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A historical Path Dependence: The development case of eco-friendly vehicles

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تقدیم به:

آنان که با قلم تباهی و درد را به چشم جهانیان پدیدار می کنند...

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Abstract

If technological innovations are one of the major historical movers of economic growth, how exactly are technological choices made? A technological choice is taken whenever a new technology is preferred over others, and firms have to come to a decision whether to develop it or not. Generally, technological decisions are being made in response to the contextual perceived threats or potential future opportunities. The contribution extent of a company's strategy on success with a technology may be changed by political and other social forces, and may also interact with company's own capabilities. Although technological decisions exhibit a similar form of disciplines, but in nature they lack a unified overall paradigm. Although technological choices have been classified based on their disciplinary background, this study will discuss that even in a presumed chosen industry, they are still different in nature.

Using the Path Dependence Concept and Resource Based Theory of Competitive Advantage, this study tries to explore the technological choice process in the companies. Resource Based Theory views the resource accumulation as a positive way to increase the firm's competitiveness, while Path Dependence claims that the company's historical asset may cause it to get trapped in an inferior standard or technology. In this regard, using an inside-out approach and considering the firm's technological trend over time, this thesis will identify the limitations of the Resource Based View.

A case study of four major Japanese eco-friendly vehicle manufacturers was adopted to better understand the nature of technological decision making in firms. Despite recent studies in eco-friendly vehicles development and their social acceptance, understanding the technological aspect still falls significantly short of achieving satisfying results. Examining the recent development history shows that "Toyota and Honda chose hybrid technology as their main electrification program, while Nissan and Mitsubishi later chose to develop EVs". In this sense, this thesis aims to scrutinize the motives and influencing factors behind the technological choice of Japanese car companies toward the development of eco-friendly vehicles.

In addition to the case study, historical patent data from 1980 to 2012 is statistically analyzed to find out more about the car companies' eco-friendly R&D investments. This will help to unveil whether the real issue could be "Path Dependency and Lock-in to the previous technological experiences" or "A mere strategic choice in response to social forces".

The findings demonstrate that for each manufacturer, electrification as a technological choice is a unique process and each company has a different set of strategic and technological factors which could have influenced them through time. Besides, *the technological choices* of companies are shaped by social forces, market trend and the companies' competitive strategies, while the importance of historical capabilities and previous technological assets shouldn't be ignored. The findings shed light on the previous technological studies, while emphasizing on the importance of strategy in the eco-friendly market.

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Abbreviations

Abbreviations	Full Name
AFV	Alternative Fuel Vehicle
ASEAN	Association of Southeast Asian Nations
BEV	Battery Electric Vehicle
CARB	California Air Resource Board
EIA	Energy Information Administration
EDF	Électricité de France (French electric utility company)
EV	Electric Vehicle
EVC	Electric Vehicle Company
FCEV (FCV)	Fuel Cell Electric Vehicle
FRF	French Francs
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engine
ICV	Internal Combustion Vehicle
IMA	Integrated Motor Assist
IPC	International Patent Classification
GVC	General Vehicle Company
Li-ion	Lithium ion
LNG	Liquefied Natural Gas
MMP	Mixed Method Paradigm
MMA	Mixed Method Approach
MMC	Mitsubishi Motor Company
NBER	National Bureau of Economic Analysis
NiMH	Nickel Metal Hydride
OECD	Organization for Economic Co-operation and Development
PCT	Patent Cooperation Treaty
PHEV	Plug-in Hybrid Electric Vehicle

RNBV	Renault Nissan BV

Abbreviations (continued)

Abbreviations	**Full Name**
SULEV	Super Ultra Low Emission Vehicle
TMC	Toyota Motor Company
THS	Toyota Hybrid System
UCS	Union of Concerned Scientists
ULEV	Ultra Low Emission Vehicle
USPTO	United States Patent and Trademark Office
VEL	Véhicule électrique
ZEA1	Zero Emission Act 1
ZEV	Zero Emission Vehicle
USD	United States Dollars

1 - Preface

This thesis presents the technological choice process in the companies, by focusing on four Japanese auto industry leaders that are producing Hybrid Electric Vehicles (HEVs) and Electric Vehicles (EVs). A technological choice is taken whenever a new technology is preferred over others, and firms have to come to a decision whether to develop it or not. In this study, we try to explain the complexity of technological decision making, as we will show that technological choices are not a simple preference of options, but they are complicated and many contextual factors could shape the selection process.

In this research we have used two theoretical concepts to understand the technological choice in the auto manufacturer companies toward the eco-friendly vehicles: Path Dependence which manifests the potential negative aspect of resource accumulation, and Resource Based View, which demonstrates the positive gain of competitive advantage for the future. The details of this theoretical examination will be given in the following Introduction chapter, as well as Theoretical framework chapter.

As far as the technological emergence is concerned, Eco-friendly vehicles came into sight in the late 90s, largely produced by auto manufacturers to meet Zero Emission Vehicle (ZEV) standards in California. In the early 1990s, due to the huge need for rapid energy saving technologies, California Air Resource Board (CARB) regulated a law to promote the use and production of zero emission vehicles. Production of green vehicles, with lower fuel consumption and CO_2 emission, hugely affected the metropolitan areas and their production was largely welcomed by positive acceptance, especially in Japan and US.

Based on the Green Car Congress report (2013), since the introduction of HEVs in 1997, more than 7 million units have been sold worldwide, led by Toyota which sold 5.5 million units. Regarding the EVs market penetration, it is different among countries, with Japan and US as the leaders with a share of 54 percent of worldwide sales. From 1996 to present, there have been more than 100 different EV models developed by auto-manufacturers, mostly as concept, test cars or for leasing. In reality, just a few of them gained success in the market. Until 2009, all major car companies didn't mass produce any EV, while some of them like Toyota and Honda have been mainly focused on HEVs. This technological choice of companies on EVs and HEVs hasn't been questioned yet in academic literature. Although, some academic scholars paid attention to the comparison of market penetration and technical aspects of the products, the reason why some companies like Toyota and Honda decided to pursue HEVs as their main eco-friendly vehicles strategy, while others like Mitsubishi and Nissan decided to pursue EVs, has not been investigated yet. Japanese auto industry leaders have been favored with huge technological capabilities and if they wanted, they could develop both EVs and HEVs at the same time. At some point, their decisions do not seem rational and this is that caught scholars' attention. Liker (2004) states that the managerial decisions about the Prius development do not seem to be the things a rational person does to get a job done quickly. It is interesting to know what kind of factors shape the technological decision of companies and how this process initiates?

This thesis aims to scrutinize what the real motive behind the technological choice of car companies toward the eco-friendly vehicle development was. This thesis's approach is not widespread because the technological approach toward eco-friendly vehicles that has been used in this study is still unknown to the majority of economic and business studies. The period of 33 years, from 1980 to 2012, is chosen and analyzed to find out more about the roots of eco-friendly R&D investments. This will help to unveil that the real issue could be "Locked-in to the previous technological experiences" or could be "a mere strategic choice".

This thesis consists of eight chapters. The second chapter, *Introduction*, explains about the importance of eco-friendly technologies as a mean for energy economics. A brief historical trend of their development, as well as the previous commercialization issues will be discussed. Also, some technical differences and the degree of market penetration so far, between Electric Cars and Hybrid Vehicles will be shown. The *Introduction* chapter also details the thesis's research design which includes research methodology, sources of data, and research scope. This research uses case studies in our attempt to understand what kind of factors affect the technological – strategic - choice of Japanese leading auto manufacturers. Four Japanese active players in the global eco-friendly vehicles industry, Toyota, Honda, Nissan, and Mitsubishi are chosen for this purpose. We Use Mixed Method Approach (MMA or MMP) to obtain a deep knowledge about the cases and practices involved. In this sense, both Qualitative and Quantitative methodologies are important for the accuracy of MMA.

The third chapter, *Literature Review*, gives a broad overview of previous academic efforts to understand auto industry, and eco-friendly vehicles commercialization. Therefore, the recent academic efforts on green vehicles and their development, such as Pohl and Yarime (2012), Tran et al. (2012), Itazaki (1999), etc will be argued. The chapter is followed by an intriguing academic discussion on two main factors influencing the development of eco-friendly vehicles, infrastructure and market. In the last section of *Literature review*, this study shows how the research question stands in the line of previous arguments and how this thesis could contribute to the existing academic body. In this chapter, we suggest that the issue of eco-friendly vehicles development and company's strategic choices behind it is overlooked by many academic scholars and previous studies in the area of Strategy and Technology were heavily focused on outside-in approach, ignoring the technological capabilities of companies to develop the new technology. In other words, focusing only on the social forces and ignoring the company's historical capabilities will lead to a biased conclusion, which in this thesis we have strongly tried to avoid. Considering both internal (company's historical capabilities, technologies) and external factors (social forces, market, etc.) will provide a better understanding of the issue. Then, we will explain that the main research issues addressed by this research are closely aligned with the "Path Dependence theory" and the "Resource based theory of competitive advantage". Path Dependence was initially proposed by David (1985, 1987) and later, it was revised and reviewed by Arthur (1989, 1990, & 1994) and Liebowitz and Margolis (1990, 1999). Using the evolution of typewriter keyboard, David (1985) proposed that a standard that is first-to-market can become entrenched. He called this "Path Dependence", which means initial actions can remain effective in the history of technological advancements. "Resource based theory of competitive advantage" as strongly proposed by Grant (1991) and Dierickx and Cool (1989), is a framework for strategy formulation. It sees organizations as bundles of resources which are combined to create organizational capabilities (Grant, 1991). This thesis uses the both of the mentioned theories to explain the strategic choice of Japanese automakers toward the eco-friendly vehicles. This chapter argues that rather than paying attention to the technological trend of a company as an entity which makes decision based only on the market need and environmental factors, we could have a better understanding if we look at the companies' capabilities at the moment of optional selection. In this chapter, an overview into technological decision making will also be presented. Pinch and Bijker (1989) and Hughes

(1989) stress on the complexity of technological decision making. In addition, Primack and Von Hippel (1974) and Barnes (1985) have shown the importance of technical experts and engineers in the decision making process, meanwhile, they argued that top management shouldn't entirely be influenced by the technical knowledge.

The fourth chapter, *Historical Background*, identifies and explains "being green" in the transport industry and reviews the history of Electric Cars and Hybrid Vehicles in the past century. It starts from the technological advancements in the late 19th century, leading to the development of early electric cars in Chicago, Detroit and Los Angeles. Then the fierce competition between ICEs and EVs in the early 20th century will be portrayed. It should be noted that the history of eco-friendly cars is divided into three parts: (a) the early years (1890–1929), including their golden age of dominance in the market from about 1895 to 1915; a slight dominance in some specific countries due to the Second World War; (b) the middle years (1960–1985), including their presence after the two oil crises; and (c) the current years (1996–present). In this study, the main focus will be on the third part, keeping in mind that the strategic choices of companies are being made earlier than the actual product introduction to the market.

The fifth chapter, *Methodology*, presents the structure of this research and acknowledges the value of Mixed Method Paradigm (MMP or MMA). In the process of carrying out this study, we became acquainted with a large number of patents, products, ideas and word of mouth strategies. A central core of MMA is to combine qualitative and quantitative approaches to have a full understanding over the companies' historical course of actions. The first part of this research data is collected through observation, short interviews, industrial and financial reports, and the products themselves. The second part was based on the statistical analysis of the case studies' technological trend. In this sense, 33 years patent history of the companies on eco-friendly technologies was cautiously analyzed. Inspired with the works of Lee (2013), we used NBER patent database, as well as USPTO and Patentlens databases to identify and analyze patents on eco-friendly technologies. The real benefit that MMA provides is to launch the analytical process with any of the qualitative or the quantitative approaches, and later, anytime the study couldn't get fed more with necessary information, the researcher could shift and apply the other approach.

The sixth chapter, *Case Studies*, will give full details on the selected cases of Japanese auto manufacturers which have been active leaders in eco-friendly vehicle production. In this chapter, the strategic drives behind the technological choice of the companies toward electrification also will be addressed. We have chosen four Japanese companies, based on their presence in the green vehicles market. Toyota and Honda, pioneers of Hybrid technology, and Nissan and Mitsubishi, current global leaders of EV production are chosen. Based on detailed contextual analysis, we capture the auto manufacturers' experiences and journeys, starting from their engagement with eco-friendly technologies until the present time. Our analysis includes their recent history of eco-friendly R&Ds, influential entrepreneurs and policy makers, technology and patents, HEV and EV development processes, financials situation, and market acceptance of company products.

In the seventh chapter, *Findings and Results*, we will answer the research questions using statistical and numerical diagrams, graphs and trends, and analysis. This thesis emphasizes that there is not a general reason for the weak presence of EVs, as well as the strong presence of HEVs, in the past two decades. But, auto manufacturers' strategic approach toward EVs and HEVs, production or halt, has been distinct among the selected companies. In addition, based on the historical trend of eco-friendly R&Ds, we stress that Toyota and Honda's approach toward hybrid technology, right on its strategic momentum in the late 1990s, could be expressed as a Path Dependent technological choice. While for companies like Nissan and Mitsubishi, other factors could be engaged. For this matter, we extracted the core technologies that have been used to produce Hybrid Vehicles and Electric Cars, and did a statistical and historical comparison between them.

The eighth chapter, *Conclusion and discussion*, summarizes the main arguments for this thesis regarding the importance of adoption of eco-friendly vehicles in the society, the strategic distinction in motives of major players for eco-friendly vehicle developments, and the influence of historical background on the future development of technologies. Based on the results, this thesis concludes that the technological choices of companies over the time are not only influenced by the social forces, market trend and the companies' competitive strategies, but also as a combination with the historical capabilities and previous technological assets. This study expresses Toyota and Honda as two main cases that were Locked-in their Hybrid technological assets, and they didn't start the Path Creation until recently. Also, this study expresses Nissan and Mitsubishi as two probable cases that their technological background had a minor influence over their technological choices, and they engaged with Electric Vehicle technology due to other reasons. In this chapter, *Limitations and Implications* are also summarized. Implications for further research include exploring non-Japanese auto manufacturers' eco-friendly vehicle development strategies, especially Ford and General Motors; because they were pioneers of eco-friendly vehicle development in US. Also, a lot of car companies, purchase their auto parts, such as electric batteries from other companies. Despite the difficulty, investigating the historical trend of battery development would also be interesting.

In terms of policy implications, the author suggests a parallel Path Creation strategy, which leaves a few doors open for the unwanted consequences of Path Dependence. There are also some limitations to this study. Firstly, the investigated cases are the major Japanese leaders in green transportation; while there are a lot of small companies with similar concept and products and observing them was beyond this research's limitations. Secondly, the patent analysis is mainly focused on the US registered patents. We would suggest that for understanding the recent trends, other patent databases of Japan and EU also will be investigated.

2- Introduction

For more than a hundred years, mankind has been using vehicles propelled by combustion engines. Stopping the growth in motor vehicle use is neither feasible nor desirable, given the economic and other benefits of increased mobility. Over the next 40 years the global fleet of passenger cars is expected to quadruple to nearly 3 billion (economist, 2009). The challenge, then, is to manage the growth of motorized transport so as to maximize its benefits while minimizing its adverse impacts on the environment and on society (Faiz et at., 1996). One of the major environmental problems is to avoid a huge increase in environmental pollutions and the greenhouse effect. Because cars driven by fossil fuel are one of the largest contributors to air pollution, and the oil won't be enough for our needs in the future, many novel ideas for solving these important problems have been developed. We had to develop new mechanical solutions and also to find other main energy sources. These problems have motivated car manufacturers to introduce new generations of cars in order to cope with fuel consumption and emission issues. Indeed, car manufacturers have already introduced many options in order to build tomorrow's cars. From the development of LNG propelled vehicles to the production of technically higher efficiency vehicles. Today, Electric vehicles and Hybrid Electric Vehicles are considered, by some, to be the solution to those problems.

Clearly, a simplified view is that car manufacturers have been dealing with different technological options through the history. Sometimes such as early twentieth century, electricity, gasoline and Steam powered vehicles were considered as rational alternatives for the transportation, while other times, especially from mid-90s, Hybrid vehicles and LNG powered vehicles are considered as viable option for the society. Of course, in the recent years, Electric

Vehicles caught the attention of automakers and they are being produced once again. These technological options are different in propulsion system, emission and fuel type.

