research questions are explained in the second chapter. Subsequently, in the third chapter, the methodology proposed in this research is explained. In the fourth chapter, the results are displayed and interpreted. In the fifth chapter, the discussions based on the results are given. Last but not least, conclusions and future work are provided.
Chapter 2

Literature review, motivation and research questions

In this chapter, the patent related literatures are first reviewed to offer a basic understanding of the research performed in patent analysis. Later, based on the literature implemented the motivation and the objective are explained. Finally, the corresponding research questions and their meaning are introduced.

2.1 Motivation and objectives

2.1.1 Motivation

It is reported that for the global market for hybrid electric vehicles from 2013 to 2023 is set to increase as customers all over the world seek to lower fuel expenditure and also manufacturers are compelled by regulation to decrease vehicle CO\textsubscript{2} emissions [11]. Moreover, as shown in Fig. 2.1, J.D. Power expects the compounded annual growth rate for global HEV sales (including HEVs, PHEVs(plug-in Hybrid electric vehicles) between 2010 and 2020 to be 13.8%. Still, despite the expected rapid growth rate, sales are projected to be just 3.88 million units in 2020, or only 5.5% of the 70.9 million passenger vehicles to be sold by that year. Furthermore, the
2.1. Motivation and objectives

United States is forecasted to account for 53% of the global HEV total, followed by Japan (20%) and Europe (16%), while the remaining 11% will be spread among all other countries [12].

Figure 2.1: Global: Sales of HEVs and PHEVs to 2020

It is believed that HEVs which combine both internal combustion engine and electric drivetrains offer a solution to both economic and environmental challenges in the automotive sector. As a consequence, HEVs will gain its popularity among consumers. This in turn will make the automakers to find methods to profitably sell these new technologies. It should be noticed that although the trend of HEVs is promising, the conventional internal combustion engine will still be the dominant power source for vehicles.

Although the technology of HEVs has been developed for a long time, it becomes popular only in recent decades. Still the sales proportion of HEVs in the whole vehicle sales is small, however, it is believed to grow in the following years. Thus, for HEVs makers they should find better way to develop new technologies which fit the needs of customers. Moreover, for other companies who wants to join the HEVs fields, it is necessary for them to have a general idea of the existing HEV technologies and to analysis the existing technology portfolio for leading HEV makers and try to locate the promising new technology develop direction for their own. In addition, with the knowledge of the existing patents, one company can make the decision of mergers, acquisitions, collaborations and strategic alliances. Consequently, the technological aspect which is crucial for any HEVs vehicle makers should be investigated. Thus, the general technological features of the whole HEVs can be clarified. Furthermore, the HEVs developing/emerging trend can
2.2. Literature review

also be confirmed.

2.1.2 Objective

As discussion in the aforementioned narration, HEVs is a promising technological field which is environment-friendly. Since the technological aspect is of significant importance to the development of any HEVs makers, the technological characteristic of existing technologies. The information about HEVs technologies is collected using the patent information which is provided freely from patent database.

Thus, based on the analysis of patent data, the objective of this study is to first provide an overall perspective of HEVs from the technological aspect to understand the basic situation of HEVs from the technological viewpoint. Later, based on the patent information the leading HEVs makers are confirmed as well as the major HEVs markets, technological feature analysis of leading HEVs makers in interesting markets are carried out. Last but not least, the technological developing trend is detected for the HEVs technology.

2.2 Literature review

As the objective of this research is defined the literatures related to the patent analysis and HEVs are reviewed to get the general idea of the method to execute the analysis. Since patent statistic contains numerous information about technology, patent information has been investigated for revealing the strength and weakness of companies from the technological aspect.

In the year of 2010, Frietsch et al. analysed the international markets using patent information. They suppose that patent statistics are a frequently used innovation indicator for the description and analysis of technological strengths and weaknesses. Furthermore, in this paper the concept of the “transnational patents” is suggested. With the help of the definition of the transnational patents, new relations can be grasped and relative positions between countries can be accurately evaluated [13].
Yang et al. analysed the electric vehicle technology in China with consideration of both the policies and patent information. The domestic and international performances of China’s EV technology are compared using transnational patents information. Based on transnational patent information the inconsistent performance of China’s EV technology is proposed and discussed [14].

The technological trends of the fuel cell electric vehicle are analysed using patent information by Kwon in 2013. In this paper, the citation information is used to evaluate the quality of a specific patent. The newly emerging technology is predicted using the technology contents of patents [15].

In the year of 2012, Gridlogics Technologies Pvt. Ltd made a report about HEVs. In this report, the technologies related to HEVs are analysed using the patent information. In this report, it categorised the patent of HEVs into 3 types: by power transmission modes, by battery types, by brakes types [16].

2.3 Research questions and their meaning

2.3.1 Research questions

From the literature review, it could be seen that the patent information has been widely used to evaluate the outcome of companies and the application number of patents, the IPCs and citation information are always adopted to assess the performance of companies and predict the trend of the industrial field. Being inspired by these related literatures and bearing the research objectives in mind, the research questions are set as following in order to fulfil the object of this study:

**RQ1**: What kind of patent strategy or patent portfolio is applied for major HEVs makers in HEVs markets of interest?

**RQ2**: How to locate and evaluate the patent portfolio of different companies based on the information of patents?
RQ3: What is the new promising or emerging technology developing field?

For the first research question, the HEVs key assignees need to be first confirmed from the patent data. Later the HEVs market of interest is defined. Then different behaviours of key players in the interested market is analysed to answer the research question. Moreover, the patent strategy or patent portfolio contains both the information of countries in which the patents are filed and also the IPC distribution.

For the second research question, in order to locate and evaluate the technology of major assignees, the coordinate should be defined. Moreover, the indicator which can evaluate the technology strengthen of a company should be defined.

For the third research question, in order to extract the promising or emerging technology developing field. Certain indicator needs to be defined to evaluate the growing rate of certain technology in HEVs.

All the research questions can only be answered based on the analysis results of the patent statistics. Thus, the patent data should be carefully extracted and analysed.

2.3.2 The meaning of this research

The meanings of solving the research questions are considered as following: Of course for each company its self, the technology strength and weaknesses are well understood, however, this understanding may be biased. With comparison of other companies behaviours, one company can comprehend its situation much better. Thus, this study which can offer an impartial description and judgement of the companies can facilitate the decision of further R&D investment with also the forecast of the developing technology field. Moreover, for standalone researchers or inventors, this study can make it easier to find the learning or investigate objects.
Chapter 3

Methodology

In this section, the methodology for extracting the technological characteristic from patent information is explained.

3.1 Patent database

There are several patent databases available for the public provided by national or regional intellectual property offices. Such as: WIPO, USPTO, EPO, SIPO, JPO, etc.

WIPO is the abbreviation for “World Intellectual Property Organization”; USPTO is the abbreviation for “United States Patent and Trademark Office”; EPO is the abbreviation for “European Patent Office”; SIPO is the abbreviation for “The State Intellectual Property Office of the People’s Republic of China”; and JPO is the abbreviation for “Japan Patent Office”; Among numerous free patent database provided by the governmental organizations, the WIPO database is selected because the PATENTSCOPE database offered by the world intellectual property organization provides access to patent documents of participating national and regional patent offices. The information may be searched by entering keywords, the names of applicants, international patent classification and many other search criteria in multiple languages.
Thus, in this study the patent information about HEVs is extracted from the International-World Patent Organization (http://www.wipo.int/portal/en/index.html)

### 3.2 Research procedure

The whole research is based on the patent information extracted from the patent database WIPO. The research procedure is first explained. In Fig. 3.1, the proposed research procedure is listed.

![Figure 3.1: The research procedure](image)

This figure shows that the first of all is to extract the useful patent data from the database. Thus, the first step is to identify the appropriate research queries. After the research queries are defined, the useful information is able to be obtained.

Based on the patent data information obtained, the overall application and publication trends are analysed. Since the HEVs is a large research topic, thus it is necessary to narrow it down. As a consequence, the major markets and the major assignees in the major markets are defined to focus on a relatively small portion of the HEVs patent. This stage here is examined from the macro level without getting into the detailed information.
3.3. Search query

Next phrase after the macro analysis is the investigation in micro level. In this level, the analysis has been done to discover the application trends of major assignees. Moreover, the behaviours of major assignees in major markets is tested to reveal the different application performances in different markets. Furthermore, the IPC distribution of major assignees is analysis to show the different technological emphasis or strength of the major assignees. Also the technological field analysis of major assignees is analysis based on the three major field. Still, the inventor analysis is conducted to demonstrate the different inventor cultivation strategy of major assignees. Last but not least, the evaluation of major assignees is carried out based on the behavioural matrix and technological volume.

Based on these macro and micro analysis results, the emerging technological field indicated by IPCs and by three main technological fields.

Therefore, by all of these researches the research questions can be answered.

3.3 Search query

The most fundamental part of this research is the extraction of the interesting patents. The extraction of the relative data needs to first define the search query and use appropriate search query. The search query is defined by the method of trial and error.

The search query contains three major parts. One of the major parts is the one declares the search period. The other two major parts are the ones which state the search objective. In this research, the search objective is defined using both text searching and IPC searching which offers better search results. These search results are considered to have little missing and overlapping.

The font search is performed as Fig. 3.3. In this phase, the keywords have the same meaning of “electrical hybrid vehicle” are found to extract all the relative patents of HEVs.
Only use the font text search is not enough and the results may include some other patent which may not relate to vehicles. For example, the abbreviation “HEV” also means “Hepatitis E Virus”, thus in order remove this unrelated patents, the search of IPCs is added here in this research to specify the technological field of interest. Similarly, for the definition of the search query of IPCs also performed using trial and error and search is carried out as Fig. 3.3

There are two kinds of search queries adopted in this research. The first search query is defined for extracting all the information about HEVs. The second kind of search queries is defined to extract the applied patents related to specific technology.

This first research query is defined as:
In this search query, FP mean the front page, AD stands for the application date and IC mean the IPCs. Using this equation the HEVs related applied patents can be extracted.

The second type of research queries is defined for extracting the patent applied in main HEVs technological fields. The main technological fields of HEVs are suggested by Gridlogics Technologies Pvt. Ltd. The technologies related to HEVs are categorised into 3 types: by power transmission system types, by battery types, by brakes types [16]. The corresponding queries are:

For transmission system:

\[
\text{AB: (battery or "电池" or "バッテリー" or "蓄電" or "电池") and IC: (H01M or G06F or H04W or H02J or H04L or H04B or H01L)}
\]

For battery:

\[
\text{AB: (battery or "电池" or "バッテリー" or "蓄電" or "电池") and IC: (H01M or G06F or H04W or H02J or H04L or H04B or H01L)}
\]

For brake:

\[
\text{AB: ("brake" or "ブレーキ" or "制动" or "刹车" or "制动") and IC: (B60T or F16D or B60K or F16H or B60W or B62D or B60R or B60L or G06F)}
\]

In addition, the assignees are also search as:

- PA: ("Toyota" or "トヨタ" or "丰田")
- PA: ("Nissan" or "日产")
- PA: ("Honda" or "本田")
- PA: ("Ford" or "フォード")
- PA: ("GM" or "General Motors")
- PA: ("Hyundai" or "ヒュンダイ")
Moreover, since not all the patents are written in English, thus here English, Japanese and Chinese are applied in the research queries to extract all the HEVs interested.
Chapter 4

Patent data analysis results

In this chapter, the results based the extracted patent data are presented to explain the whole HEV patent trend and major assignees patent behaviours in major markets. The analysis is conducted from the macro level first to examine the whole HEV patent data first to get the basic understanding of the overall HEV technology field. Subsequently, the technological characteristics of key players in the HEV field are confirmed.

4.1 Macro HEVs patent data analysis

4.1.1 Overall application and publication trend

During the last decades, technologies related to HEVs have been developed rapidly due to the requirement of the improvement of the HEV technologies. Thus, it is necessary to understand the overall trend of HEV technologies. In Fig. 4.1, it demonstrates that the application trend of HEV is like a “M” alphabet. It is saying that the application number increased from 2005 to 2008 and from 2010 to 2011, however, it decreased from 2008 to 2009 and 2011 to 2014. However, due to the delay of publication phrase the publication trend of HEVs patents is different from the application one. The publication trend shows that the HEVs technology steadily increased until 2010 and experienced a little decrease in 2011 and increased again from 2011 to 2013. In
2014, the number of publications decreased again.

Figure 4.1: Overall patent trend of HEV technology

It is considered that the application number can indicate the activity level of R& D. On the other hand, the publication number can reveal the technological strength of one company. Here in this research more attention is paid to the activity level of R& D, hence, the application data of patent are investigated.

4.1.2 Overall detailed application trend

In order to have a better understanding about the HEVs technology trend, the “10*logratio” is defined here.

\[
10 \times \log\text{ratio} = 10 \times \log_{10}\left(\frac{Ap_i}{AVG}\right) \tag{4.1}
\]

where \(Ap_i\) is the number of patent application in \(i^{th}\) year and \(AVG = \frac{\text{sum of years}}{10}\) is the average application number of HEVs from 2005 to 2014. Thus, the sum means the summation of the patents applied from 2005 to 2014 and the years is 10.

Consequently, by using the Eq. 4.1, the trend can be easily compared to the average level. It is clear that once the application number of certain year is larger than the average number the log10 function results in positive number. In contrast, once the application of a certain year is
less than the average of the log10 function leads to a negative number. Here 10 is multiplied to simply offer a clear number which is enlarged.