Conventional vehicles are propelled by only igniting fossil fuel [LNG or Gasoline] in a combustion chamber inside and integral to the engine and converting the ignition energy into mechanical rotation and translation (Irani, 2009). It is correct that current cars are about 20 times cleaner than cars 20 years ago, but cars still put millions of tons of toxic chemicals into the air and water. The waste products and toxins that are released from the cars exhaust pipes are known to cause urban air pollution, climate change and global warming. These include carbon monoxide, nitrogen oxide, particulate matter, hydrocarbons and volatile organic compounds (Green Vehicle Guide, 2008). This had been led by market demand followed by car manufacturers, oil companies and governments. The emission from motor vehicles exhaust is very harmful to human health and to the environment especially in large quantities. The air pollutant causes breathing and heart problems as well as increases the risk of cancer (Minnesota Pollution Control Agency, 2009). Numerous studies which highlight the disastrous impact of climate change on ecosystems and economies have already been published. These concerns could be explained by the fact that the increase of greenhouse gas concentration in the atmosphere is responsible for global warming and climate change that is happening around the world. Meanwhile, the oil‘s price ups and downs have had a dramatic impact on the economies of OECD, East Asian and North American countries.

As a result, the combination of the world‘s need for lower emissions, non-fossil energy sources and the development of battery technologies has opened up new possibilities for the future of automotives. Many interesting innovative ideas and new mechanical practices for solving these important problems have been developed. The automotive industry is looking at pure Electric Vehicles as well as Hybrid Electric Vehicles to meet these global demands. The interrelations and synergies between the different propulsion alternatives of eco-friendly vehicles are strong, but considering the technological nature, we divided them into EVs, HEVs. Car manufacturers pursued Electric Vehicles (EVs) because of their mechanical simplicity and the absence of direct pollutant emissions to cope with fuel consumption and emission issues. The problem is that the current battery technology is not suitable enough for electric vehicles to compete with internal combustion vehicles. Hybrid Electric Vehicles (HEVs) in which an internal combustion engine would supplement the batteries, are also considered to be another solution to those problems.

As Coopersmith (2009) explained, in history of industrial development, "failure is an integral and normal part of a technology's evolution". Failure extends from a commercial collapse of a firm promoting a new technology and the inability of a technology to profit in the marketplace (Ibid). History of eco-friendly vehicles is saturated with mainly failed artifacts and a few cases of successful ones. And as Coopersmith (2009) states history tends to be written about the successful, not the failed.

Currently there are a few electric vehicles available to buy, while hybrid ones have more of a variety and acceptance. One of the best recent successful cases of EV is Nissan Leaf, with more than 75,000 Leafs which have been sold worldwide by August 2013 (Cobb, 2013). Also, the best known successful HEV is the Toyota Prius family with 3.67 million units through the end of March 2013 (Toyota Press Room, 2013). Rather than HEVs, the sales figures of EVs from the very beginning weren't always an upward trend. While based on a logical cost calculation, it is rational to buy a hybrid car; choosing an EV has more consequences. EV is more negatively influenced by social and technological forces. Studies have indicated that whether EVs are considered as a new product or as a new industry (Scott, 1995a), their radically different composition makes probable the substantial alteration of production systems, the creation of new ones (patchell, 1999). In contrast to the current pessimistic views toward EVs, some reports forecast a brighter future for them. Brown et al. (2010) argued that although currently the EV in its entirety represents a very small proportion of the total number of passenger vehicles in most jurisdictions, it is widely expected that the EV will experience rapid growth over the coming decades. In a 2009 study, JP Morgan estimated that by 2020 11 million EVs could be sold worldwide, including 6 million in North America (Automotive News, 2009). According to JP Morgan, this will mean that the EV will equal nearly 20% of the North American market and 13% of the global passenger market at that point in time (Brown et al., 2010). We will witness in this study an effort to balance this historical trend by discussing the failed eco-friendly vehicles.

As far as electric vehicles acceptance is only concerned, there is an important question to be asked: will customers buy EVs? Of course, the answer to this question depends on some additional conditions such as the cost of EV purchasing and operating compared to the cost of a conventional gasoline-powered vehicle, the trends over the next decades, and the feasibility and ease of access to the electricity needed to power EVs? Hensley et al. (2009) stated that the market for electric vehicles will take off sooner or later, but there are several unpredictable variables that determines when.

One issue that previous studies have shown interest in is the effect of a century of ICE development and penetration in the society. Air and noise pollution and huge fossil energy consumption are the basic necessities of this effect. These issues have been the center of attention in economic, environmental and energy studies for the past two decades. 20th century experiment of car companies with ICE has been summed up and as a result, recent gasoline vehicles are being produced with better designs, comfort and safety. These are not the only effects that the 20th century had on auto manufacturers. The other aspect is the effect of long time absence of auto manufacturers' experiment with the current eco-friendly vehicles development; and it is rather left out of the literature. In this sense, this study tends to analyze this issue by investigating the bondage between companies' history and their ability to develop a new product.

This study will try to discover why it took so long for car companies to mass produce a successful eco-friendly vehicle and in this way, what kind of limitations existed so far? The study will provide a great insight into how eco-friendly vehicles could be commercialized and adopted, and how they could be commercialized in other ways to be more successful in the future. This research will help the academic body and other interested policy makers to see the application and development trend of green vehicles through the eyes of technology scholars. In the next section, research design and methodology will be explained. A brief overview into research question also will be demonstrated.

2.1. Research design, methodology

This section outlines the research design for this thesis. We begin by explaining our research methodology, it's superiority to other methodologies, and present the thesis's main research question in short. Next, we will discuss the main sources of this research followed by the research scope.

A Mixed Methodology of Qualitative and Quantitative research paradigms (MMP) is used to provide a thorough insight into the car companies' background and their strategies toward the eco-friendly vehicles. This thesis uses case study approach to explore the qualitative features of the not so recent eco-friendly vehicles in Japan, especially after the influence of

CARB regulations on the auto manufacturer's technological activities from 1990 to 2012, such as the formation of organizational projects in favor of environmental issues and green vehicle development; financial situations, namely ups and downs in the past two decades; changes in the commercialization strategies; and influential contextual factors for green vehicle development. This thesis also uses statistical patent analysis to explore the quantitative features of the technological development in the aforementioned companies, such as technological shifts in R&D investments; and technological comparison. As explained in the past section, the objective of this thesis is to explore what influential factors are engaged with the technological choices of the auto companies in Japan. Hence, the fundamental research question for this study is the following:

> *What were the strategic and technological factors behind Toyota and Honda's choice of HEVs, as well as Nissan and Mitsubishi's choice of EVs?*

In order to investigate this question, we have chosen Case study and patent analysis as our main research approaches. There are a few main reasons for the choice of case study. One of the reasons is Case study provides a detailed contextual analysis of a complex phenomenon.

Contextualization is important because it provides a greater understanding as to how an issue occurs and develops. In other words, it is impossible to see the full picture unless a detailed contextual analysis is conducted. Yin (1984, p.23) defines the case study research method as "an empirical enquiry that investigates a contemporary phenomenon within its real life context; when the boundaries between the phenomenon and context are not really clearly evident; and in which multiple sources of evidence are used." This implies that at the outset, case study method fits our research objective best we are exploring a social phenomenon which is socially constructed. This is to say that we are dealing with understanding the subjective nature of a social phenomenon – why some companies' technological choices are different from others. Scholars of Social Construction of Technology (SCOT) also often use the case study method in their research such as the works of Pinch and Bijker (1987), Latour (1987), and MacKenzie (1990). The most similar work in this case is the study of Callon (1987), which has used case study approach to investigate the development of Electric vehicles in France in late 80s.

The second reason in the use of case study method is, case study complements the limitations of quantitative methods and satisfy the three tenets of the qualitative method namely: describing, understanding, and explaining (Yin, 1984). The 'why', 'how', 'when', etc. questions allow us to record interesting vignettes or particular nuances that illuminate a topic. This kind of data cannot be captured in a survey instrument alone.

Currently, there are more than a hundred eco-friendly vehicles produced as a test, concept, or for mass production. A majority of this share goes to small start-ups, which their outcome is only for the test or prototype purpose. From Japanese companies, there are only four auto manufacturers that have mass produced eco-friendly vehicles that we have selected as our main case studies. We then begin by providing an overview of our main selected cases, following by in-depth analysis of the companies' strategies toward eco-vehicles.

As Yin (1984) indicates, the objective of the case study is to achieve an in-depth comprehension of the problem. Thus, qualitative research methods which describe, explain, and illuminate are the best to adopt. The objective of achieving a balance between depth and staying in the target frame, leads us to short semi-structured focus interviews. An interview method along the other data gathering methods complements the limitation of data conducted only through quantitative surveys.

2.2. Sources of research

This thesis utilizes four different sources of data. Each source of data offers its own advantages and limitations. Collectively all of these data provide an understanding to explain the main factors affecting the companies' technological decision and overall condition of eco-friendly vehicles development in Japan.

The first group of data for this thesis comes from the studied corporations (Toyota, Honda, Nissan, Mitsubishi, as well as Renault due to its strategic alliance with Nissan). The company's annual reports, financial and environmental reports, press releases, website, industrial reports, etc. are the main sources of this group of data. All of these companies have a very strong online presence, and provide websites which include information such as the company's profile, historical background, previous and current projects, and financial reports. For case study companies, annual and financial reports, company's announcements such as press releases, and word of mouth strategic reports provide additional information about the status of their financial condition, shareholders, business strategy, and vision. Such information is important to provide the background and a reasonable understanding to our case studies. The problem with this source of data is information from annual reports or press releases tend to magnify the "successful projects and positive outcomes" and miniaturize the "failed projects and bad conditions".

The second group of data is the third party reports and studies on the projects or the subjects related to case studies, as well as data reports from industrial associations and international organizations. Some of the above organizations are directly involved in the development of eco-friendly vehicles and conduct yearly, quarterly surveys or reports on green automobiles, and energy issues. Some of the most important reports that we referred to in this thesis is the yearly energy surveys conducted by US Energy Information Administration (EIA).

Other reports that concern the development of eco-friendly vehicles include the following: World Bank Energy Council, IMD International Guide, yearly project and market reports on global eco-friendly projects by Green Vehicle Guide, etc. Several data sources are used including short interview reports with CEOs and project managers that have been somehow engaged with the electrification projects of these Japanese companies, industrial reports by professional websites such as Green Car Congress, Auto Blog, Hybrid Cars Co., and other professional reports.

The third group of data is the interview data. We interviewed a total number of 8 different companies active in eco-friendly vehicle development (Waseda Group, Naigai denki, TGMY, SimDrive, O2 Motors, Vector Co., Triton Co., Toyota, and Nissan). We compiled this interview list based on the research needs and the company's positive response to our initial contact. Three series of interview were conducted in Oct 2011, Sep 2012, and Sep 2013 in EVEX (Electric Vehicle Development Technology Exhibition in Tokyo - 電気自動車開発技術展). All of the interviews were conducted in English and lasted a short time of 15 to 20 minutes. We have used focused semi-structured interview format which enables the researcher to only address the main influential points and prevent the bias. We have found focus interviews the best tool for our needs, because the objective is to understand the respondent's point of view rather than make generalizations and emotional assumptions (e.g. Rosales, 2013).

The interview data allows for in-depth and through investigation on the initiation of green projects, technological shifts, and strategic issues. Interviews enable the examiner to seek clarification, to probe further a particular issue and to deepen the understanding of a specific object. For example, we have seen that some project managers indicate the battery as the main problem in front of further EV penetration in the society, while other believe that in a long-run, battery won't be the main problem and infrastructure development must be at the center of attention. Additional information from the interviews such as green projects' history, amount of efforts, eco-friendly vehicle barriers, etc. provided answers that go beyond statistics and financial reports.

The limitation of focus interview data is disclosure of sensitive information, being unable to get all the answers we want due to confidentiality and strategic reasons. Secondly, interview data is subjective since it is based on the accounts of one person's knowledge and past experience. In order to deal with this kind of limitation, we tried to verify as much as possible the interviewee's answers with newspaper articles, related statistic data, and industrial reports that we could obtain.

Aside, this study has mainly employed the patent database of companies and observed if the assumptions made in this study are correct. This study will provide a technology oriented interpretation of how Japanese auto manufacturers strategically decided to shift their vehicle production from ICE to greener ones.

The fourth group of data which this thesis sourced from is quantitative statistical data. This thesis uses listed United States patents from the National Bureau of Economic Research (NBER), USPTO and Patentlens databases. A 33 years patent history of the case study companies on eco-friendly technologies was cautiously analyzed. Inspired with the works of Lee (2013) and the way he analyzed Korean firms' patent data, we conducted a historical patent analysis of Toyota, Honda, Nissan and Mitsubishi on Core HEV and EV technologies. Later, we also included General Motors and Ford general patent data between 1985 and 1995. The details of analytical methodology are given in the chapter six.

Using “Path Dependence concept” (David, 1985, 1987; Arthur, 1988, 1994) and “Resource based theory of competitive advantage” (Grant, 1991; Dierickx and Cool, 1989), this study will expect to see a relation between the companies historical portfolio of technological investments and their strategic choices over the time. In this regard, based on the resource accumulation concept, 33 years of technological experience of main Japanese car manufacturers, i.e. patents on EV and HEV technologies, were historically analyzed and compared. The longer timeframe allows up providing a richer analysis of the case studies. As conceptually described by previous scholars, we expect to see that companies with more historical investments on core HEV technologies (something that in this research is defined as HEV asset) strategically chose HEV over EV technology. While companies with a richer historical background and investment on core EV technologies chose EV over HEV.

As a result, our inside-out approach enables and facilitates the analysis to be made by those who have studied eco-friendly vehicles as a commercial product, not a technology. This research helps to advance the techno-social concept of the company’s historical background as a determinant of technological Lock-in. It strongly bolds the importance of companies’ past technological investments, patents and products and the role that these assets play in the current state of the industrial presence. One common myth used to be that auto manufacturers had already mastered the EV technology and it should make it available to the consumer sooner than expected. This study will also show that this was far from the reality.

This thesis expresses the currency amounts in Japanese Yen (¥), US Dollars ($US, USD), European Euros (€), British Pounds (£), and French Franc (FRF). In some occasions, the amount of specified monetary unit is converted based on the average yearly exchange rate, as presented in the Appendix. If no specific years are indicated or the amount is expressed over a range of years (such as Net income from 1985 to 2005, etc.), we simply use a currency exchange of the date (US$1: ¥104). Occasionally, the currency amount denominated in Euros, Francs, or Pounds is converted to US Dollars or Japanese Yen based on the exchange rate presented in the Appendix. Thus, the value expressed in US Dollar may sometimes vary from the actual amount due to currency conversions.

2.3. Research scope, terms and definitions

The specified scope of this research is the development of eco-friendly vehicles (namely EVs, HEVs) from 1995 to present. This research also has another scope to include other important periods from early 20th century to present. In this regard, from 1890 to 1929, from 1945 to 1955, from 1965 to 1985 are also being covered and explained. In this thesis, the word "eco-friendly vehicle (green vehicle, clean vehicle)" takes the definition provided by Union of Concerned Scientists (UCS) which refers it to "Clean vehicle is the foundation for the practical, realistic half the Oil savings plan, which would dramatically reduce oil use by boosting vehicle fuel efficiency, increasing the use of clean bio-fuels, and creating the next generation of advanced vehicles that no longer rely exclusively on oil" (UCS, 2013). The words "Electric Vehicle (battery Electric vehicle, zero emission vehicle)" and "Hybrid Electric Vehicle" take the definition provided by CARB which refers them to "EV: A motor vehicle that uses an electric motor as the basis of its operation. Such vehicles emit virtually no air pollutants", and "HEV: A vehicle that combines an internal combustion engine with a battery and electric motor. This combination offers the range and refueling capabilities of a conventional vehicle, while providing improved fuel economy and lower emissions" (CARB, 2013).

In the end, we are aware that as any other research, certain bias might exist because of the limitations, but since our findings largely complement the technology literature, and provide academic contribution to understand the nature of eco-friendly vehicles' development, we believe such limitations did not impose a major concern in this research.

The structure of this thesis is as follows: Chapter two contains a Literature review of the previous remarkable studies. A review on the historical development of eco-friendly vehicles and theoretical background follows in Chapters three and four. Chapter five will explain about the research methodology and questions. Regarding the green vehicles development in Japan, chapter seventh gives a detailed explanation of the four selected auto manufacturer cases. Chapter eighth concentrates on the statistical results and facts. The final remarks, conclusion and discussion will be presented in Chapter nine.