Figure 4.2 displayed the application trend in the field of HEVs. The orange line indicates the cumulated number of the patents applied until specific year. The gradient of this orange line is steady and positive until 2011, which means that the application of HEVs technology grew steadily until 2012. This can be also inferred from the \(10 \times \log\text{ratio}\). This ratio is positive during the year of 2006 to 2012, which means that the application during these years are more active than the average level. However, this ratio becomes negative in 2013 and 2014, which manifests the activity level of HEVs technology is relatively low. In conclusion, the application of HEVs patent is of high activity.

![Overall HEVs application trend](image)

**Figure 4.2: Overall HEVs patent application trend**

4.1.3 Definition of major markets

Although patents of HEVs are applied universally, the behaviours of HEVs patent in major markets are more interesting. From Fig. 4.3, it can be understood that the major markets
of HEVs are: Japan, United States and China from both patent application number and publication number. Moreover, it should be noticed that Europe and South Korea also have high patent application/publication number of HEVs. However, here the major markets interested are defined as Japan, United States and China. Later, the key players in these three major markets and also the corresponding patent behaviours can be confirmed.

Figure 4.3: HEVs patents in different countries
4.1.4 Definition of major assignees

After the major markets are confirmed, the key players or the key assignees in these markets can be defined by the patent application or publication number during the research period.

Figure 4.4 shown below demonstrates that the key players in the major markets are: Toyota, Nissan, Honda, General Motor, Ford, and Hyundai from both the number of applied and published HEVs patents. Again the attention should be paid here that although China is a large market, however due to the lack of technological strength, Chinese HEVs makers do not have satisfying behaviour.

Figure 4.4: HEVs patents of different assignees
Until now, the major markets and the major assignees of HEVs are confirmed. Thus, by investigating the patent strategy or patent portfolio can provide an overlook of the HEVs technological field. Hence, for the HEVs companies they can know themselves better as well as their competitor.

4.2 Micro HEVs patent data analysis

In last section, the major markets and major assignees are defined from the Macro level. In this section, the behaviours of key assignees in the major markets are examined comprehensively from the number of patent applications IPC codes and the inventors.

4.2.1 Application trends of major assignees

The picture below shows the number of applied HEVs patents in major markets by the major assignees. In order to show the graph more clearly, there are two scales adopted here. The one the right is for Toyota which applied around 50% of the HEVs patents. For the rest of the other major assignees (Nissan, Honda, Ford, General Motor, Hyundai), the scale on the left is applied.

Figure 4.5: HEVs applications of major assignees in major markets
In this figure, it could be seen that from 2005 to 2014 the application trend of Toyota is like an “M” which is similar to the whole trend of all HEVs patents applications. For Nissan, it could be noticed that its application in HEVs decreased. For Honda, it has a peak in the year of 2010 and after 2010 the application decreased. And for General motor its application experience the peak in the year of 2008 and has a decreasing trend afterwards. On the contrary, Ford and Hyundai have an overall increasing trend. Moreover, in the year of 2014 the HEVs applications of all these six companies are decreased.

Figure 4.6 indicates the share of HEVs applications of major assignees in major markets. It demonstrates Toyota always has absolute superiority in the share of HEVs patent applications except in 2014. Furthermore, this figure shows that the share of Nissan and Honda decreased, however, the share of Hyundai and Ford increased. In addition, the share of General Motor did not vary very much.

![HEVs applications share of key assignees in major markets](image)

Figure 4.6: HEVs applications share of major assignees

The combination of Fig. 4.5 and Fig. 4.6 can provide a comprehensive view of the patent applied by the six major companies in the interested markets. Nonetheless, the detailed information about in each market, in each technological field and also the major inventors are not provided. Thus, the more detailed analysis is necessary.
4.2.2 The 10*logratio of major assignees

The 10*logratio is defined earlier to measure the application trend with respect to the average level. Here in this subsection this ratio is plotted for each of the six companies. The trends of the ratios are displayed in Fig. 4.7. In this figure, when the ratio is positive it means the applied patent is larger than the average applied number, on the other hand, once the ratio is negative it means the number of the applied patent is smaller than the average level of certain company. Additionally, the overall patent ratio is also plotted using the dash point line in dark blue.

It is inferred from this figure that Toyota has almost the same application trend with the overall trend. This is because the application number of Toyota is quite large which has the dominant influence on the whole HEVs patent application number. Moreover, the 10*logratio of Toyota is positive from 2007 to 2012, however this ratio became negative from 2013 to 2014. This indicates that Toyota has paid much attention to the HEVs field from 2007 to 2012 intensively, however, it leaned its emphasis on other technology field from 2013 to 2014. For Nissan, the 10*logratio manifests that Nissan sharply decreased its HEVs application in the year of 2014. The 10*logratio of Honda shows that it emphasized the HEVs patent application from 2009 to 2011, nevertheless, it decreased the application number of HEVs from 2012 to 2014. Moreover, the behaviour of General Motor has experienced it peak in the year of 2008 and gradually decreased its application number. Opposite to Toyota, Nissan, Honda and General Motor, the application ratio of Ford and Hyundai have an increasing trend. Therefore, the conclusion has been arrived that for the whole HEVs trend it went through increasing phrase from 2007 to 2012 and decreased recently. For the six companies, their HEVs patent application behaviours can be categorized into three groups: 1. Overall oscillation: Toyota, Honda, General Motor; 2. Overall increasing trend: Ford and Hyundai; 3. Overall decreasing trend: Nissan.
Consequently, it could be seen that although the overall trend has a “M” shape which is mainly influenced by the behaviour of Toyota, different companies have different strategies for HEVs patents application.

### 4.2.3 The behaviours of major assignees in major markets

As has been discussed earlier in this chapter, there are three major markets of HEVs and the behaviours of the major assignees in these markets should be analysed to tell the different patent strategies in the aspect of markets.

The following figure shows the applications of HEVs in the major markets. It demonstrates that Toyota, Nissan, Honda and Ford have more than 50% percentage of their HEVs application applied in their domestic markets and has a comparative number of the patent application in the other two markets. On the other hand, General Motor applied almost 70% of its HEVs patents in China. In addition, Hyundai has a balance behaviour in the three major markets. Moreover, it can be seen that Ford and General Motor applied few HEVs patents in Japan. From this, it is inferred that Ford and General Motor paid little attention to the Japanese
4.2. Micro HEVs patent data analysis

market due to the difficult barrier of this market.

![Figure 4.8: The behaviours of major assignees in major markets](image)

(a) Absolute application number

(b) Percentage application share

It is clear from the Fig.4.3, most of the major assignees have a strong domestic advantage over the other counties, which means that companies always file more patent application in their home patent office than other foreign patent offices. Numerous reasons can be accounted for this, such as corporation market strategies, geographic proximity, language conveniences, national traditions and cultural differences [14].

Moreover, the applications HEVs are plotted in Fig. 4.9-Fig. 4.11. From Fig. 4.9, it can be seen that most of the HEVs patents applied in Japan are applied by Japanese companies. This indicates that the technological barrier of Japan is quite high to the foreign HEVs makers. Moreover, applications of the HEVs patents reached its peak in 2008 and deceased from 2011.
4.2. Micro HEVs patent data analysis

and had a sharply decrease in 2014.

For the market of the United States, the application of HEVs has an overall increasing trend from 2011 to 2013 and also has a sharp decrease in 2014. It should be observed that the applications of HEVs patents not only applied by the American HEVs makers but also foreign HEVs makers. Furthermore, the share of foreign companies’ applications in HEVs is around 50%. This indicates that the market in the United States does not have the technological barrier as high as Japan’s.
The HEVs market in China has an overall increase until 2013 and has decreased in the year of 2014. Moreover, the major assignees in China in the field of HEVs are all foreign companies. That is to say the strength of Chinese HEVs makers is considerably weak. Moreover, among the foreign HEVs makers, the Japanese companies applied almost the same amount of HEVs patents.

In a word, although the market share of Japan is the largest, however it is not easy to enter the Japanese HEVs market for foreign companies. And among the Japanese companies, Toyota has the absolute priority than the others. The American market of HEVs is comparable easier for foreign companies to enter. Moreover, the major foreign assignee is Toyota. Last but not least, for the Chinese market of HEVs, the American HEVs makers (Ford and General Motor) and the Japanese companies (Toyota, Nissan, Honda) share large amount of the HEVs applications.

4.2.4 The technological field analysis of major assignees

As discussed in the last chapter, HEVs patents can be classified into three major classifications: power transmission system, brake system, and battery. This three classifications are of great importance to HEVs. Now the applications in each of these three classifications are extracted for each of the major assignees to plot the technological map of these companies in consideration.
of these three technological fields. The technological map here has three axes and each of the axis indicates one of the technological field. Consequently, the technological map is depicted in Fig. 4.12.

![Technological map in consideration of the three major technologies](image)

Figure 4.12: Technological map in consideration of the three major technologies

From this figure, it could be seen that the area of the blue line which is plotted for Toyota has the largest area. It again indicates that Toyota has the advantage in all of these three technologies. Moreover, it could be seen that for Toyota, it has a higher number of patent applications in the brake technology field while it has less HEVs patent applications in the field of battery. Since Toyota applied much more HEVs patents than the other companies, the technological map is depicted again without Toyota.

![Technological map in consideration of the three major technologies (without Toyota)](image)

Figure 4.13: Technological map in consideration of the three major technologies (without Toyota)
The second technological map shown in the Fig. 4.13 indicates that Honda, Ford, and General Motor, almost have the same shape of the triangles and this reveals that they paid much attention to the technological field of the transmission system. In addition, the yellow (Ford), purple (General Motor) and grey (Honda) triangles are isosceles triangles, it means that these companies put equal effort on the brake and battery of HEVs patent applications. Moreover, the green triangle shows a little bit advantage in the technological field of brake. Furthermore, the shape of the orange triangle shows strength in the technological field of brake and has comparatively smaller applications in transmission system and battery.

Figure 4.14: Normalized Technological map

In summary, this kind of technological map shows the differences of each company in different technological fields. The Fig. 4.14 is the normalized technological map. This map can clearly demonstrate the emphasis of technological field within each company. The conclusion can be arrived that all of the companies expect for Nissan attach great importance in the technological field of the transmission system. Moreover, since the green and blue triangles have almost the same triangle shape and area, the behaviours of Toyota and Hyundai are quite similar to each other in the aspect of technological fields. They both have a little bit emphasis in brake system than in battery system. Last but not least, Nissan has outstanding performances in the technological field of brake.
4.2.5 The IPC distributions of major assignees

In the last subsections, the application trends and the $10^{\text{logratio}}$ are interpreted. In this subsection, the more detailed information about the IPC distributions are examined for the major assignees to discover differences between these companies from the technological aspect.

Figure 4.15 exhibits the first 15 main IPC codes of each of the major assignees. From this bubble chart it could be seen that all of the six companies analysed here have a large number of applications of HEVs with the IPC code of B60W, B60K, B60L, F02D and F16H. The detailed explanations of these three IPC are listed in the Table 4.1. From the explanations, it can be seen that the control of sub-units specially adapted for HEVs, the arrangement of propulsion, the electrical support, and the electrodynamic brake are the key technological fields of HEVs applied by the major assignees in the major markets. This coincides with the classification of HEVs explained in the third chapter. This can be easily understood that since the main characteristic of HEVs is that they have more than one energy resources thus the control of the transmission should have high importance. Moreover, since HEVs always need battery to provide propulsion thus the related electrical parts should also attract much attention. Furthermore, much importance should also be attached to the brake which is crucial to any vehicles. In addition, since the regenerating brake is widely applied in HEVs, the importance of this kind of brake to HEVs is enhanced.
Moreover, after the first 5th IPCs, the following main IPCs varies to different companies. These differences can be perceived with careful observation of Fig. 4.15. Since Toyota applied around 50% of HEVs patents, the bubbles of Toyota’s main IPCs are much larger than the other ones of the rest companies. In order to have a clear view of the features of the rest companies with respect to IPCs, their main IPCs are depicted in Fig.4.16. The notice should be paid to Nissan which has a considerably high level of application in F16D. F16D indicates the technology related to transmission system and brake. Moreover, applications in G06F of Hyundai, General Motor and Ford are also very high. G06F indicates the technologies related with the electrical digital data processing. In addition for the rest IPCs the detailed explanations are listed in the Table. 4.1 and Table. 4.3.
4.2. Micro HEVs patent data analysis

Figure 4.16: IPC distributions of patent applications of major assignees (except Toyota)

Table 4.1: Explanations of IPC (International patent classification)

<table>
<thead>
<tr>
<th>IPC</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>B60W</td>
<td>Conjoint control of vehicle sub-units of different type or different function; Control systems specially adapted for hybrid vehicle drive control systems for purposes not related to the control of a particular sub-unit</td>
</tr>
<tr>
<td>B60K</td>
<td>Arrangement or mounting of propulsion units or of transmission in vehicles; Arrangement or mounting of plural diverse prime-movers in vehicles; for vehicles; Instrumentation or dashboards for vehicles; Auxiliary drives for vehicles; instrumentation or dashboards for vehicles; arrangements in connection with cooling, air intake, gas exhaust or fuel supply of propulsion units in vehicles</td>
</tr>
</tbody>
</table>
### Table 4.2: Explanations of IPC (continue1)