3 - Literature Review

EVs and HEVs are touted as the best available environmentally friendly alternatives to the conventional ICE car. Eco-friendly vehicles are not a new technology, indeed their history is a long one. Scharff (1992) explains, EVs were popular much earlier in the 20^{th} century and, at one point, were more commonly used than combustion-engine vehicles. Interestingly, in the past two decades, economists and academic scholars have dusted it off, and studied the pros and cons of the idea again. Why in the recent years, environmental-friendly vehicles became so important again? The currently popular paradigm for discussing the environment originated in the 1970s, when the ideas of global warming and finite oil reserves were first proposed (Minton & Rose 1997; Pelletier et al. 1998). Academic literature on auto industry technologies and energy crisis are bonded to each other. The factors of gas and gasoline prices are the important ones, and as the prices increase, so the willingness of customers to purchase eco-friendly vehicles (e.g. Gerstenfeld, 2010). Newell (2009) states that because of the potential environmental impacts of technological change, economists tried to assess the role of technological change on long-term environmental and economic well-being.

3.1. Eco-friendly vehicles literature

Eco-friendly vehicles literature should be viewed from different scholarly dimensions. While the importance of green vehicles for the society and environment has been talked about for some years, yet the bulk of the available literature from the 1970s is focused on the technical aspects of the technology. There is a large amount of literature mainly focused on the engineering and technical design such as battery advancements, vehicle design, drive control and etc. While this study focuses on the technological aspect of eco-friendly vehicles, the literature on the influential historical factors such as technical advancements (battery, etc), infrastructure, energy issues, CO2 emission, laws and regulations, and negative impacts of electrification will be skimmed too.

As it is mentioned before, recent works mainly have investigated the technical features of eco-friendly vehicles, while a very few earlier scholarly works, viewed Eco-friendly vehicles as a technology or an innovation that adopting it has the same adoption barriers like other technologies. Some of the most influential earliest works are done by Callon (1989) and Cowan and Hulten (1996). While explaining the VEL electric car (Véhicule électrique) development project in France in the early 1970s, Callon (1989) introduces actor networks that simultaneously give rise to society and to technology. He argues that a technology is a combination of actors with their links and this combination is permanently influenced by social forces. He explains that the 1970s short-term development of EVs in France was also an unaccounted reaction to the unknown future by French automakers, something that is doomed to fail any time. The condition was similar to the 1990s and the frightened auto manufacturer's reaction to the environmental issues and political regulations. By the early 2000s, all manufacturers pulled their EVs from the market and stopped further production. Callon (1989) writes:

> *"Car manufacturers, with Renault in the forefront, kept quiet, terrorized by the future promised them. In order to hold their own, they started to work feverishly on the VEL project. They knew little or nothing about electrochemistry and did not know how to tackle the EDF[1] forecasts that cheap high performance fuel cells*

[1] Électricité de France (EDF) is a French electric utility company, mainly owned by the French government.

would be available by the end of the 1980s, thus opening up the vast market of private transport…"

Cowan and Hulten (1996) used the historical advancements of EV development as a mean to propose a way to escape Lock-in. They explained when users have invested so much time and money in a dominating technology, they would become unwilling to switch technologies. Through a historical comparison between ICE and EV, they proposed six factors that may help to escape Lock-in. Although, they made it clear that a rapid escape from Lock-in, from ICE to EV, is not feasible. Here is when we face a technological barrier that we are going to call "An Eco-technology paradox":

Consistent with the above argument, technology scholars indicated that the paradigmatic shifts in technology are long and slow processes (Kline and Rosenberg, 1986) and the electrification of road vehicles is no exception (Pohl and Yarime, 2012). On the other hand, some research findings suggest the opposite, i.e. that achieving sustainable energy policy requires rapid diffusion of new technologies i.e. smart grids, electric vehicles, photovoltaic, heat pumps, smart meters, etc. (World Energy Outlook, 2012; Beise and Rennings, 2005). Thus, we strongly believe that Hybrid technology has acted as a bridge in this Paradigmatic shift toward the future acceptance of EVs.

A greater part of literature on eco-friendly vehicles consists of engineer's point of view. Engineers usually look at the problem from an analytical lens and only focus on the technical features. For example, Chan (2002) believes that the engineering philosophy of the eco-friendly vehicles, namely battery, energy technology, or propulsion technology is the main factor in their penetration. Scholars like Hodkinson and Fenton (2001), Miller (2010), and Erjavec (2012) studied the engineering and technical design of green vehicles. Some other studies investigated the battery hindrance in the way of further green vehicles development. Unnewehr and Nasar (1982), Oweis et al. (1999), Martins (2005), and Teratani et al. (2008) compared different battery models and explored the future potential of battery technology for EV development. These studies mainly suggested that between the available battery technologies, Lithium-ion (Li-ion) batteries can be produced in different shapes and have a higher energy density than many other battery technologies (e.g. Teratani et al., 2008). Meanwhile, the cost of the Li-ion battery pack is one of the largest disadvantages with EVs today. On the other hand, Boschert (2006) explored many obstacles hindering widespread production of EVs. She believes none are more important than obtaining Nickel Metal hydride (NiMH) batteries. She details how Chevron Oil gained control of the patents covering most NiMH batteries and now the oil/automotive industrial complex controls the production of these batteries.

Consistent with the above findings, in terms of charging issues, some studies concluded that HEVs have privileges over EVs and Plug-in hybrid technology could be considered as a bridge between them. For example, Benecchi et al. (2010) said PHEVs overcome this “range anxiety” altogether, as they are capable of running fully on gasoline when the battery becomes discharged. Studies like Aoki (2010), Accenture (2011), and Kintner-Meyer et al. (2007) investigated the range anxiety in EV drivers, but they believe that this problem won’t exist in the near future. Greene and Plotkin (2011) stated that technological breakthroughs with new battery chemistries such as lithium-air would allow BEVs to attain a range equal to ICE vehicles.

Regarding the production issues, there are some other works saying battery development is faster than our expectation and this is due to the huge recent market transformation for batteries. For example, Witkin (2011) argued that the battery will still have enough capacity for other purposes, and will therefore maintain some level of value. Second-life uses could be telecommunications back-up power storage, transmission support, and residential and commercial load following to help enable distributed generation from renewable sources (Cready et al., 2003).

Like other technologies, cars do not develop alone. Infrastructure (charging stations, battery swap stations, etc.) is another important factor which heavily influenced the adoption of eco-friendly vehicles. The supportive backbone for the gasoline vehicles has evolved over the past century in conjunction with the car itself, and this supportive system cannot easily be remodeled or replaced. In fact, ICE's main infrastructure, which is roads, existed even before the invention of the vehicle. Studies like Dow et al. (2010), DeForest et al. (2009), Hadley and Tsevotka (2008), and Kintner-Meyer et al. (2007) studied pros and cons of charging facilities and explained the importance of smart grid technology to adjust increasing electricity demand. There are some other influential works such as Narich et al. (2011) and Becker et al. (2009) that investigated the role of private partnership and business remodeling in the quick development of infrastructure. Meanwhile, Ralston and Nigro (2011) concluded that regulations and governmental policies play a more important role in the infrastructure development. In addition to the importance of battery advancement as a solution for EV drivers range anxiety, Tran et al. (2012) suggested that range anxiety is mitigated by charging opportunity rather than longer-range vehicle capability. People are not willing to adopt Alternative Fuel Vehicles (AFVs) until adequate charging infrastructure is in place. In contrast, it is rather interesting that in a controversial study, Nansai et al. (2001) found out that the development of the charging infrastructure almost did not change the advantage of EV compared to gasoline vehicle in terms of CO_2 emissions. Consistent with the above finding, Koyanagi and Uriu (1998) found out that electric vehicles are effective for load leveling under some sort of market regulations. If there is no regulation in the EV market, power shortage will occur on both nighttime and daytime because of the concentration of the nighttime charge and the quick charge. In conclusion, some technology scholars, such as Berman (2009) and Hermance and Sasaki (1998), argued that Hybrid technology is like a bridge to revolutionary EV technology. In other words, Hybrids are believed to be a transitive and less infrastructure intensive technology than EVs.

The Energy economy of eco-friendly vehicles versus conventional ones has also been studied by economists. Studies like Lidicker et al. (2010), Husain (2003), and Suzuki & Taylor (2009) investigated the fuel economy of ICEs and compared them with the electricity economy of EVs. Granovskii et al. (2006) wrote that hybrid and electric cars exhibit advantages over the other types [ICEs]. The economic efficiency and environmental impact of electric car use depends substantially on the source of the electricity. If the electricity comes from renewable energy sources, the electric car is advantageous compared to the hybrid. If the electricity comes from fossil fuels, the electric car remains competitive only if the electricity is generated on board (Ibid).

The process of energy transmission from the basic primitive source to the vehicle wheels could be characterized by an efficiency chain. As far as the energy efficiency is concerned, studies such as Barkenbus (2010), Maxwell (2001), and Mees (2000) discuss that while the society takes the energy for granted and drivers' behavior and concern over the air pollution and environment stay the same, vehicles efficiency improvement won't be influential. Meanwhile, Keirstead (2007) found that people's awareness of energy issues is changing. The efficiency chain for an electric vehicle is much longer than for ICE vehicles, but the total energy conversion efficiency is similar in both cases: 15–19% for ICE vehicles and 14–20% for EV, but if 10% of the total number of vehicles had an electric drive, the CO2 emission would decrease by 60 million tons per year and if all vehicles had an electric drive CO2 emission would decrease by half (Husain, 2003). Christensen et al. (2012) also emphasized that the implementation of electric cars can potentially improve the efficiency of the energy system and improve the economy of renewable energy sources such as wind power.

In general, most of the academic works on the environmental issues found a direct relationship between vehicle electrification and green house gas emission reduction. Saber and Venayagamoorthy (2011), Peterson et al. (2011), and Kammen et al. (2008) found the positive impact of the passenger cars electrification on the CO2 emission reduction. Matsuhashi et al. (2000), and Doucette and McCulloch (2011) have investigated the CO2 emission of different vehicle types and modulated the results. While, Elgowainy et al. (2009) has focused on the cost parity and CO2 emission comparison of different energy types, and he has found that a change in energy mix for electricity generation affects the rate of CO2 emission.

Changes in governmental policies, laws and regulations concerning the auto industry may also have a major impact on the economy. Especially, governments' impact through legislation and regulation cannot be underestimated. Feng and Figliozzi (2012) indicated that the fast rate of commercial vehicle activity growth over the last decades and the higher impact of conventional commercial vehicles externalities (e.g. congestion, noise, and pollution) are resulting in stricter government regulation in dense urban areas. One example is the case of California Air Resources Board (CARB), which from 1990, have affected eco-friendly vehicles acceptance and shaped a new market direction. Limiting the fossil-fueled alternatives could be an effective policy tool in fostering the commercialization of electric vehicles (Yang, 2010). Broadly defined, promoting EVs won't be successful in sales unless legal restrictions on the use of gasoline-fueled vehicles enacted.

It should be mentioned that policy scholars have different opinions toward the current political system and standards in favor of future promotion of eco-friendly vehicles. For example, Brown et al. (2010) stated that the current standards which guide the implementation of electrical transmission infrastructure will be adequate. While, Struben and Sterman (2008), and Sood et al. (2009) suggested that the current standards do not allow the implementation of future applications and increase uncertainty and inhibit investment. As far as governmental subsidies are concerned, according to Delloite's (2009) report, subsidies have a positive impact on the enormous spread of EVs, while others believe the opposite. Tran et al. (2012) wrote subsidies are not sustainable over the long term for inducing mass adoption. Forbes in 2010 reported that subsidies play an important role for eco-friendly vehicles acceptance in China and east Europe.

Some studies investigated the negative effects of electrification in the transportation fleet. For example, Mees (2000) and Whitelegg (1997) stated that while EVs may produce zero local emissions and be quieter than traditional motor cars, they still can do little to mitigate other negative effects such as road accidents, community disruption or social inequity. According to World Bank (2001), the vast majority of our electricity production requires the use of fossil resources. Critiques of EVs also say that EVs charged from the electric grid transfer CO2 emissions from the transport sector into the energy sector. Transferring emissions from the transport sector into the energy sector means that the energy sector is forced to implement further energy savings or increase the share of renewable energy sources in order to provide the needed electricity without exceeding the emission cap (Christensen et al., 2012). Some other works also referred to "Range Anxiety" as one of the burdens that accompanies any EV. Tate et al. (2008) defined range anxiety as a continual concern and fear of being stranded with a discharged battery in a limited range vehicle. Another concern is that EVs are believed to be a threat to the stability of the National Grid. A report to the Climate Change Committee shows how the predicted uptake of EVs in the UK could indeed be a threat to the stability of the National Grid (Element Energy, 2009). Table 1 shows the literature orientation among researchers of eco-friendly vehicles, especially the main topics that were covered in this chapter.

Table 1.,
Literature orientation among the researchers

item	research
Climate & Green house issues, CO2 emission, Health issue	OECD (2003), OECD (2010), USEPA (2011), Bigazzi and Figliozzi (2012), Saber and Venayagamoorthy (2011), Peterson et al. (2011), Kammen et al. (2008), Matsuhashi et al. (2000), Doucette and McCulloch (2011), Elgowainy et al. (2009), Christensen et al. (2012)
Energy issues, Fuel economy	Aftabuzzaman and Mazloumi (2011), Musardo et al. (2005), Granovskii et al. (2006), World Energy Outlook (2012), Beise and Rennings (2005), Lidicker et al. (2010), Husain (2003), Suzuki & Taylor (2009), Barkenbus (2010), Maxwell (2001), Mees (2000), Keirstead (2007), Christensen et al. (2012)
Battery hindrance	Chan (2002), Martin (2011), Teratani et al. (2008), Unnewehr and Nasar (1982), Jungst (2001), Kuhn et al. (2005), Juda (2011), Oweis et al. (1999), Boschert (2006), Greene and Plotkin (2011), Witkin (2011), Cready et al. (2003)
Design, technology, innovation	Itazaki (1999), Williander (2007), Hodkinson and Fenton (2001), Moreno (2006), Chwei-sen (2005), Klouz et al. (2002), Chan and Chau (2001), Hori et al. (1998), Powell et al. (1995), Callon (1989), Cowan and Hulten (1996), Hodkinson and Fenton (2001), Miller (2010), Erjavec (2012), Berman (2009), Hermance and Sasaki (1998)
Economics, forecasting	Shepherd et al. (2012), Kwon (2005), Tran et al. (2012), Feng and Figliozzi (2012), Utterback and Suárez (1993), Tran et al. (2012), Brown et al. (2010), Aoki (2010), Accenture (2011), Kintner-Meyer et al. (2007)
Infrastructure	Kohler et al. (2010), Meyer and Winebrake (2009), Dow et al. (2010), DeForest et al. (2009), Hadley and Tsevotka (2008), Kintner-Meyer et al. (2007), Narich et al. (2011), Becker et al. (2009), Koyanagi and Uriu (1998)
Regulations, Policies	Walther et al. (2010), Pohl and Yarime (2012), Ahman (2006), Ralston and Nigro (2011), Feng and Figliozzi (2012), Yang (2010), Brown et al. (2010), Struben and Sterman (2008). Sood et al. (2009)
EV and HEV history	Pohl and Yarime (2012), Kirsch (2000), Scharff (1992), Hoyer (2008), Teratani et al. (2008), Georgano (1985), Dreyer (2009), Domm (2009), Stein (1967)
Negative impacts	Mesken et al.(2008), Tate et al. (2008)

Based on the past theoretical studies, we can explain why companies like Toyota and Honda pursued HEVs, while other companies like Nissan and Mitsubishi pursued EVs. The main issues addressed by this research are closely aligned with a branch of theories on Technology and Innovation called "Path Dependence" concept and "Resource based theory of competitive advantage”. Therefore, a theoretical review on these concepts will be presented. Also, at the end of this chapter, a section is dedicated to “Technological decision making”. Overlapping decision making literature with technological studies will help us understand how technological decisions are being made and what factors could shape them.

3.2. Path Dependence and technological lock-in

The economic concept of Path Dependence explains how the set of decisions one faces for any given circumstance is limited by the decisions one has made in the past, even though past circumstances may no longer be relevant (Praeger, 2007). In a short term, “History matters”. Path Dependence is a very powerful perspective being employed increasingly to explain the emergence of innovations.