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B60L</td>
<td>Propulsion of electrically-propelled vehicles; Supplying electric power for auxiliary equipment of electrically-propelled vehicles; Electrodynamics brake systems for vehicles in general; Magnetic suspension or levitation for vehicles; Monitoring operating variables of electrically-propelled vehicles; Electric safety devices for electrically-propelled vehicles</td>
</tr>
<tr>
<td>F02D</td>
<td>Controlling combustion engines</td>
</tr>
<tr>
<td>F16H</td>
<td>Gearing</td>
</tr>
<tr>
<td>H01M</td>
<td>Processes or means, e.g. batteries, for the direct conversion of chemical energy into electrical energy</td>
</tr>
<tr>
<td>H02J</td>
<td>Circuit arrangements or systems for supplying or distributing electric power; systems for storing electric energy</td>
</tr>
<tr>
<td>F02N</td>
<td>Starting of combustion engines; Starting aids for such engines, not otherwise provided for</td>
</tr>
<tr>
<td>F16D</td>
<td>Couplings for transmitting rotation; Clutches; Brakes</td>
</tr>
<tr>
<td>H02K</td>
<td>Dynamo-electric machines</td>
</tr>
<tr>
<td>H02P</td>
<td>Control or regulation of electric motors, electric generators or dynamo-electric converters; controlling transformers, reactors or choke coils</td>
</tr>
<tr>
<td>F01N</td>
<td>Gas-flow silencers or exhaust apparatus for machines or engines in general; gas-flow silencers or exhaust apparatus for internal-combustion engines</td>
</tr>
<tr>
<td>F02M</td>
<td>Supplying combustion engines in general with combustible mixtures or constituents thereof</td>
</tr>
<tr>
<td>G06F</td>
<td>Electric digital data processing</td>
</tr>
<tr>
<td>B60R</td>
<td>Vehicles, vehicle fittings, or vehicle parts, not otherwise provided for</td>
</tr>
<tr>
<td>B60T</td>
<td>Vehicle brake control systems or parts thereof; brake control systems or parts thereof, in general; arrangement of braking elements on vehicles in general; portable devices for preventing unwanted movement of vehicles; vehicle modifications to facilitate cooling of brakes</td>
</tr>
<tr>
<td>F02B</td>
<td>Internal-combustion piston engines; combustion engines in general</td>
</tr>
<tr>
<td>B60H</td>
<td>Arrangements or adaptations of heating, cooling, ventilating, or other air-treating devices specially for passenger or goods spaces of vehicles</td>
</tr>
<tr>
<td>F02P</td>
<td>Ignition, other than compression ignition, for internal-combustion engines; testing of ignition timing in compression-ignition engines</td>
</tr>
<tr>
<td>G05D</td>
<td>Systems for controlling or regulating non-electric variables</td>
</tr>
</tbody>
</table>
4.2. Micro HEVs patent data analysis

<table>
<thead>
<tr>
<th>IPC Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B62M</td>
<td>Rider propulsion of wheeled vehicles or sledges; powered propulsion of sledges or cycles; transmissions specially adapted for such vehicles</td>
</tr>
<tr>
<td>B62K</td>
<td>Cycles; cycle frames; cycle steering devices; rider-operated terminal controls specially adapted for cycles; cycle axle suspensions; cycle sidecars, forecars, or the like</td>
</tr>
<tr>
<td>B62D</td>
<td>Motor vehicles; trailers</td>
</tr>
<tr>
<td>G01R</td>
<td>Measuring electric variables; measuring magnetic variables</td>
</tr>
</tbody>
</table>

4.2.6 The inventor analysis of major assignees

After the technological feature of the major assignees has been analysed from both IPC distribution and technological classification, the inventors which invented the technology which later is applied as patents should be analysed to know the cultivation of inventors in each of the major assignees.

![Behaviours of inventors of major assignees](image)

Figure 4.17: Behaviours of inventors of major assignees

In Fig. 4.17, the 10 top inventors of each major assignee are extracted. The ratio is calculated using Eq. 4.2 where App\textsubscript{i} is the number of the patents applied by the ith inventor of c company and APP indicates all the patent applied by c company. This equation means dividing the sum of all top 10 inventors’ application by the number of all the application applied by specific
4.2. Micro HEVs patent data analysis

$c$ company. Moreover, the average here is computed by Eq. 4.3, which means the average number of the applied patents by the top 10 inventors of the specific $c$ company.

\[
\text{ratio}_c = \frac{\sum_{i=1}^{10} App_{ci}}{APP_c} \quad (4.2)
\]

\[
\text{average}_c = \frac{\sum_{i=1}^{10} App_{ci}}{10} \quad (4.3)
\]

This figure demonstrates that Toyota has the least concentration ratio of inventors which means each of the key inventors’ HEVs application takes only a small amount of the total HEVs of the whole company. Whereas Toyota has the largest average HEVs patent average number, which means that although the concentration ratio of Toyota is low compared to the rest of the major companies, the applied number of each key inventors are high. This two indicators reveal that Toyota cultivate numbers of inventors and each of them has a high level of activity to applied HEVs related patents. Furthermore, General Motor has the largest concentration ratio which means it pays more attention to small number of inventors. In addition, although Honda has modest concentrate ratio, the average applied HEVs patent by the key inventors is least. This shows that the level of the activity of the key inventors of Honda is relatively low.

In summary, it is always difficult to have many of the inventors whose actively level is high. Thus, for a company although the cultivation of inventors costs time and capital, it is preferable to cultivate the inventors by letting them learn from the masters.

4.2.7 The evaluation of major assignees

In aforementioned subsections, the HEVs patent features are investigated from both the market aspect and also the technological aspect respectively. Now in this subsection, the evaluation of major assignees is made based on both the market size and technological side. First the behavioral matrix of each major assignees is determined based on the patent application information. Here the behavioural matrix is defined as:
4.2. Micro HEVs patent data analysis

Table 4.4: Behavioural matrix

<table>
<thead>
<tr>
<th>Company</th>
<th>JP</th>
<th>US</th>
<th>CN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission</td>
<td>$App_{11}$</td>
<td>$App_{12}$</td>
<td>$App_{13}$</td>
</tr>
<tr>
<td>Battery</td>
<td>$App_{21}$</td>
<td>$App_{22}$</td>
<td>$App_{23}$</td>
</tr>
<tr>
<td>Brake</td>
<td>$App_{31}$</td>
<td>$App_{32}$</td>
<td>$App_{33}$</td>
</tr>
</tbody>
</table>

\[ B_{\text{company}} = \{r_1, r_2, r_3\} \] \tag{4.4}

where $r_1 = \{App_{11}, App_{21}, App_{31}\}^T$, $r_2 = \{App_{12}, App_{22}, App_{23}\}^T$, and $r_3 = \{App_{31}, App_{32}, App_{33}\}^T$.

The $App_{ij}$ in the matrix refers to the number of the HEVs application in $i$ technological field applied in the $j$ country. Thus for a certain company the matrix can be extracted from the patent data information. Consequently, the matrices for the six major assignees are obtained as the following matrices:

\[
B_{\text{Toyota}} = \begin{pmatrix}
430 & 47 & 30 \\
130 & 40 & 18 \\
278 & 54 & 23
\end{pmatrix};
\quad B_{\text{Nissan}} = \begin{pmatrix}
39 & 5 & 14 \\
11 & 3 & 0 \\
79 & 10 & 7
\end{pmatrix};
\quad B_{\text{Honda}} = \begin{pmatrix}
55 & 12 & 22 \\
8 & 5 & 0 \\
11 & 3 & 4
\end{pmatrix}
\]

\[
B_{\text{Ford}} = \begin{pmatrix}
8 & 115 & 68 \\
2 & 25 & 1 \\
1 & 17 & 6
\end{pmatrix};
\quad B_{\text{GM}} = \begin{pmatrix}
1 & 33 & 192 \\
0 & 30 & 12 \\
0 & 10 & 37
\end{pmatrix};
\quad B_{\text{Hyundai}} = \begin{pmatrix}
17 & 55 & 37 \\
11 & 29 & 12 \\
22 & 24 & 11
\end{pmatrix}
\]

It is known from the definition of the determinant that the absolute value of the determinant of the matrix formed by the rows constructed from the vectors $r_1$, $r_2$, and $r_3$ indicates the volume of the parallelepiped shown in Fig. 4.18.

As a consequence, here in this research the technological volume is defined with consideration of the markets as the absolute value of the determinant of the behavioural matrices determined by Eq.4.4. The results of the technological volume are listed in Table 4.5. Using this indicator the performance of the major assignees can be easily analysed with both consideration of the technological aspect and also the market aspect. From the values of the technological volumes, it is inferred that Toyota has the largest volume and Honda has the smallest one.
Moreover, as discussed earlier, the domestic bias appear in almost all the main player(expect for General Motor and Hyundai). In order to compensate the effect of the domestic bias, the so-called Revealed Technological Advantage [17] for comparison of patent activities in specific fields is adopted in this research. The Revealed Technological Advantage is defined as Eq. 4.5.

$$\text{RTA}_{ij} = \frac{\text{App}_{ij}}{\sum_i \text{App}_{ij}} \times \frac{\sum_j \text{App}_{ij}}{\sum_{ij} \text{App}_{ij}}$$

In the above equation $\text{App}_{ij}$ is the same as the one defined in Eq. 4.4 which refers to the number of patent applications in $i$ technological field and $j$ to the applied country. Therefore, using the Eq.4.5 the share of a specific technology applied in a specific country in relation to the share of this field within all patent applications at a specific patent office. This RTA index is suggested for determining the specialisation profiles of companies, and it partly compensates the bias linked to the domestic advantage due to the normalisation by the total averages. Correspondingly, the behavioural matrix defined in Eq. 4.4 can be redefined as:
where $\mathbf{R}_1 = \{\text{RTA}_{11}, \text{RTA}_{21}, \text{RTA}_{31}\}^\top$, $\mathbf{r}_2 = \{\text{RTA}_{12}, \text{RTA}_{22}, \text{RTA}_{32}\}^\top$ and $\mathbf{r}_3 = \{\text{RTA}_{31}, \text{RTA}_{32}, \text{RTA}_{33}\}^\top$. Consequently, the normalized behavioural matrices for six major assignees are obtained as:

\[
\mathbf{B}_{\text{Toyota}} = \begin{pmatrix} 0.460 & 0.097 & 0.090 \\ 0.267 & 0.159 & 0.104 \\ 0.503 & 0.189 & 0.117 \end{pmatrix}, \quad \mathbf{B}_{\text{Nissan}} = \begin{pmatrix} 0.042 & 0.010 & 0.042 \\ 0.023 & 0.012 & 0.000 \\ 0.143 & 0.035 & 0.036 \end{pmatrix};
\]
\[
\mathbf{B}_{\text{Honda}} = \begin{pmatrix} 0.016 & 0.020 & 0.000 \\ 0.020 & 0.010 & 0.020 \end{pmatrix}, \quad \mathbf{B}_{\text{Ford}} = \begin{pmatrix} 0.004 & 0.099 & 0.006 \\ 0.002 & 0.059 & 0.030 \end{pmatrix};
\]
\[
\mathbf{B}_{\text{GM}} = \begin{pmatrix} 0.001 & 0.068 & 0.576 \\ 0.000 & 0.119 & 0.069 \\ 0.000 & 0.035 & 0.188 \end{pmatrix}, \quad \mathbf{B}_{\text{Hyundai}} = \begin{pmatrix} 0.018 & 0.114 & 0.111 \\ 0.023 & 0.115 & 0.069 \\ 0.040 & 0.084 & 0.056 \end{pmatrix}.
\]

Again the normalized technological volumes can be calculated based on the normalized behavioural matrix and they tabled in Table 4.6 From this table, it could be seen that again

<table>
<thead>
<tr>
<th>Company</th>
<th>Toyota</th>
<th>Nissan</th>
<th>Honda</th>
<th>Ford</th>
<th>GM</th>
<th>Hyundai</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technological volume</td>
<td>0.0011</td>
<td>2.84E-05</td>
<td>2.40E-07</td>
<td>5.59E-06</td>
<td>2.00E-05</td>
<td>1.17E-04</td>
</tr>
</tbody>
</table>

Toyota still has the largest number of the normalised technological volume and Honda has the smallest one. This indicates that although almost all the companies have large domestic advantage, the total technological volume is still not influenced that much.
4.3 The emerging technological field

In last two sections, the HEVs patent features are investigated from both macro and micro level. Now in this section, the emerging technological field is predicted based on the macro and micro analysis results.

4.3.1 The emerging technological field indicated by three main technological fields

As discussed in the last chapter, technologies related to HEVs can be classified into 3 major technological fields, namely: Transmission system, battery and brake. Here the emerging technological field is again predicted using the information of these three major technological fields. Similarly as in the last subsection in which the emerging technological field is predicted by the IPCs information, the trend of the 3 technological field is first plotted in Fig. 4.19.
In this figure, the growth rate is defined similarly as the one defined in Eq. 4.7. From this figure, it could be easily seen that the growth rate of all these 3 technological fields have positive values from 2006 to 2011. This period can be considered as the growing period for HEVs. Since in 2014 all the technological field decreased their application as shown by the lines, the growth rate suddenly becomes negative. It seems that from this figure, no promising field can be found, since they all decreased.

However, this is because the total application number decreased. In order to have a clear comparison without the influence of the total decreasing trend, the average growth rate and the average applied number (log10) are defined.

In Fig. 4.20, the blue line indicates the average application number (log10) and the purple one indicates the average growth rate. These two lines divide the plane into 4 quadrants.

![Technological fields classification diagram](image)

Figure 4.20: The classification of main technological fields of HEVs

It can be seen that the technological field of the transmission system has both a higher growth rate and a larger number of applications can be defined as the crucial technological field for
HEVs. Moreover, it can be seen that the technological field of battery and brake have a lower growth rate and a smaller value of the application number. This means that not much attention has been paid to these two fields compared to the technological field of transmission. This figure indicates that there is no technological field which can be defined as the promising one. Thus, for the newly emerging field should be investigated carefully by investigating more technological field of HEVs not only constraint to these 3 main technological field.

### 4.3.2 The emerging technological field indicated by IPCs

In order to predict the promising technological field not only within the three major technological fields, the IPC trend of the HEVs patents are also examined. The first 15 main IPCs obtained from the whole HEVs’ market are studied here to show the number of the applications related with this IPCs.