The root of Path Dependence can be traced to Paul David’s (1985) explanation of the evolution of the typewriter keyboard. He explained that users solved the problem of jamming typewriter keys by using the QWERTY layout. With the adoption of more advanced technologies such as the ball keyface mechanism, the typing problem disappeared, yet, users continued using the original technology, QWERTY layout. In economic development, David (1985) said that a standard that is first-to-market can become entrenched. He called this "path dependence" concept and said that inferior standards can persist simply because of the legacy they have built. This could be a reason why Toyota executives wanted to be the first who market Prius Hybrid.

Path Dependence has been effectively used at different levels of economic analysis. Path-dependent economy features the range from small-scale technical standards to large-scale organizations and patterns of economic development. At the individual level, it points that decision making and learning tend to be path dependent as soon as decisions are taken sequentially over time, reflect uncertainty or imperfect information, depend on local interactions, and even more so if one accepts that preferences are endogenous in the first place (Aversi et al, 1999). At the technological level, path dependence is a historical persistence to lock in particular choices affected by technological, strategic and soft assets. A famous example, out of many, of lock in into a suboptimal technology is the QWERTY keyboard supported by the path-dependent reproduction of users' skills (David, 1985). Organizational path dependence has been linked to various factors that explain persistence of organizational choices and that emphasize the importance that past events bear for the future orientation of organizations (e.g. Sydow, et al., 2009). Table 2 shows the literature orientation among researchers of Path Dependence, as well as initiators of the talk before the concept was proposed.

For example, Farrell and Saloner (1985) investigated the standardization and the feasibility of getting trapped in an obsolete or inferior standard, when there is a better alternative available. In a timeless model, they proposed that in an incomplete presence of information, this can occur. Later in 1986, they revised their model and emphasized on the role early adopters play. Farrell and Saloner (1986) discussed that even with the presence of complete information, there can be excess inertia. Nelson and Winter (1982) reviewed the concept of choice in the companies. In page 70 of their famous book "*An Evolutionary Theory of Economic Change*", they wrote that there is a sense in which the objectives of an organization are a 'path-dependent' historical phenomenon. Even if the underlying motivational picture is constant and starkly drawn--such as 'We are in business to make money'--the delineation of objectives in terms sufficiently precise to inform choice is ordinarily deferred to an actual choice situation (Ibid).

Cohen (1984) provided an economic explanation for technological change with the focus on the importance of the process. He further concluded that industrial innovations couldn't be only explained by the general economic incentives, but the historical process that yields technological change also needs to be understood. In this sense, rather than initial demands, the different structure of demand through time, could alter the patterns of innovation and technological changes (see Cohen, 1984).

Table 2.,
Literature Review on Path Dependence

items	Source of literature
Positive and Negative externalities	Farrell and Saloner (1985, 1986); Arthur (1988, 1994); Katz and Shapiro (1985);
Organizations	Cyert and March (1963); Nelson and Winter (1982); Powell and DiMaggio (1991); Stinchcomb (1965); Hannan and Freeman (1977); Baum and Singh (1994); Sastry (1977)
Institutional theories	North (1990); Whitley (1992); Karnoe et al. (1999)
Technological trajectories	Dosi (1982); Hughes (1983)
Market	Liebowitz and Margolis (1990, 1999)
Processes	David (1985, 1987); Puffert (2010); Page (2006), Freeman (2011), Jackson and Kollman (2012), Cohen (1984)

Later, Brian Arthur (1989) introduced "lock-in by historical events". The lock-in in path dependence is a lock-in to something bad, or at least a lock-out of something better. It constitutes an inferior economic outcome such as an inferior standard or product where superior alternatives exist, are known, and where the costs of switching are not high.

David (1985, 1987) and Puffert (2010) specified three conditions which may work together to give rise to the processes of path dependent technological change: first, the technical interrelatedness of system components; second, quasi-irreversibility of investment (durability of capital equipment or more generally, switching costs); and third, positive externalities or increasing returns to scale. A dynamic process generates increasing returns if an outcome of any type in period t increases the probability of generating that outcome in the next period (Page, 2006). These conditions lead agents to coordinate their choices and also lend persistence to the resulting allocation. Brian Arthur (1989, 1990, 1994) stated that positive externalities could appear in the demand or supply side of the market.

Path Dependence at least in its extreme form is all about getting locked-in to an inefficient design essentially (not necessarily with a lower profit margin), because there are some kinds of switching costs to move out, or innovation along the way that is localized and so focused on the existing (inefficient) design which makes it even harder or more costly to switch later on. But of course, even if an efficient design is chosen at the time of adoption, and later it became inefficient for some reason (arrival of a better alternative, change in conditions, etc), there might still be switching costs to shift to the new design. Would a technology researcher also call that path dependence? What a technology researcher needs to think about is whether path dependence is really about anything more than just switching costs. And no matter what case studies are investigated, he should be asking himself that question. In this way, cognitional conclusion of the researcher has a bold role.

Even if we acknowledge the benefits of adopting the Path Dependence concept, there are some controversies debated in the literature, mainly from Liebowitz and Margolis (1999). They argued over the importance of the information gained prior to advancements and market inefficiencies to fulfill such tasks. They divided the concept into three different degrees, First, Second and Third degree Path Dependence. First degree Path Dependence: When an initial action puts us on a path that cannot be left without some cost, but that path happens to be optimal (although not necessarily uniquely optimal) (Liebowitz and Margolis, 1999). Second degree Path

Dependence: the decisions appearing efficient *ex ante* may not always appear to be efficient *ex post*. Here the inferiority of a chosen path is unknowable at the time a choice is made, but we later recognize that some alternative path would have yielded greater wealth. They lead to outcomes that are regrettable and costly to change. They are not, however, inefficient in any meaningful sense (Ibid). Third degree Path Dependence: it leads to an outcome that is inefficient, but in this case the outcome is remediable (Ibid).

Indeed, there are some merits to Liebowitz and Margolis' arguments. However, this debate has become faded in this controversy as the main concept has much to offer. It should be noted that we do not agree that Path Dependence always generates inefficient outcomes, as many have already shown (e.g. Liebowitz and Margolis, 1990, 1995a, 1995b, 1998). Recently, there has been a new argument in the literature that without a proper measurement, Path Dependent processes have turned into an ambitious term. Jackson and Kollman (2012) wrote too often the precise specification of the process by which these historical events remain important is not defined. Freeman (2011) also wrote we do not know how (if) path dependence is manifest in data and studies provide little guidance about how (if) certain statistical results connote path dependence. In this study, we will make an effort to measure Path Dependent processes by using the historical patent data.

While Path dependence viewed as one watching the rearview mirror and driving forward, Entrepreneurs need "Path Creation" to escape lock-in. Based on Garud and Karnoe (2012), Path Creation is a remedy that gives weight to the processes that are involved in the creation of new states. Simply said, an agent assumes all the probable options and sets a new path or more in parallel for the future. Path Creation declines the switching costs by allowing entrepreneurs to deviate easier from the existing strategies, and span between relevant structures. In Path Creation history matters too, but entrepreneurs use the history to shape the future and offer their strategic interpretations. We will show that Toyota and Honda's eco-friendly vehicle development was Path Dependent, but later, they shifted to Path Creation using huge R&D investments and intensive Patenting on both EV and HEV core technologies. Table 3 shows the literature orientation among researchers of Path Creation, as well as initiators of the talk.

Table 3.,
Literature Review on Path Creation

items	Source of literature
Entrepreneurs role	Blumer (1969); Garud and Nayyar (1994); Garud and Rappa (1994); Rosenberg (1994); Weick (1979a, 1979b); March (1991a); Law (1992); Latour (1987); Dierickx and Cool (1989); Nonaka (1994)
Social practices and agents	Christensen (1997); Giddens (1984); March (1994); Callon (1986); Teece (1987); Bijker et al. (1987); Karnoe and Garud (1998); Dougherty (1992); Pinch and Bijker (1987)
Market role	Kirzner (1992); Schutz (1973); Koppl and Langlois (1994); Ventresca and Porac (2000)
Technological structures	Molina (1999); Hughes (1983); Callon (1992); Bijker et al. (1987); Brown and Duguid (1991); Giddens (1979, 1984), Callon and Law (1997)

3.3. Resource based theory of competitive advantage

A firm's ability to earn a rate of profit in excess of its cost of capital depends upon two factors: the attractiveness of the industry in which it is located, and its establishment of competitive advantage over rivals (Grant, 1991). As proposed by Grant (1991), Resource based theory of competitive advantage focuses on the link between the organization's internal resources and the strategic choice of the firm toward the technology. Resources are inputs into the production process- they are the basic units of analysis (Ibid). Patents, finance, process technology, etc are examples of a firm's main resources. The process of resource accumulation can sustain competitive advantage (Dierickx and Cool, 1989). We will show in chapter 8 that companies like Toyota and Honda started a huge patenting (HEV core resource accumulation) to protect their competitive advantage in the market. Figure 9 shows Grant's (1991) proposed practical framework of the Resource based approach. The main task of this approach is to assist strategic choice toward the technology. In this regard, the first step is to identify and classify the firm's resources. It is to provide a picture of the firm's strategic base and find out how strong the company can compete in the market. Then, the relationship between the resources and intended capabilities must be investigated. This investigation can also help to trace the roots of any lock-in, as a biased resources' portfolio can bias the company's capabilities. The next step is to assess the capabilities relative to the next technological choice and those of competitors.

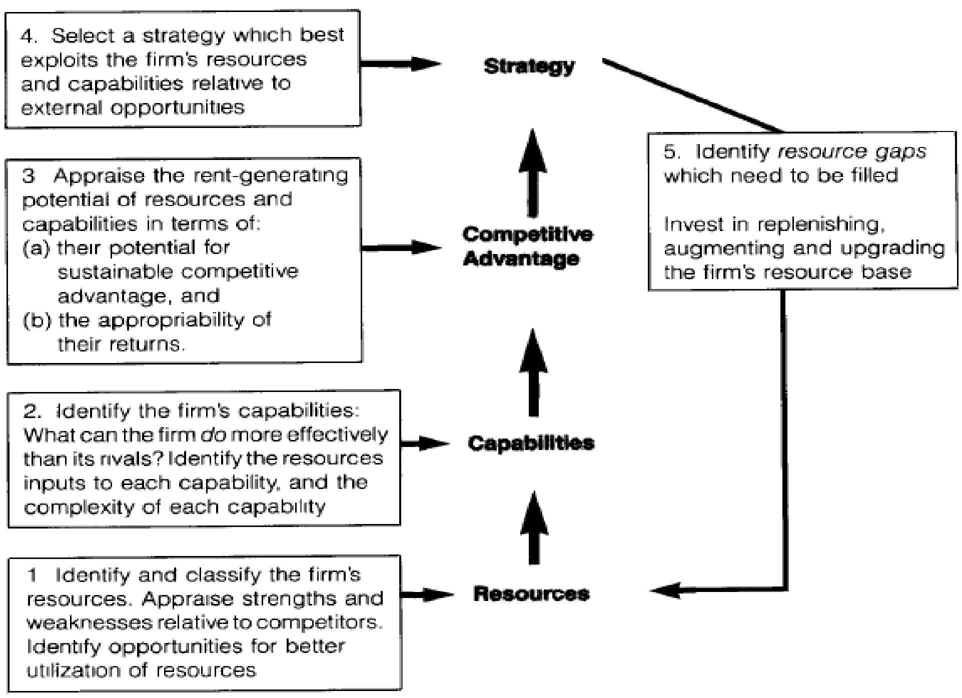


Figure 1., Practical framework of resource based approach (Grant, 1991)

As far as formulating strategy is concerned, the firm's most important path is to exploit resources that are durable, difficult to identify and understand, under the firm's clear ownership, and not transferable and replicable (e.g. Grant, 1991). Grant (1991, pp. 130) warns designing strategy only around the most critically owned resources could limit the firms strategic scope to those activities where it possesses a clear competitive advantage. The final step includes identifying resource gaps and extending the firm's resource base to fill the gap. We will show companies like Toyota and Honda, which later on recognized their gaps and tried to invest more on eco-friendly technology patents to fill the gap. There have been similar studies that focused on the patent accumulation and expected innovation growth. Through a business-unit level of analysis, Roper and Hewitt-Dundas (2011) investigated the casual positive role of the Knowledge stock (patents) on the innovation activities within the company. Artz et al. (2010) stated that there is widespread evidence of the positive role of firms' internal knowledge investments on innovation and business performance. Guellec and van Pottelsberghe (2004) have identified the positive impact of R&D spending on productivity growth.

Along with the Resource based view to competitive advantage, Hiroyuki Itami (1987) proposed "Dynamic Resource Fit". He states that through pursuing its present strategy, a firm develops the expertise, technology and resources required for its future strategy. Consistent with Dierickx and Cool's (1989) view on resource accumulation, Itami (1987) pointed that the strategic choice of companies makes certain changes in the asset portfolio for the future. We will show that Toyota and Honda's massive HEV technology asset was shaped by the companies' previous strategic choices. In addition, later strategic choices were shaped by former intensive HEV technology assets (HEV technology accumulation, then limited technological choice, then huge Patenting to stay competitive).

3.4. Technological decision making

Technological innovations are one of the major movers of economic growth, and finding out how they emerge and what could shape their process is important in innovation studies.

Technological decisions are being made in response to the contextual perceived threats or potential future opportunities. The competition concept strongly influences technological choices, but it is more of a struggle between different alternatives, rather than the neo-classical concept of price competition in the market. As Mokyr (1997) states, the adoption of a wholly new technology is often the target of long debates, and without an understanding of the political economy of technological change, the historical development of economic growth will remain a mystery. Technological choices are always accompanies with Inertia, but not all resistance to technological change is necessarily socially detrimental (Ibid).

Pinch & Bijker (1989) have sought to understand the choice of technology through understanding the different interpretations that various social groups attached to an artifact. In their terms, the technological decision making cannot be simply explained unless using a social constructivist analysis of technology, which necessitates not making any priori distinction among different types of social groups.

Hughes (1989) explained about the managerial decision making in technological systems. He states that because components of a technological system interact, their characteristics derive from the system. As a result, management in technological system often chooses technical components that support the structure, or organizational form, or management (Ibid). Hughes (1989) also defined *a system momentum* as a mass of technical and organizational components, goals and directions. A momentum is a driving force within or outside the company that causes the firm to become more mature and to grow. In technological decision making however, there is *a technological choice moment* which is also a driving force for the company. The difference is that the technological moment is not a continuum and it happens in a special occasion, when the company decides to choose a technology over the other alternatives. It is an emergence of the company's capabilities in the form of a technological shift.

As far as the influential forces on the technological decisions are concerned, Engelhardt and Caplan (1987) have categorized five closure factors in controversial choices. These categories are dealing with scientific controversies, but three of them are relevant to technological decision making as well. For example, to understand what contextual factors may have affected the Toyota's first electrification project's launch, it would be interesting to see whether any of these factors was effective. The first factor is "closure through loss of interest", which implies that a closure will be achieved due to participants loss of interest. The second factor is "closure through force", which occurs when an external institution imposes a regulation or law. CARB ZEA 1 in 1990 is one of the best examples that caused an obligatory force for other companies to initiate eco-friendly projects. And the third category is "closure through resolution", which occurs when an agreement is reached on the merits of participants.

As it was mentioned before, the approach in this study is a technological point of view, which means how the top management of the firms makes the technological choice, while mainly in the literature, technical features and engineering philosophy of eco-friendly vehicles are the main factors for further development. But, it should be noted that even in technological decision making, engineers have the ability to influence policies and give advices. This is the art of managerial echelon manipulation through their construction of technical wisdom. Primack and Von Hippel (1974) wrote that they [engineers] are able to filter information reaching the top management or boards and to define the range of options from which those in charge can select, being careful to present the options as that their preferred option is most attractive. That is the reason why Barnes (1985) argued that by focusing increasingly on technical issues "we are diverted from more significant and fundamental issues and even start to lose our capacity to deal with them". Meanwhile, technological decision makers are obliged not to be influenced solely by the public opinions and masses debates without paying attention to policy makers. Nelkin and Pollack (1977) stated that "thrust upon the public as if they were noncontroversial technical decisions" and without policy makers, appearing to be arrogant or undemocratic in doing so without open debate (Martin, 1977). This brings to attention the HEV technological choice in the mid-90s, when Toyota's newly elected president, Hiroshi Okuda, with a background in commercial science envisioned the future in hybrid technology, while the Toyota engineers, environmentalists and social movements believed strongly in zero emission vehicles (e.g. Itazaki, 1999).

One last issue in technological decision making is to recognize who is controlling the flow of the technology. Is it the decision maker, the technical experts or the contextual factors? In public institutions, this flow is shared between all of the entities based on the political and social power associated with them. In private sector, decision makers have more authority and influence than technical experts, while the social power still remains powerful.