Here the growth rate is defined as Eq. 4.7.

\[
rate = \log_{10}(\frac{App_i}{AVG_i})
\]  

(4.7)

where \( App_i \) is the number applied patents containing \( i \) IPC in a specific year and \( AVG_i \) is the average number of the applied HEVs patent related to \( i \) IPC. It is clear that once in a certain year applied HEVs patent has larger value of the average number the rate is positive, vice versa.

The following figure shows that since the total amount of the HEVs patent filled decreased in the year of 2014, the growth rate of the main IPCs also has a similar trend. It can be seen that from the year of 2005 until 2011, almost all of the main IPCs studied here have a positive growth rate. Thus, from this picture, it seems that all the IPCs decreased the promising trend cannot be detected.
In order to tell the promising technological field related IPC, the total trend should be deleted to see the absolute trend. Thus, the average growth rate of all 15 main IPCs is calculated. And this average growth rate is calculated to be -0.105. Moreover, the average of the log10 number of the applied HEVs patents is computed to be 2.521. The figure is plotted as the following figure.
4.3. The emerging technological field

In Fig. 4.22, the purple line refers to the average growth rate and the green line indicates the average applied number (log10). It can be seen that all the 15 main IPCs are classified into 4 districts. The IPCs (B60K, B60W and B60L) located in the first quadrant show a higher growth rate and large number of the application indicate the key or the crucial technological field for HEVs. Companies have to pay much attention to this field. However, since these IPCs are the basic IPCs related to HEVs, they cannot be considered as the emerging or the promising technological field. On the other hand, the IPCs located in the second quadrant also have a higher growth rate, nevertheless, the application number in these fields is relatively low. This demonstrates that the companies are trying to apply more applications in these IPCs while the number of applications is still low. As a result, in this research the IPCs placed in the 2nd quadrant are defined as the promising ones or the emerging ones. There is only one IPC located in the 3rd quadrant. The position of this IPC indicates that it has a low growth rate and at the meantime has lower application number. This reveals that there little attention
been paid to this IPC related technologies compared to the other IPCs.
Chapter 5

Discussion

In this chapter, the discussions are presented based on the research results. The discussions here are basically the interpretation of the research results based on the understanding of the author.

5.1 Discussion from macro level

From results of the macro analysis for HEVs, it is clear that during the application number of HEVs is increased until the year of 2013. The reason why the number decreased in the year of 2014 is considered as: 1. Not all applied patents are published to the public; 2. The major technological field for HEVs should be the drive-train system which combines the internal combustion engines and other sources such as battery. And these technologies have already been registered, thus the HEVs makers pay paid less attention to the other secondary technologies. But it should be noticed from the sales aspect that the future market of HEVs is still promising. This means for HEVs companies it is better for them to invest in the technology which makes their product over-performed in some specific areas.

Furthermore, considering about the market of the HEVs, although United States and Japan may be the first two large markets, the effort of entering the market of China should also be
enhanced. Still, the market of Europe and Korea should also be strengthened. However, pay attention to all the markets may not be economical possible, thus for companies, they should choose the appropriate strategy for the selection of the market in which more effort should be paid. This kind of strategy related much to the globalization strategy of companies.

in addition, although the market seems to be dominant by the major assignees(Toyota, Honda, Nissan, General Motor, Ford, Hyundai), it is not saying that other HEV makers cannot enter. However, as mentioned earlier that the major technologies related to the powertrain, internal combustion engine are already quite mature, thus, for other companies wants to enter the HEVs market they should pay attention to other supplementary parts of HEVs.

5.2 Discussion from micro level

In this section, the discussions are based on the analysis results provides in the last chapter about the specific assignees, markets and technological fields.

5.2.1 Discussion on the application trend

The results for major assignees in major markets show different behaviours. From the number of applications, the share of assignees and also the 10*logratio indicates that these major assignees can be divided into three types. 1. Overall oscillation: Toyota, Honda, General Motor; 2. Overall increasing trend: Ford and Hyundai; 3. Overall decreasing trend: Nissan. The reasons why they have these kind of behaviours are: 1. For the ones have oscillation mode, their performance in HEVs vary from different years. Toyota, Honda, General motor are the companies which also have great advantages in the conventional internal combustion engine vehicles. They can change their emphasises in the field of conventional vehicles but not HEVs. Thus, applications of patent related to HEVs varied in different years and the overall trend is oscillated. 2. For companies which have the increasing trend (Hyundai and Ford), the reason why they have this increasing trend is because they put much attention in the field of HEVs.
Although they also have the business in the conventional vehicles. Especially, for Hyundai, although the absolute application number of HEVs is comparatively small, however, the share of the application and also the 10*logratio demonstrate that Hyundai is a very promising company in the field of HEVs.

Moreover, it is easy to be understood that the application number is just a single criterion for evaluation of the companies, thus, in this the absolute number, the share with compare of other companies and also the 10*logratio which indicate the growth of companies with respect to their own average application number. By using all of these three criteria companies behaviours can be accurately assessed from the absolute value and the comparison of other companies and their own performances.

5.2.2 Discussion on globalization strategy of major assignees

The strategy of globalization of companies influences the performance of the patent application in different markets. Moreover, the competitive situation of markets also affects the globalization strategy of companies. The results displayed in last chapter subsection 4.2.3 indicate that almost all of the companies applied most of their HEVs patents in their domestic market. This is because of the advantages they have in the domestic market, such as the language, the relation with the local patent agency and offices. Furthermore, it should also be noticed that all the Japanese companies studied here(Toyota, Honda, Nissan) applied over 50% of their HEVs patents in Japan. And they spend almost the same efforts on the market of the United States and China. Thus, for Japanese companies, the globalization of their HEVs products is not very high. Among Japanese companies, Honda has better globalization than Toyota and Nissan. As discussed earlier, the markets except Japan are very large, thus for Japanese HEVs makers, it is recommended to pay more attention to the other international markets. Similar to Japanese companies, Ford also emphasizes their domestic market the most, and only paid little attention to the Japanese and Chinese markets. On the other hand, General Motor emphasises the Chinese market more than its domestic market. Hyundai has a balanced behaviour in the major markets. From this discussion, it is obvious that for different companies their
5.2. Discussion from micro level

globalization levels are different. It is not saying that every company should have good globalization, but within the era when almost everything is globalized it is necessary for companies to take considerations of the global needs and the global market. Moreover, companies should clear about the feature of other local markets to make an easier entry. Furthermore, even for the international markets, companies should choose the prior local market to be focussed with consideration of the limited resources.