4 - Historical Background

Eco-friendly vehicles as a technological option haven't been at the center of attention only in the past two decades, but also in the early twentieth century, they were one of the most popular means of transport. To understand how and why the technology had emerged and what factors influenced the emergence and stoppage of eco-friendly vehicles, it is necessary to look at the development history of subject. It will be shown that surprisingly, many of the supposedly recent ideas for further market penetration of eco-friendly vehicles came forward more than a hundred years ago.

As it was mentioned before, the history of EVs development can be divided into three parts: the early years (1890–1929), the middle years (1960–1985), and the current years (1996–present). Figure 1 shows the EV development and the historical oil price timeline. There is evidence that in the early and middle years, companies in US and Europe took a great step on EV technology improvement and EVs were available for military, industrial and private purposes; And in some cases, EVs even went a step further and made it through mass production. On the other hand, in both periods, HEVs didn't have any chance to compete against other available technologies and any known case of HEV was just for a technical test purpose or ended up with a failure. In other words, the early and middle years' pages have some evidence of HEVs presence in the market. In this regard, we will put HEVs development timeline under the same three parts of the EVs survey.

This chapter's emphasis is not merely on the historical details, but mainly on the presentation of core explanatory concepts, like the roots of technology and the reason why some of the core concepts have remained until now and some faded. The first part of this chapter deals with the historical study of the development of eco-friendly vehicles in the late 19th century and the early 20th century. The second part will review the major advancements during the World War II, as it is called a slight dominance of EVs. Also, the middle years of eco-friendly vehicles development will be reviewed. In the third part, we will discuss about the green fleet technology penetration in the recent years that started from US and Japan, and later in major countries of Europe, North and South America and Asia.

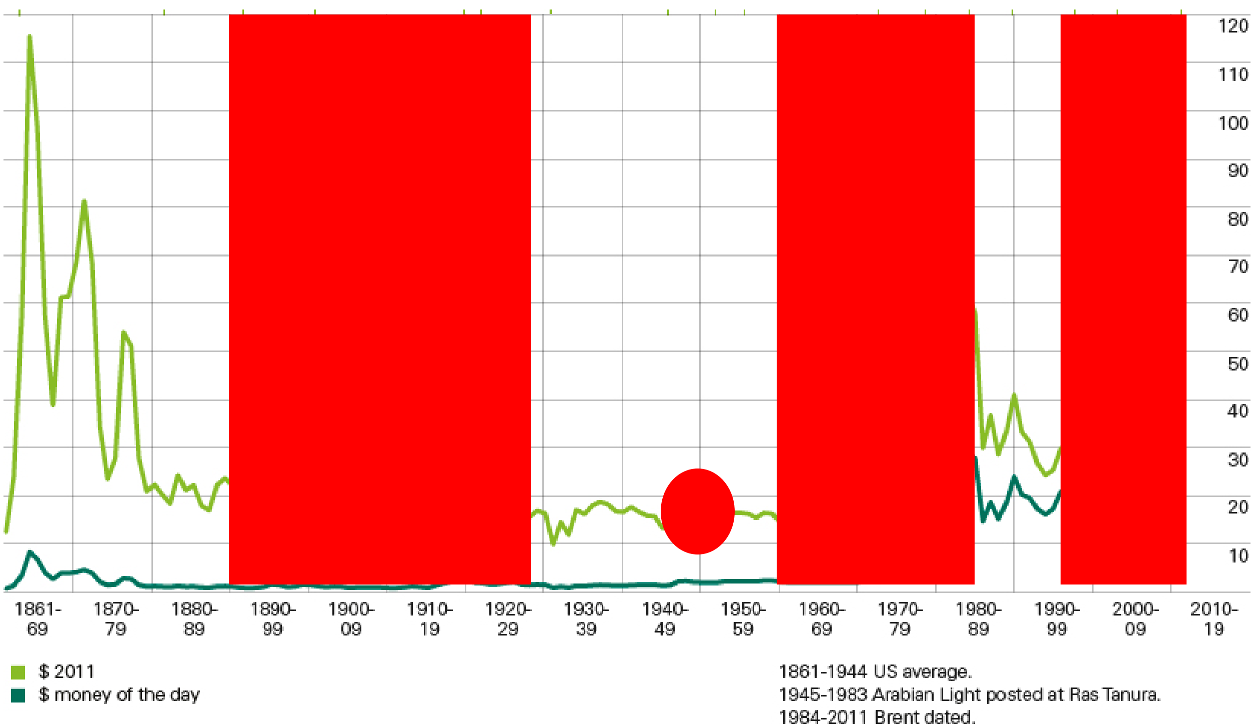


Figure 2., the EV development timeline and historical oil price (green line is based on 2011 Dollar, dark green line is price of the day) (compiled from: Energy Forum, 2011)

4.1. The Early years of eco-friendly vehicles

Some scholars believe the history of electric cars is closely related to the history of batteries (Wakefield, 1994; Sperling, 1995; Westbrook, 2001; Anderson and Anderson, 2005). In 1800, Alessandro Volta demonstrated that electric energy could be stored chemically. In 1821, the conversion of electrical energy into mechanical energy and the invention of the electric motor were demonstrated by Michael Faraday. As the first breakthrough, the first experimental electric vehicles thus appeared in the US, the UK and the Netherlands in the mid 1830s. In 1859, Gaston Plante´ made the first lead-acid battery cell. This implied the invention of the lead-acid battery which is still used as a starter battery in all Internal Combustion Engine (ICE) cars and also as a power battery in most early electric cars. Plante´ rechargeable battery furthered the development of EVs and made it possible to store higher amounts of energy, but with the cost of increased weight (e.g. Teratani et al., 2008). In 1881, the first practical electric vehicle was made by William Ayrton and John Perry, both professors at Finsbury Technical College, UK. The first commercial application of EVs was a fleet of New York taxicabs in 1897.

It should be noted that the development of early EVs, was in parallel with the development of early ICEs and Steam Engine powered vehicles. The first American ICE automobile was made in 1877 by George Selden. He applied for a patent in 1879, but the patent application expired because the vehicle was never built. After a delay of sixteen years and a series of attachments to his application, in 1895, Selden was granted a US patent (NO 549160).

In 1892, A German engineer Rudolf Diesel was granted a patent for a "New Rational Combustion Engine". In 1897, he built the first Diesel Engine (Stein, 1967). Steam cars were available longer before any other vehicle. They were on the road from the early 19th century as the carriage, but with the emergence of ICEs, their producing companies went into building gasoline cars or stopped the production. This argument suggests that in the early 20th century, there was a win-lose competition between the three popular technologies: electricity, gasoline and steam powered automobiles.

At the outset, the general perception of EVs was that it had many benefits compared to gasoline and steam powered cars. It was free of vibration, clean, silent, thoroughly reliable, easy to start and control (no crank or shifting required) and produced no dirt or odor. The disadvantages were short range and high initial cost. From 1980 to 1905, EV manufacturers had the most exhibitions. For example, the 1893 World Exhibition in Chicago featured six types of electric cars. Famous scientists such as Nicola Tesla and Thomas Edison, also known companies like JP Morgan, General Electric, Westing House, and Brush were participated. Figure 2 shows a rare ad of the Chicago exhibition, which drew the attention of American companies to EVs.

Figure 3. Chicago World Fair advertisement in 1983 (Source: Appelbaum, 2009)

Before 1900, Taxi fleets in major cities such as London, Los Angeles, Chicago, New York and Paris were candidates to thrive of this business. But, of all of those, only US companies made it as a commercial product. The original idea of battery swapping appeared then. The taxi companies maintained the batteries in their garages and the daily distances travelled by the cabs were well within the battery range. The taxi drivers themselves were reported to be very enthusiastic about these new cars, firstly called “horseless carriages” only soon later to be called “automobiles”, a term first used by a London newspaper in 1895 (Hoyer, 2008).

From 1900 to 1915, Electric vehicles outsold all other types of cars in America. In 1900, between a total of 4200 sold cars in the USA was 38% of electric vehicles (Juda, 2011). As Westbrook (2001) explains, during the "Golden Ages" of EVs, which was from 1895 to 1915, a wide variety of models were built and the most commercialization was done. As it was mentioned before, in early the 1900s, three types of cars were contesting for market control: electric, steam and gasoline powered car. By 1900, there were about 75 factories in the USA producing 4,192 automobiles a year: 1,688 steam automobiles, 1,575 electric vehicles and 929 petrol vehicles (Ulrich, 2011). Figure 3 shows an example ad of dominant automobile technologies in 1904. For about fifteen years, this technologic competition for higher market share was continued.

By 1912, 40% of American automobiles were powered by steam, 38% by electricity, and 22% by gasoline (Britannica). In 1912, the peak was reached in the USA with about 34,000 electric vehicles (Ibid). It is rather interesting to know that United States automobile production reached 44,000 in 1907, while as for total registered vehicles, by 1913, the United States accounted for some 485,000 units out of the world production of 606,124 motor vehicles (e.g. Flink, 1982). Eventually, the expense of running an electric vehicle vs. a gas-powered car became a decisive blow to the EV. As the 1920s approached, it was pretty much the end of steam and electricity as viable sources. From 1915 to 1929, the Golden Age of EV started to vanish, and over a period of ten to fifteen years, all of major EV producers went bankrupt or stopped production. In 1924, 391 electric vehicles were produced in the US, compared with 3,185,490 gasoline cars (Cowan and Hulten, 1996).

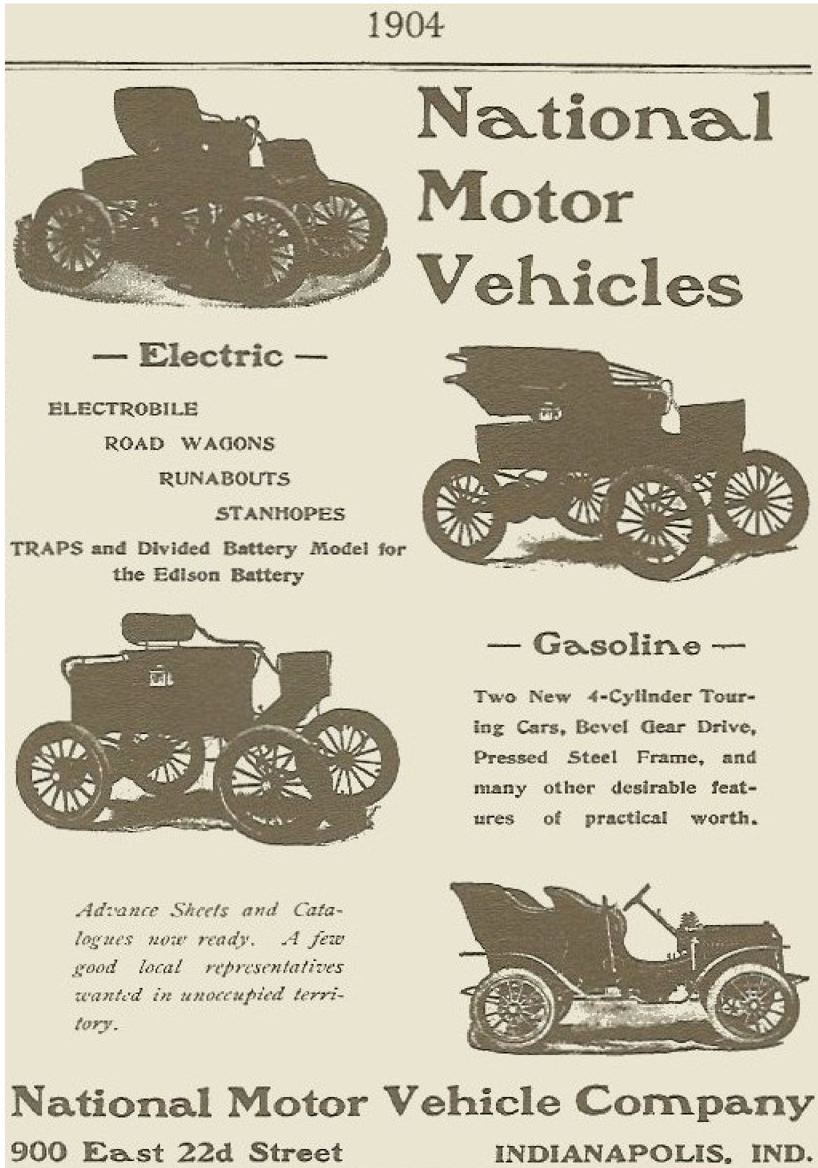


Figure 4., example ad of dominant early technologies in 1900s (source: Schroeder, 1971)

Why early EVs lost in the competition against ICEs? We have found a few technological and cultural reasons for the incident. Based on the importance and the amount of influence that each of these factors had, we prioritized them.

- *Influence of Ransom Olds and his company Oldsmobile on the auto industry:*

While in the management history, Henry Ford is called as a pioneer in establishment of modern assembly lines, Ransom Olds started this idea a few years earlier and registered the first patent for assembly line in 1901. That time, other auto manufacturers were barely producing 20 units per month; by this invention he could produce 20 units per day. Olds used it to build the first mass-produced automobile, the Oldsmobile Curved Dash, beginning in 1901 (Domm, 2009). This new approach to putting together automobiles enabled him to more than quintuple his factory's output, from 425 cars in 1901 to 2,500 in 1902 (Redgap, 2007). Figure 4 compares the two popular production methods back then, craftsmen and assembly line.

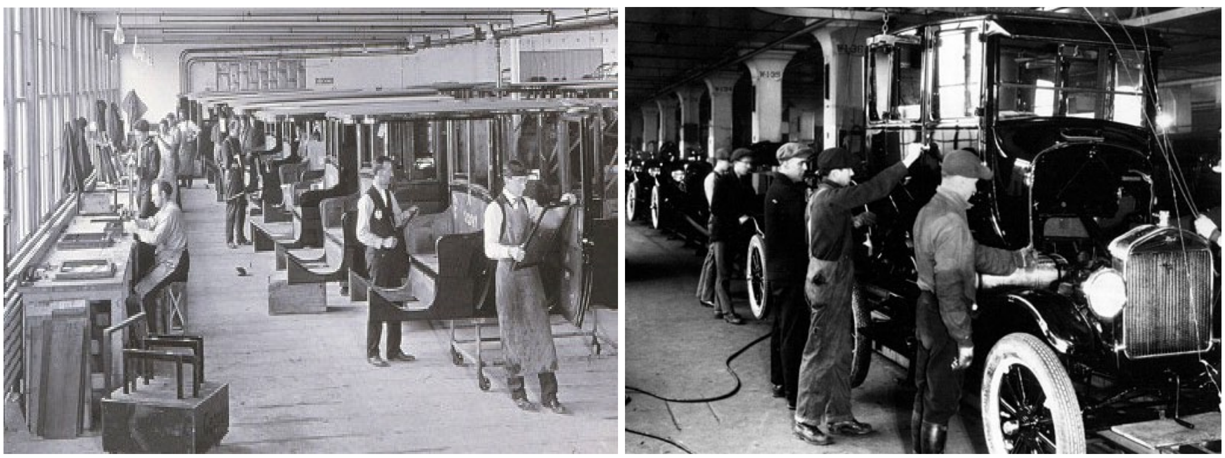


Figure 5., Craftsmen production (left) vs. Modern assembly line (right) (source: Seward Institute, 2011; McFarlane, 2010)

Speaking of which, Oldsmobile from 1901, Ford from 1908, and General Motors from 1908~1912 established modern assembly lines for producing ICVs, while EV factories remained as craftsmen. Olds also had another influence on the auto industry and that was the improvement of design and technology of automobiles. Gasoline vehicles at the beginning of 20th century, started to have more superior design and technology over the EVs. Before 1901, any manufactured automobile had a design similar to 19th century horse powered carriages. While Olds redesigned his gasoline vehicles with a new style, EVs kept their previous carriage design.

Figure 5 compares a simple carriage with some of the popular EVs in the early 20th century[2]. Michael Schiffer (1994) in his book “Taking charge: the electric automobile in America” stated that the gasoline motors went farther and faster than electric ones; they were also more reliable. Figure 6 shows the popular design of Gasoline vehicles in the 1900s (comparing to Figure 5).

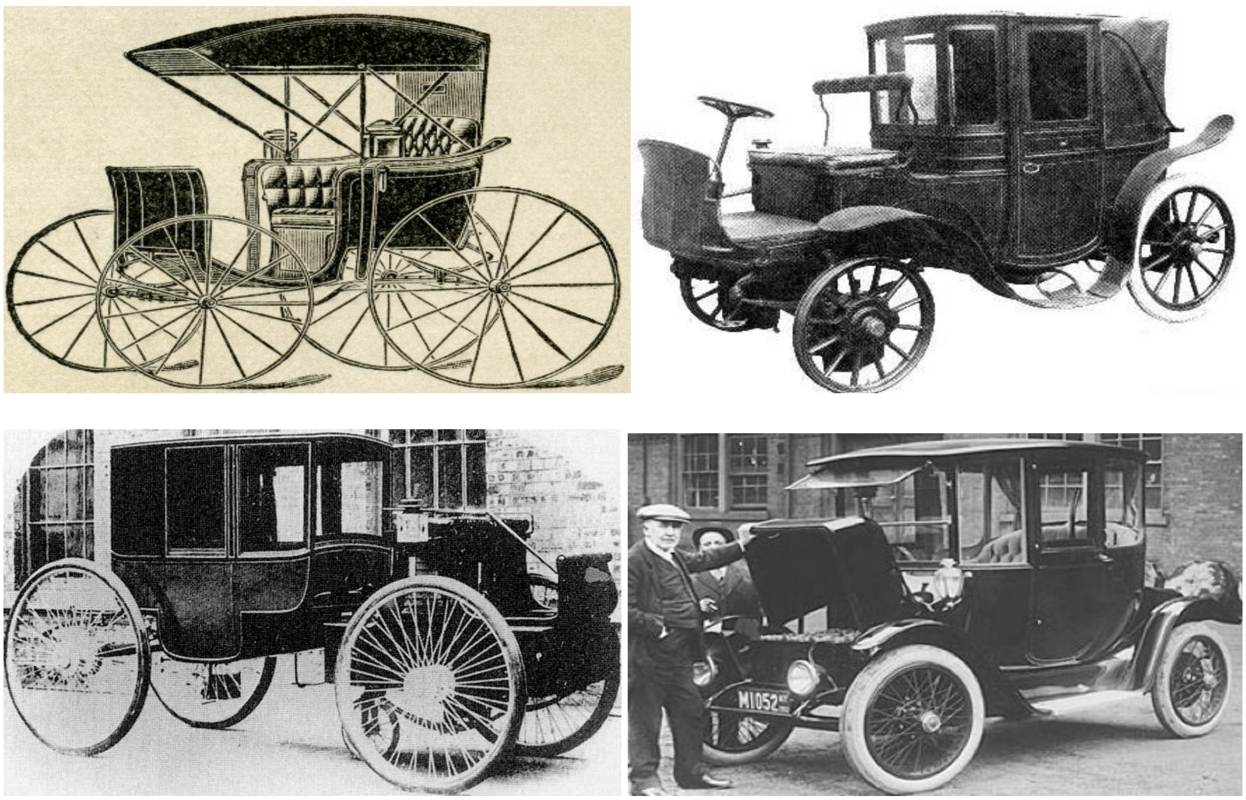


Figure 6., early EV models: Upper-left: 1904 The Columbus Carriage ad (simple carriage); Upper-right: 1897 Krieger EV; Lower-left: 1898 Madelvic EV, Lower-right: 1900 Circa EV (compiled from: The Delineator magazine, 1904; Didik, 2001; Gracie, 2003; Saidani, 2011)

- *Influence of Henry Ford and Alfred Sloan on the price and affordability of ICEs:*

Henry Ford‘s, founder of Ford Motor Company, mass production of gasoline cars made them cheaper and affordable for the society. In spite of being a pioneer in the modern vehicle

2 A very great collection of early EV designs can be found at http://louderfunier.blogspot.jp/2009/01/electric-cars-of-1800s.html

assembly line, production of Oldsmobile is not comparable with Ford, which his addition of the conveyor is what is used today and made him credited for invention. Due to Ford's mass production system, in 1912, an electric roadster sold for $1,750 (roughly $42,000 nowadays), while a gasoline car sold for less than half of that, $650 (roughly $16,000 today) (Bellis, 2006). Ford Model T, produced from 1908, is the first cause that made automobiles popular. Giving a picture of Ford Model T penetration, by 1920 an estimated three-fifths of US cars and 50 percent of all the cars in the world were Model Ts.

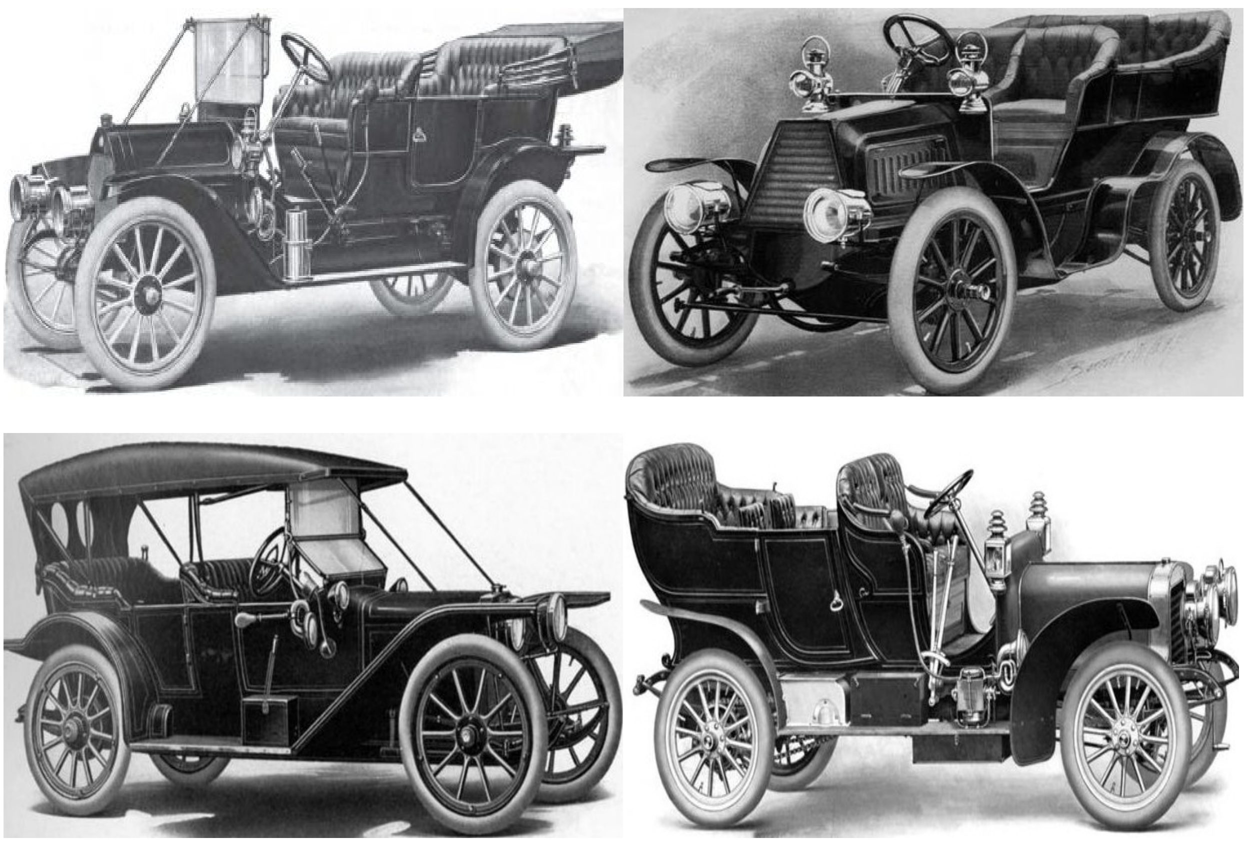


Figure 7., early ICE models: Upper-left: 1911 Oldsmobile Reo; Upper-right: 1902 Berg; Lower-left: 1905 Underslung; Lower-right: 1903 Acme Motor (compiled from: CarType, 2008; Robinson, 2011a; Robinson, 2011b; Robinson, 2011c)

The Model T runabout sold for $850 in 1908 (Ward, 1974), $575 in 1912 (less than the average annual wage in the US), and $440 in 1914 (Georgano, 1985). By 1927, its price had been reduced to $290 for the coupe, 15 million units had been sold (Flink, 1982). In order to regain the competitiveness against ICEs, the Electric Vehicle Company built 2000 taxicabs, trucks and busses in the States when Henry Ford started producing low-priced gasoline vehicles. The company failed within a few years.

It should be noted that in the early years, major EV producers such as Electric Vehicle Company (largest car manufacturer in US), didn't choose the right strategy to make EVs more affordable for the society. David Kirsh from University of Maryland stated that EVC opted to rent or lease its vehicles instead of selling them, because they assumed that the customers didn't have the know-how or facilities to maintain their own cars. EVC bankruptcy took electric cars down with it and Investors, soured by their experience with the EVC, swore they'd never put money into the industry again (e.g. Koerth-Baker, 2012).

Consistent with the Ford's efforts, Alfred Sloan, president of GM from 1923, had a huge influence in the penetration of ICEs in the society. He transformed the auto industry around the world and GM to the industrial leadership by the 1930s. Sloan's efforts are especially appreciated after the First World War (1914-18). By ending World War and anticipating a sudden increase in demand, automakers flooded the market with new cheap cars. As a result, in a few years, Sloan realized that because more Americans were becoming car owners, the market for first-time buyers was shrinking; cars were no longer novelty items (Dreyer, 2009). He started his famous price structuring with introducing different brands, such as Chevrolet, Pontiac, Oldsmobile, Buick, and Cadillac (from least to most expensive). He changed the cosmetic appearance of the car (and sometimes the technical features), consumers had incentives to buy newer models, to trade up, or add a second car to the family's garage (Ibid).

- *Huge transform in US infrastructure (Roads, Gasoline stations) and drop of oil price:*

Until 1912-14, EVs limited range did not pose major problems and range anxiety didn't exist. The Federal Aid Road Act of 1916 allocated $75 million for building roads, and the Federal Aid Highway Act of 1921 provided additional funding for road construction. By 1924 there were 31,000 miles of paved road in the US. In order to travel using these roads, cars with greater range than electric vehicles were needed. The outcome was that EVs remained as city cars, while ICEs became easier to operate.

It is useful to understand that EV manufacturers knew about the range anxiety from earlier years and there were some interesting efforts to overcome this limitation. Some may think that the ideas such as battery swapping, charging stations and regenerative braking are new ideas that came to existence in the past two decades. But surprisingly, from the late 19th century, the same solutions were proposed and used in order to overcome the range anxiety.

An exchangeable battery service was first proposed as early as 1896 (Kirsch, 2000). The idea was first put into practice by Hartford Electric Light Company through the General Vehicle Company's (GVC) battery service. The vehicle owner purchased the vehicle from GVC (a subsidiary of the General Electric Company) without a battery and the electricity was purchased from Hartford Electric through an exchangeable battery. The owner paid a variable per-mile charge and a monthly service fee to cover maintenance and storage. The service was provided between 1910 and 1924 (e.g. Hoyer, 2008; kirsch, 2000). Both EVs and exchangeable batteries were modified to make the swapping process quicker. Beginning in 1917, a similar service was operated in Chicago for owners of Milburn Light Electric cars who also could buy the vehicle without the batteries (Kirsch, 2000).

A Practical establishment of charging stations started even earlier than other solutions. Between 1895 and 1915, Grids of charging stations were established, and there were continuous discussions about the further expansion of them. In New York, around 1900, a system of charging hydrants was established, i.e. a coin-operated mechanism with both voltmeter and wattmeter. It was set up and driven by an electricity supply company. When the driver deposited the right amount of coins, he could get out the number of watt-hours needed for charging (Hoyer, 2008). However, this new infrastructure would never be able to compete with the extensive development of gasoline stations that began more or less in the same period (Ibid). Figure 7 shows an early charging station.

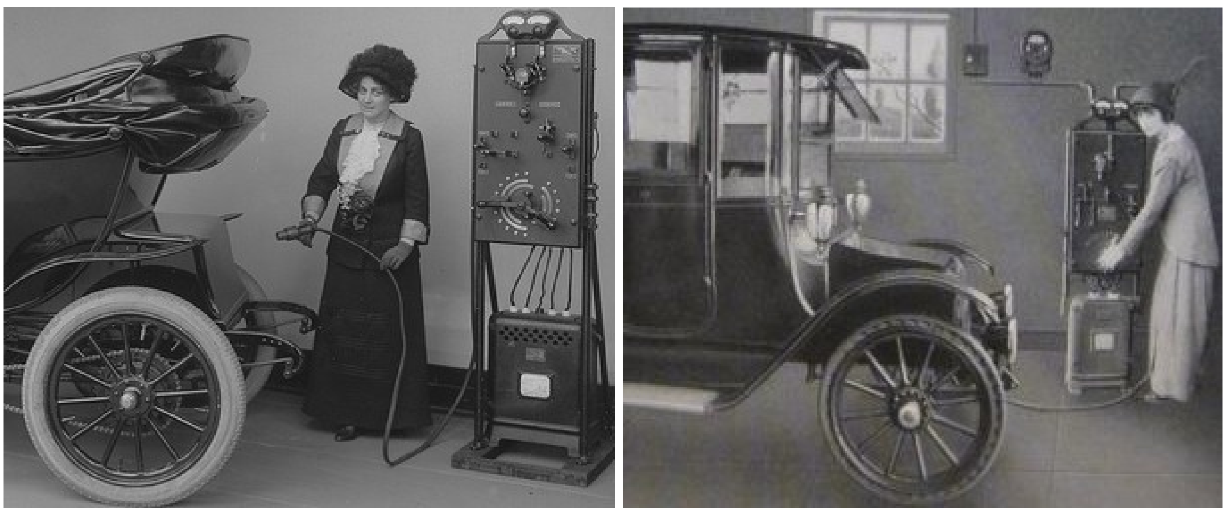


Figure 8., Early charging stations for Baker Electric EV (compiled from: General Electric Company, 1914; Thetruthaboutcars, 2012)

The principle of regenerative braking was demonstrated in Paris in 1887, an increase in car ranges up to 40%, and utilizing the ability of the electric drive motor to act as a generator charging the battery when overdriven mechanically by the vehicle wheels (Hoyer, 2008). Such regenerative braking became standard equipment in many of the models already sold in the early years (Wakefield, 1994; Westbrook, 2001).

The pace of infrastructure development for Gasoline vehicles was much faster than for Electric cars. The first filling station cropped up in St. Louis in 1905 by Automobile Gasoline Co.

Standard Oil of California (now Chevron) built its first in 1907 in Seattle. In 1914, 34 companies operated gas stations across the US. Finally by 1920, gas stations made their way across the United States and fueling up a car became as easy as buying a loaf of bread. Switching to the internal combustion engine was a no-brainer.

Another issue is the rapid discovery and spread of Oil wells from late nineteenth century, which caused Gasoline price to become cheaper and more affordable for the society. Oil has never been as costly as it was at the birth of the industry. After the Edwin Drake's first oil well in Pennsylvania in 1859, there was no problem selling at a price in 2010 dollars a little below \$500/barrel (\$20/barrel in 1859). Although Pennsylvania was the most important source of U.S. oil production in the 19th century (e.g. Hamilton, 2013), discovery of other wells in Ohio, Texas, New York, and West Virginia enlarged the production of oil from 4.2 million barrels in 1869 to 126.5 million barrels in 1906. Meanwhile, the price of oil quickly fell under \$1.5 (under \$35/barrel in 2010 dollars) in 1890s (Figure 8).