In order to make the decision of the globalization strategy, just as mentioned earlier the feature of local markets, the competitive situation, and the needs of local markets should be analysed. From the results of the major markets shown in Fig. 4.8 Fig. 4.11. It is inferred that since Japanese HEVs companies have strength in the HEVs field over 50% of the applications of HEVs applied in Japan is applied by Japanese companies. This indicates that the Japanese market of HEVs is quite difficult for foreign companies to enter. This influences the globalization strategy of American companies (Ford, General Motor). American companies decide to spend little efforts in Japanese markets. Since the patents of HEVs in the United States are applied by foreign companies and American companies equally, thus, the market of the United States is considered to be comparatively easier to enter. As a consequence, when companies select the local markets, the American market with large potential is appealing. Furthermore, the Chinese market is always appealing since the potential is large and the technological barrier is quite low in the field of HEVs.

In summary, although the market of Japan is large however, the technological barrier is high quite high for other foreign companies to enter, it is recommended to consider more about the Chinese market which potential is high and the technological barrier is quite low.

5.2.3 Discussion on technological feature of major assignees

The technological features of major assignees are analysed from both the three major technological fields and also the IPC distribution. The results of the three major technological fields indicate that most of the companies attach great importance to the transmission systems and have balanced performance in brake and battery. This is because that for HEVs the key
technology should be the ones of powertrain which combines different power sources. Thus, most of the HEVs pay much of their attention to the transmission system. However, it is noticeable that Nissan has great HEVs patent applications in the field of brake. The reason for this is considered to be that Nissan wants to develop new technological strength rather than the transmission system to make a competitive point for it. This strategy can be taken as the differentiation strategy.

Moreover, the technological feature of companies can be also demonstrated from the distribution of the IPC codes. The results shown in Fig.4.15 and Fig.4.16 indicates that all of the major assignees applied most of their HEVs patent related to the IPC B60W, B60K, B60L, F02D and F16H. These IPC codes represent the technologies related to the transmission systems, combustion engines and gearing. These again indicate that the key technology of HEVs is the transmission. Furthermore, Hyundai, General Motor and Ford also pay some attention to the technologies related to IPC code G06F. This IPC code represents the technologies related to the electrical digital data processing. For Honda it emphasizes the technologies related to the IPC code B62M which represents the technologies of transmission. Additionally, Nissan emphasizes technologies related to the B60T. B60T represents the technologies related to the control of brake systems. This conclusion consists with the analysis of the three major technological fields. The reason why companies have technological emphasis on the IPC codes expect for the first 5 major IPC codes is that they are trying to find the different technological field which can become the competence.

5.2.4 Discussion on inventors of major assignees

The results here indicate the cultivation system of the major assignees. For Toyota, it has a large average application number of HEVs which means that the research activity level of the inventors in Toyota is comparatively high. On the other hand, the concentration ratio of Toyota is the lowest. This means that Toyota cultivates lots of inventors and since the concentration ratio is lowest. Thus, Toyota does not rely much on specific inventors. Even if some of the major inventors leave the company, it won’t cause large damage to the company.
On the contrary, the company who has a large concentration ratio has a higher possibility to experience the damage induced by losing major inventors. Among the major assignees, Honda has the lowest average applied number of HEVs patents, which indicates the activity level or the strength of the inventors in Honda is relatively low. As a consequence, it is better to make an analysis of companies about their inventors, since inventors are the crucial element of the technology-based companies. Furthermore, it is better for a company to have a high average applied number while with low concentration ratio. In this way, the company can keep its high competence and lower risks of facing the damages cause by losing major inventors.

5.2.5 Discussion on the emerging technological field

The promising or the emerging technological field is predicted based on the information of three main technological fields and IPCs respectively. The results shown in Fig. 4.20 divides the three major technologies into four quadrants. The one which has a high growth rate and small application number should be considered as the promising technological field. However, among the three major technological fields there is no one located at the second quadrant. This can be understood that all the three major technological fields are the already highly developed technologies, thus none of them could be considered as the promising one. Nevertheless, besides the three major technological fields there are many other technologies related to HEVs and among these technologies the promising one could be defined. In order to do this analysis for the further analysis which contains more detailed information. One possible method is investigating the emerging technological field using IPC codes. The result shown in Fig. 4.22 indicates that the IPC codes located at the second quadrant are deemed as the ones which represent the emerging technological field. Since the IPCs include more information not only about the three major technological field the emerging technological field can be detected. Among this the F16H is the one which has the highest growth ratio. It indicates the technologies related to gearing. Other IPCs with higher growth rate are: F16D and F02N. These IPCs are related to the mechanical parts of the transmission and starting parts of the combustion engine. This demonstrates that although the mechanical parts of vehicles have already been developed for a
long time, for HEVs the mechanical parts are the potential fields. Since HEVs needs combine different sources, thus the implementation of this combination is important. Consequently, the mechanical parts which are used to implement the combination are considered to be promising.
Chapter 6

Conclusion and future work

In this chapter, summary of the achievements and the future plan are explained. In the achievements section, the summary is available for the answers to the research questions. In the future work section, several proposed plans for both the mathematical analysis and the finite analysis are suggested.

6.1 Conclusions

In this research, three research questions have been proposed the summary of the answers to these questions are given here.

Answer1:
It should be seen that for different companies they always have various patent portfolio and patent strategies. From the application trend, it can be known that all the interested companies decreased their application in 2014. However, the total trend of the companies can be categorized into 3 types: 1. Overall oscillation: Toyota, Honda, General Motor; 2. Overall increasing trend: Ford and Hyundai; 3. Overall decreasing trend: Nissan. Moreover, the performance of major assignees in interesting markets demonstrates that most of the companies have domestic advantage and Hyundai has a balanced performance in three markets. On the IPCs analysis, the results show all companies have a large number of HEVs application in B60W, B60K,
B60L and F02D. The technological field analysis shows that all the companies expect for Nissan paid much attention in the field of transmission. The results of the inventor analysis reveal that the concentration rate of Toyota is the lowest whereas the activity level of inventors are highest.

**Answer2:** As discussed in the evaluation subsection in Chapter 4, based on the definition of the major market and also the three major technological fields, the behavioural matrices of companies can be defined and the absolute value of the determinant of the behavioural matrix indicated the technological volume of one company. Thus, the technological performance can be evaluated based on the technological volume with consideration of both the technological aspect and market aspect. The results reveal that Toyota has the largest technological volume has the superiority than other companies.

**Answer3:**
Although the promising technological field is not observed based on the analysis from three major technological fields. Nonetheless, promising technological fields are defined as the ones which are related to the IPCs of F16H, F02D, F16D, F02N, B60R, F01N, H02P, H02K, H01M, H02J from the more detailed IPC classification.

### 6.2 Future Work

Since for the research question 3, although there is no promising technological field found within the three major technological fields, the other technological field should also be investigated but not only the major ones. Moreover, within the three major technological field more detailed classification should also be analysed for deeper understanding of the technological features of HEVs makers.

Moreover, in this research the evaluation is only based on the patent information, however, the output of companies is not only based on the information of patents. Thus, in order to have a comprehensive understanding of companies, the intensive analysis containing patent information, strategic information, sales information and even the academic publication information
need to be concluded.
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