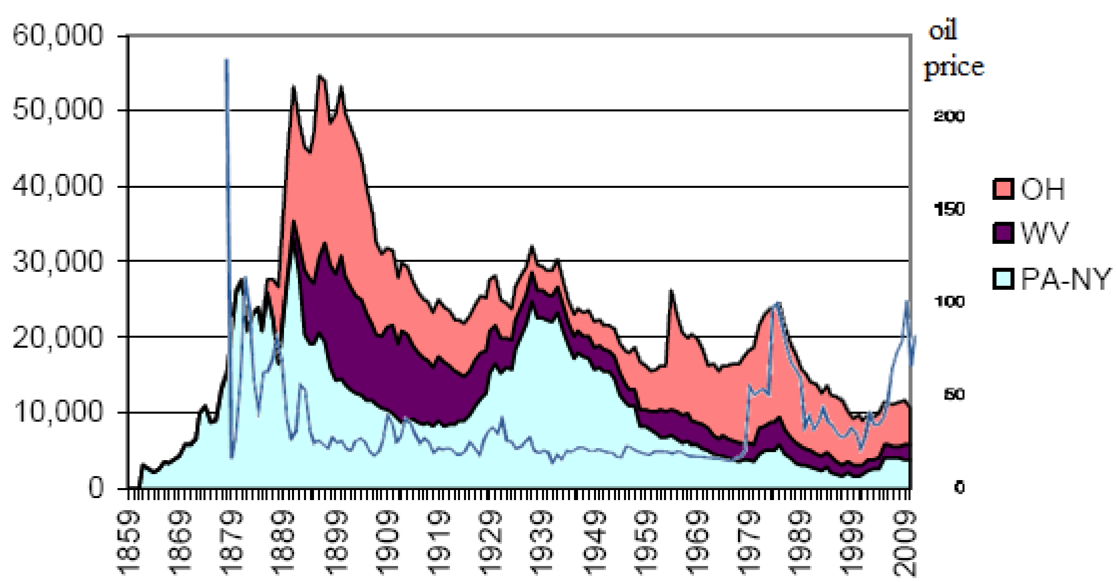


Figure 9., price of oil in 2010 dollars per barrel 1860-2010 (blue line), and combined annual crude oil production from major oil producer states in late 19th century (Pennsylvania, New York, West Virginia, and Ohio) (from Hamilton, 2013)

- *Ease of using ICEs by the invention of the electric starter:*

Another important factor which helped faster penetration of ICEs in the society was the invention of the electric starter by Charles Kettering (co-founder of Delco) in 1911. Before the invention, automobiles had to be started using a hand crank, usually located on the front of the car. The Crank required a huge amount of effort to turn and was also dangerous and not suitable for lady drivers.

From 1912, some of car companies started to use an electric starter in their models such as Cadillac, etc. Ford Model T started to use an electric starter from 1919. By 1920, most manufacturers included a starter in their vehicles. The Electric starter improved the safety and cleanness features of ICEs, which made ICEs more acceptable for ladies.

As far as the first HEV development is concerned, the notable car developer Ferdinand Porsche was one of the first inventors in this field. His gasoline-electric car was shown at the Paris Exposition in 1900. These early hybrids also included regenerative braking technologies (Hoyer, 2008). Unfortunately, Porsche didn't see any reason to continue the development of these hybrid vehicles, as gasoline became exceptionally cheap, and the extra electric motors were prohibitively expensive (Green, 2012).

In the US, the Middle Electric Car Company produced several models of Krieger Hybrid in the period 1901-06 (Krieger was produced mainly as an EV). Their four-seat hybrid (1903) had about the same weight as an electric car, but had a range similar to a petrol car. The petrol engine was placed beneath the driver seat and could be used for charging the batteries (Anderson and Anderson, 2005). In 1911, the first practical hybrid car was released by the Woods Motor Vehicle Company of Chicago. The hybrid was a commercial failure, proving to be too slow for its price, and too difficult to service (Valdes-Dapena, 2006). As one of the last efforts, in 1916, Baker of Cleveland and Woods of Chicago, offered hybrid cars. But they were more expensive and less powerful than its gasoline competition, and therefore sold poorly. As Hoyer (2008) states, hybrid cars are more costly to produce than the pure ICE cars. This is one of the reasons why they totally disappeared from the market before 1920.

4.2. From a slight dominance to Middle years of eco-friendly vehicles development

In US, from 1935 to 1960, EVs were completely disappeared and this gap is called Dead Electric Vehicles gap in the literature (e.g. Bellis, 2006b). While, due to the war [WW II] and gasoline shortage, mainly in European countries, a new attention toward EVs was given. For example, in Germany, during wartime they had about 30,000 electric vehicles running (Hoyer, 2008). In the 1950s in UK and mostly as milk vans, the fleet grew to a total of about 30,000 to come (Hoyer, 2008).

It should be noted that Japan's first experience with EVs started this time. The Tama Electric Motorcar Company of Tokyo produced a popular electric car from 1949 to 1951, a time of severe gasoline shortages in Japan. It had a range of 125 miles and a speed of 35 mph. In 1952 when gasoline became more readily available, the company began making gasoline-powered cars and changed its name to Prince (Anderson and Anderson, 2010). Later due to merger with Nissan, the car transferred to Nissan ownership. Nippon Denso also developed a concept EV called DensoGo (デンソー号) in 1950. In the literature, this short period from 1945 to 1955 is called the slight dominance of EVs.

In the 1960s, a quite new debate turned up. Rachel Carson (1963) published her book Silent Spring. This book is by many considered to represent the real advent of the modern environmental debate. As a result, for the first time the world's major car producers showed an interest in electric cars (Hoyer, 2008). Followed by the book, the first oil crisis in 1973 and the second oil crisis in 1979 led to renewed interest in alternative fuels. The western world and Japan were hit by oil crises. Within very few years, renewable energy production became an integral part not only of the public energy debates, but also of governmental energy plans. In the US, Europe and Japan, major car producers were involved in developing EVs with various drive systems and battery types. But this development never really took off (Wakefield, 1994). In other words, green vehicles took centre stage, but for the most part their futuristic designs and limited capabilities meant they failed to grasp the mainstream's interest. And at that time, the activities in electric car development once more faded out worldwide (Ibid).

All of the developed cases in the middle years were prototypes, not the practical vehicles for the real world. Concept cars appeared over the years, such as the Scottish Aviation Scamp (1965), the Enfield 8000 (1966), two electric versions of GMs gasoline cars, the Electrovair (1966), Amitron (1967), Ford Comuta EV (1967), Electrovette (1976), Electron (1977). But none of them went through mass production. Nissan of Japan also experimented with concept and prototype vehicles in the 1970s, producing the EV4P, powered by a lead-acid battery. Nissan later produced Minica EV, which it was the only mass produced EV in the world in the Middle years (about 1000 units sold to power companies). Eco-friendly vehicles development in the Middle years was a frightened reaction to environmental issues and as Hoyer (2008) states, they weren't very impressive figures compared to the models produced some sixty years before. Generally, the 1960s only demonstrated the difficulties in developing electric cars with acceptable ranges, driving performances and, not least, costs (Westbrook, 2001).

In the middle years of eco-friendly vehicles development, HEV production wasn't a part of the auto manufacturers' policy. There are a few cases, but all of them were experiments and not for the real production such as GM 512 (1969), VW taxi hybrid (1973), Briggs and Stratton hybrid (1980), and Audi Duo (1989). The first Japanese car companies experience with Hybrid technology was in the 1970s, as Nissan made a variation of a battery-hybrid vehicle known as the EV4H, which combined lead-acid with zinc-air batteries. Meanwhile, in 1976, Toyota made its first hybrid vehicle Sports 800 gas turbine hybrid.

4.3. The current years of eco-friendly vehicles development

The current race to develop and produce eco-friendly vehicles spurred mainly by government incentives in US and market need in Japan. Environmental issues brought renewed interest in air quality and the impact of pollution from the internal combustion engine on the environment, resulting in legislation such as the Clean Air Act in 1990, California Air Resources Board (CARB) regulations in 1990, and the Energy Act in 1992. In 1990, California Air Resources Board (CARB) with a goal of promoting cleaner automobiles in the society depicted a set of regulations that forced manufacturers to sell a certain number of zero emission vehicles (battery powered vehicles only) in the state by 1998 or incur severe monetary penalties. As result, it prompted main Japanese and US car companies to revisit HEVs and EVs as a means to support a potential market of environmentally conscious American buyers, and meet regulations for automotive fuel consumption. In contrast to US regulations, Pohl and Yarime (2012) stated that the Japanese national policy has so far had a limited direct role in the electrification of vehicles; and this achievement has been very largely decided and carried out in-house at the automakers.

From 1996, manufacturers have shown a serious interest in fleet electrification and companies like Toyota and Honda, filled the market with different hybrid models, but EV penetration has been up and down. EV penetration from 1996 can be divided into two parts: The first (1996 - 2003) and the second (2008 - present) waves of EV development. From 2003 to 2008, while, major car companied halted their EV production and pulled out the previous models from the market, HEV activities intensified. From 2008 again, EVs came back to the market, but this time with more support and technological advancements.

From 1996, there have been more than a hundred different models of EVs, but most of them as prototype or test model and barely a few made it through a successful mass production. As we will discuss this trend in detail in the case studies chapters, companies like Toyota and Honda structured their main policy based on the HEV production and until recently, they didn't consider EVs as a practical solution for the current situation. In contrast, companies like Nissan and Mitsubishi started their environmental policies with focus on EV development and they didn't considered HEVs as a viable solution for environment.

In summary, until recently HEVs and EVs have never been able to compete with conventional cars, but the introduction of Prius Hybrid I and later Insight Hybrid I in late 90s, has changed the situation. It is interesting to see when green vehicles lost the competition against ICEs in early twenty century, why have they emerged again and how can they survive? And is it a repeating history which dooms eco-friendly vehicles to fail again?

5 - Methodology

In the introduction chapter, a detailed explanation of qualitative data gathering plus a brief explanation on quantitative data gathering were presented. In this chapter, while reviewing the first part, a thorough explanation of the statistical patent analysis will be presented.

From the data gathering and goal aspects, this research is a Mixed Method study. Mixing qualitative and quantitative researches is a major methodological movement across the social science and many researchers view it as a third approach to research, alongside qualitative and quantitative research (Johnson and Onwuegbuzie, 2004; Tashakkori and Teddlie, 1998). In this approach, the researcher decides to combine or blend both qualitative and quantitative methods, because the methods together result in a better understanding of the problem being researched. For example, the researcher can examine statistical results, along with in-depth or semi-structured perspectives to obtain stronger trends. There are many reasons that researchers choose to use mixed methods in their research studies. One of the mixed approach applications in social science is explanatory design. The explanatory design is a two-phase mixed method design in which the quantitative and qualitative methods are implemented in a sequence (Figure 10). This thesis's design starts with the collection and analysis of mainly qualitative data. This qualitative phase is then followed by the subsequent collection and analysis of quantitative data in a second phase. Based on Hesse-Biber and Leavy (2008), each phase of the study is designed so that it follows from, or is connected to, the results of the initial phase. For an example, the researcher can examine statistical results, the company's financial reports, market sales, and librarian documents, along with in-depth or semi-structured interviews, and qualitative perspectives to obtain stronger insights.

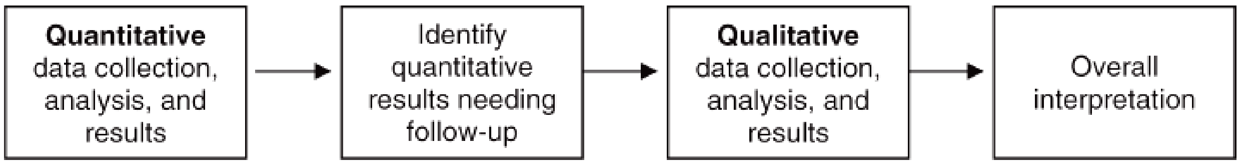


Figure 10., Explanatory design (Creswell and Plano Clark, 2007).

A two level data gathering for the analysis section was conducted starting with the qualitative case study analysis. As Gerring (2004) noted, the case study is probably best understood as an ideal type rather than a method with hard-and-fast rules. Case studies can either involve single or multiple cases, and numerous levels of analysis (Yin, 1984). Previous methodological studies also found that case studies are the best tools for accomplishing various aims such as descriptions and exploratory studies (Kidder, 1982), testing theories (Pinfield, 1986; Anderson, 1983), and generating theories (e.g. Gersick, 1988; Harris and Sutton, 1986). As far as using case studies as an appropriate tool for Path Dependence is concerned, Garud et al. (2010) advocated for a case study method in general (Dobusch and Kapeller, 2013).

We started with collecting the financial and industrial data. In the technical innovation centered market (engineer sociologist based market), success is measured by the amount of profit gained (Callon, 1989), rate of expansion, and market share. Then, the results were refined via a series of arranged focused interviews with a few high rank engineers and project leaders of Toyota and Nissan car companies. In a focused interview, the respondent is interviewed for only a short time, and the questions asked could have come from the case study protocol (Tellis, 1997). The questions were prepared based on the result of an analysis of the financial data as well as the archival project histories.

Although the interviews were very helpful in understanding the overall procedure of decision making and new technology development, there were a few limitations. First, there are unwanted memorial gaps in the collected information. Because of the workforce limitations, some certain critical issues and time periods weren't available. For example, one could remember a special project from ten years ago, but he couldn't remember the motives, vice versa. Second, the collected data via interviews couldn't point to any further relation between the items. Third, the interview and word of mouth data lack the richness and support of statistical data. Using this type of data for making a conclusion will lead to an unwanted bias to ignore the influence of history and focus on the spur of the moment decisions. To overcome the above limitations of interview data gathering, a quantitative statistical analysis on the historical-technological patents of the cases was conducted. The importance of our research agenda is to measure the technological change and as Archibugi and Pianta (1996) defined, it is a demanding task. First, innovation is not a linear process from R&D activities to the commercialization of products. Second, technological change impinges on codified and tacit knowledge, the sources of innovation may be either internal or external, and innovations can either be embodied in capital goods and products or disembodied. While patents are particularly appropriate indicators for capturing the proprietary and competitive dimension of technological change (Ibid). In addition, Patents statistics can be used to understand a long time trend of technological change in a company.

Hagedoorn and Cloodt (2003) have indicated that patents could be a more than acceptable indicator of innovative output. They explained that in large parts of the economics literature, patent counts are generally accepted as one of the most appropriate indicators that enable researchers to compare the inventive or innovative performance of companies in terms of new technologies, new processes and new products (Acs and Audretsch, 1989; Aspden, 1983; Bresman et al., 1999; Cantwell and Hodson, 1991; Freeman and Soete, 1997; Griliches, 1998;

Napolitano and Sirilli, 1990; Patel and Pavitt, 1995; Pavitt, 1988). Even authors who are somewhat critical of the overall use of patents as a performance indicator, such as Arundel and Kabla (1998) and Mansfield (1986), admit that patents can be an appropriate indicator in the context of many high-tech sectors. The research design is depicted in Figure 11 in a simplified form.

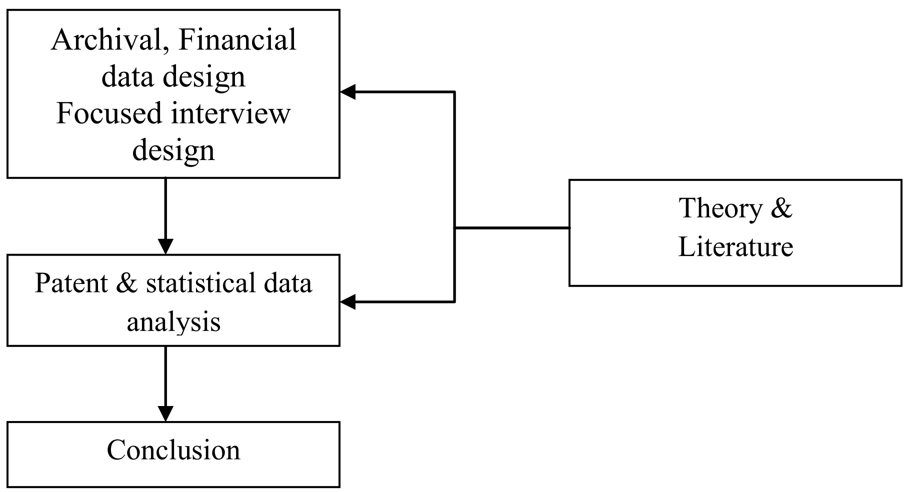


Figure 11., Research design

A 33 years patent history of the companies on eco-friendly technologies was cautiously analyzed. Inspired with the works of Lee (2013), we used the US patent data, as a standard unit of technological innovation, to make cross industry comparison feasible. The reason is that the main influencing cause of the electrification projects around the world started from the US and remained within the country for almost two decades. In 1990, CARB enacted Zero Emission Act I, and in response Japanese auto manufacturers started their EV and HEV projects. As we will show in detail in the next chapter, Japanese companies started this trend to be able to sell in the

American market, while in other regions like Europe, Japan, China, etc., the standard sale measures weren't fully defined yet.

In this regard, the United States Patent and Trademark Office (USPTO) and the National Bureau of Economic Research (NBER) patent databases were used to identify and analyze patents on eco-friendly technologies. NBER patent source from 1963 to 1999 is publicly available at its website (http://www.nber.org/patents/), while the updated version of the database from 1976 to 2006 is currently available at NBER website (https://sites.google.com/site/patentdataproject/Home). This giant dataset includes all patents granted to all countries, that is 2,923,922 patents. This patent source base has categorized information on the patents based on the number, grant year, grant date, application year, country and state, assignee ID, assignee type, technological sectors and classes, and the number of claims. For extracting the general number of patents and classifying the technological item, we have used the second updated version.

As Griliches (1998) explained, there is a major problem called classification in using patents for economic analysis. It is primarily a technical problem. How does one allocate patent data organized by firms or by substantive patent classes into economically relevant industry or product groupings? For fading this problem, we have also used Patentlens database (http://www.patentlens.net), one of the most recent classified patent search engines that is backed by Bill and Melinda Gates foundation, Rockfeller foundation, and the United Nations. It provides a thorough search between more than ten million full text patents including US, EU, PCT and Australian patents. One of this database's privileges is that it provides abstract and images of the patents, which helped us narrow our classified search and avoid unwanted hits and misses. Usually most of the previous researches which have used the same method of patent analysis were trapped in unwanted hits and misses. Broadly defined, there are a lot of replicated and missing entries in every patent database, which are the results of human mistake or unfamiliarity with the language of the assignee's country of origin. For example, Mitsubishi Motors has registered patents under the assignee names of "Mitsubishi Motors", "Mitsubishi Jidosha", "Mitsubishi Jidosha Kogyou", etc. that must be considered cautiously. In our analysis, a deep and careful scrutiny has been done to avoid the misses due to different names. Another ignored problem in previous patent analyses is dealing with hidden patent information. Companies usually use the legal patent names that hide the detailed information about the technology, Such as "motion detection for <u>motor vehicle</u>", which motor vehicle refers to EV. In these cases, the patent abstract could help understanding the nature of the patent. In our analysis, we paid very careful attention to these ambiguous titles. We believe that this research patent analysis of eco-friendly technologies is the most accurate, detailed and up to date one so far.

Based on the previous works on the technological background and strategic technological choice, a conceptual model supporting the notion of historical Path Dependence was developed. Our theoretical model states that companies' previous engagement with a technology development will have an impact on its later technological choices. Hypotheses concerning the effect and the direct role are now discussed. Here, the study hypotheses are divided into two separate branches and presented. First, we focus on the interplay between the company's historical background and its technological choice of the selected moment and how this interaction may affect a new technology commercialization. Second, we argue that those auto manufacturers with a historical asset of core Hybrid technologies are expected to strategically choose HEV over EV technology, while those car companies with a historical asset of core EV technologies are expected to choose EV over HEV technology.

For recognizing HEV and EV core technologies, technical papers and engineering studies were thoroughly scrutinized. Especially, proceedings of the Institute of Electrical and Electronics Engineers (IEEE) as well as Electrical and Mechanical engineering journals were analyzed. HEV core technologies were selected based on the important scholarly works of Husain (2003, 2011), Ehsani et al. (2007), and Emadi et al. (2005) suggested core HEV components. For example, Husain's (2003) suggested components for HEV are the heat engine, electric generator, and drive system. Based on his suggestions, a schematic view of the HEV components is shown in Appendix VIII. After this cautious selection and authorization by academic and technology experts, Engine, Fuel economy/Emission control, Generator, and Hybrid Drive System were selected as the core technologies of HEV production process. EV core technologies were selected based on the technical works of Husain (2003), Shimizu et al. (1997), Chan and Chau (1997), Riemer and Klaiber (1997), and Radev (1999) suggested EV components. For example, Husain (2003) suggests that primary components of an EV system are the motor, controller [drive system], power source [battery], and transmission [cables, wires, etc.]. A schematic view of the EV components is shown in Appendix IX. We did the same for the extraction of EV core technologies and Electric Battery, Electric Motor, Fuel Cell Battery and Electric Drive System were chosen. These selections are based on the application and the source of competitiveness of the technology. In addition, we have used the definition of IPC patent classes for dirty and clean technologies (Aghiton et al., 2012). Patent documents are categorized using the International Patent Classification (IPC). Auto industry patents are related to clean (electric, hybrid, fuel cell) and dirty (ICE) technologies. In general, this selection relies heavily on previous OECD works, as well as Aghiton et al. (2012), Vollebergh (2010), and Hascic et al. (2008).

Broadly defined, some of the technologies still exist and are being used in both systems, but the influential factors of being a core component and embedded inside do not govern. For example, for our analysis, patents on diesel engines are excluded. Patents on <u>out of the engine</u>'s power transmission, <u>out of the engine</u>'s exhaust purification system, etc. are excluded. These technologies are not the source of competitiveness and can be embedded in any other normal vehicle, regardless of ICE or Hybrid system. Another example is that battery pack is listed as the competitive source of EV, because in the Hybrid system, they are smaller, cheaper, abundant, and take a lot less room than EV. In EVs, the battery is the sole source of power and it weights between 400 and 600 Kg. While in HEV, battery weight is between 30 and 45 kg.

We have analyzed patent applications. There are different interpretations among scholars and professional patent analyzers in terms of using patent filing data or published granted ones. For example, Prescott (2008) stated that patent applications are ambiguous because they can bear different meanings and are capable of misleading even experienced professionals. Greenfield (2011) pointed out the patent coverage and scope problem in technological patent applications. He states that a patent may include several different embodiments, or modified forms of the invention. In a prosecution process, sometimes when all the limitations of the claim are met, it is desirable for the company to alter the scope of the claims by drafting new claims or amending the claims. As result, published grated patent may include several different embodiments, or modified forms of the invention. In other words, a filed patent like "Hybrid Drive System" after the alternation could become a published patent like "Hybrid Vehicle's power transmission".

This means based on our study measures, the first one could be included, while the second one couldn't. As far as patent grants are concerned, scholars are concerned about the possible application to grant delays. Gans et al. (2007) investigated some of the evidence from patent grant delays. They concluded that the impact of the patent system depends on the strategic and institutional environment in which firms operate. For example, while the prosecution process takes from a year to eighteen months in US, in Japan it can take up to seven years. Though Regibeau and Rockett (2004) state that more important patents should be approved more quickly, Johnson and Popp (2003) conclude that more important patents experience longer delays.

Through a five months analysis, more than 78,140 records were analyzed. 14,700 records for Toyota, 15,980 records for Honda, 9,870 records for Nissan, 980 records for Mitsubishi Motors, and 37,590 records for Mitsubishi Group conglomerate were analyzed. It should be noted that Mitsubishi group conglomerate mainly consists of 25 sub-companies such as Mitsubishi Electric, Mitsubishi Steel, Mitsubishi Chemicals, Mitsubishi Motors, Mitsubishi Cable industries, Mitsubishi Heavy Industries, etc. The reason why we have also included Mitsubishi Group in our analysis is that under the Mitsubishi umbrella, any sub-company could access the new technology from the other group members and use them in their products. For example, we have witnessed that Mitsubishi Motors in some cases has used the Hybrid and EV technologies that were developed by Mitsubishi Heavy Industries and vice versa.

Based on the above arguments, the key question being investigated here is whether companies' technological background leads to the different technology preference. Based on our perception of previous research and theories, we have formulated the key question of this study:

What were the strategic and technological factors behind Toyota and Honda's choice of HEVs, as well as Nissan and Mitsubishi's choice of EVs?

6 - Case studies

The case study chapter collects together materials and historical evidence from financial data of the companies in the past two decades, and also from focused interviews of key engineers and managers of Nissan and Toyota's EV and HEV projects. Case studies are a roadmap to understanding the strategic motives behind the companies' electrification plans and technological shift through their history. In contrast to previous studies that see the eco-friendly vehicles business as a whole and try to provide a general answer, this study believes that different companies have shown various reasons for developing, discontinuing or delaying their green projects, and each one of them is different from other and must be investigated in its own condition. In the end, with putting together case studies' strategic grounds and next chapter's statistical results, we could make a meaningful conclusion on the subject.

6.1. Toyota's green transformation and technological background

Toyota Motor Corporation has always been known for its considerable influence on the world class car manufacturing. Among Toyota cars and as a Hybrid Electric Vehicle, Prius 1997 is the World's first mass produced hybrid vehicle. Before its production, Toyota had never been much of a pioneer. It was known as a fast follower company. Prius went on sale in 1997 and brought an incremental success for the company. Meanwhile, the first version of the Toyota electric vehicle (RAV4 EV) became available on a limited basis from 1997 to 2003, but many consider this car as a failure for the company. It would be interesting to find out if Toyota Prius hybrid affected the production of Toyota electric vehicle RAV EV I (first generation). In other words, is the Prius sale success in the market a reason for Toyota to stop the production of its own EV I? In this section, the mutual influence of two rival technologies on each other will be investigated. Furthermore, some influential strategic factors in two decades of Toyota‘s eco-friendly vehicles development will be discussed.

It is important to ask how the structural location of Toyota positioned its response to environmental movements. We might be concerned as well with how advertising affected the sales of the green vehicles and with how the non-availability of cheaper electric cars affected its promotion in the society. To understand the success and failures of first generation green vehicles, we need to be concerned about the socio-organizational structure of Toyota between 1996 and 2003.

In 1993, Toyota company's chairman, Eiji Toyoda expressed the company's concern about the future of the automobiles. A project known as G21 initiated to develop a future-oriented new car technology. By 1994, the G21 team had concluded that the increasing oil price would require the new car to be fuel-efficient. As a result, engineers were ordered to develop a concept car with a hybrid power train for the 1995 Tokyo Motor Show (e.g. Taylor A., 2006). The first Toyota Prius was the brainchild of Takeshi Uchiyamada, an engineer and expert in noise and vibration control. *In 1995, with a change in the company's president, Toyota got serious about putting Prius into production.* One year later, competition for Prius body design started and Erwin Lui from Toyota's design studio in Newport Beach CA, got three weeks to prepare models for four-door sedan Prius.

The first Prius (model NHW10) went on sale in 1997 and it was available only in Japan (Taylor A., 2006), doubling the fuel efficiency to 28km per liter compared with a conventional Corolla. By mid-2000, Prius was subsequently introduced in US. Until 2012, Toyota introduced 4 generations of Prius in more than 70 countries. Prius I‘s (first generation) largest markets being those of Japan and US, and from the introduction of Prius II, Europe also came in to the picture. In US, Honda introduced its hybrid car Insight I (first generation) seven months ahead of Prius. This helped Toyota to modify the Prius for US needs. In other words, Toyota used the Fast follower strategy to introduce the Prius right after the Insight (in this strategy, the follower company learns quickly from those companies who enter first). For example, An Insight buyer in the US posted his cars manual on his Web site, and TMS used the information to modify its warranties (ibid.). In contrast to Prius, Honda‘s Insight looked like something out of a science fiction movie. The Insight was small and impractical, demanding that its buyers sacrifice space, comfort, and appearance in exchange for high gas mileage. Customers were unwilling to do so, and Honda Insight I was discontinued in 2006 (Rego et al., 2007). Again In 2009, Honda introduced Insight II to make hybrid technology more affordable to a wide range of buyers.

On Prius I, Toyota was losing over $20,000 per vehicle, selling it for $20,000 while it cost $41,000 to build (Anderson and Anderson, 2005)[3]. Toyota executives stated that the company broke even financially on sales of Prius first-generation. But gradually, Prius retained 57% of its value after three years. Price of ownership was so high that only 2% of buyers opted to lease (Taylor A., 2006). This success increased more with the introduction of the second and the third generations of Prius. Table 4 shows the annual sales of Toyota Prius I by region.

As you can see in Table 4, Prius I‘s largest markets have been US and Japan. Toyota's initial strategy for the Prius I was to target innovators and early adopters of new technologies. In this sense, a special website about Prius I was developed as early as two years before the introduction of the product. Also, Toyota used Internet-based advertisement, such as online e-brochures with a 17-seconds video clip that was sent to the almost 44,000 people. Coordinating

3 Based on another report, It cost at least 32,000$, for the company to produce a unit, but the retail price of the car was less than 17,000$ (e.g. Bloomberg Businessweek, 1997).

900 dealers to execute a 'rental' program was another way to let the customers deal more with the new hybrid technology of the company.

Table 4.,
Prius I annual worldwide sales by region - in thousands

Year	World	Japan	North America	US	Europe	Other
1997	0.3	0.3				
1998	17.7	17.7				
1999	15.2	15.2				
2000	19.0	12.5	5.8	5.6	0.7	0.01
2001	29.5	11.0	16.0	15.6	2.3	0.2
2002	28.1	6.7	20.3	20.1	0.8	0.2
2003	43.2	17.0	24.9	24.6	0.9	0.4

(Source: greencarcongress.com, TMC)

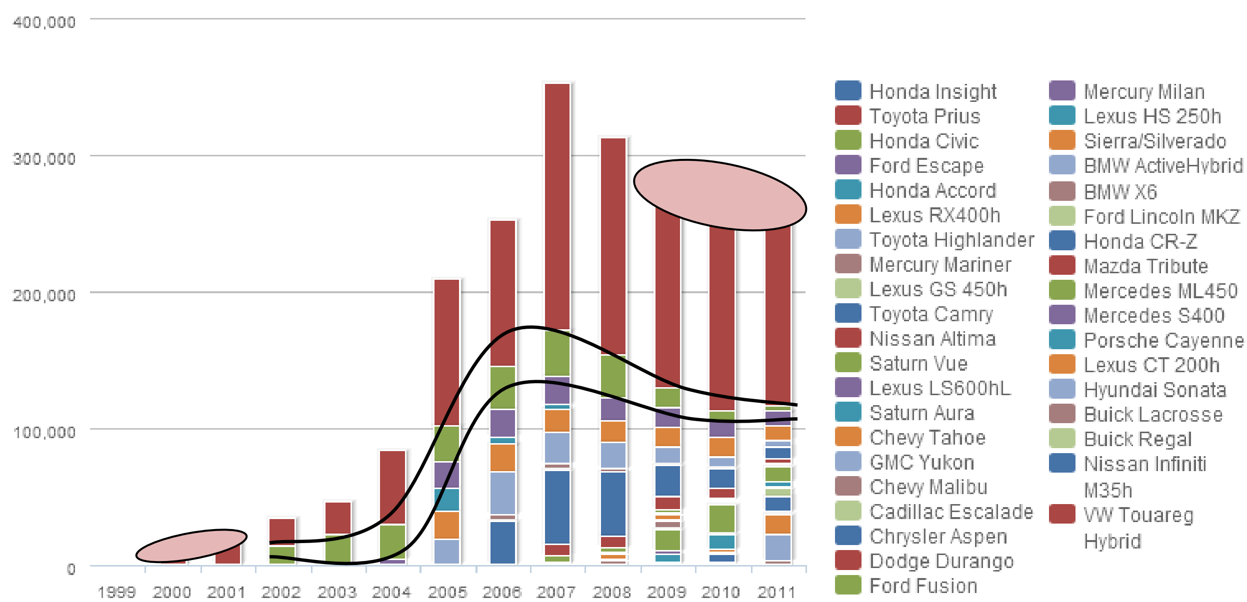


Fig 12., US hybrid sales – Honda Insight I and II and Honda Civic Hybrid are shown (Source: Alternative Fuels Data Center)

In four years and right before Toyota introduced its second generation of Prius in 2004, Toyota Prius I had 39 percent and Honda Civic had 55 percent of the US hybrid market share (Figure 13). Toyota introduced the second generation of Prius (model NHW20) in 2004, targeting the early majority of customers (refer to Figure 12). Toyota used television and newspaper advertisements to aim at the mass market using the mass media. Compared to the previous generation, Prius II was more environmentally friendly, longer in size and it had a more aerodynamic body balance. Table 5 shows the annual worldwide sales of Prius II by region.

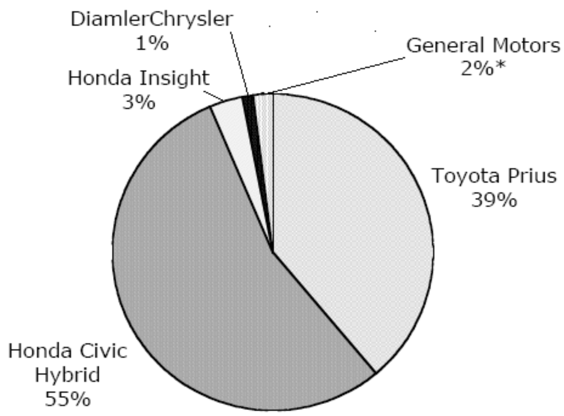


Figure 13., US hybrid market share in 2003 (Rodriguez and Page, 2004)

Table 5.,
Prius II annual worldwide sales by region - in thousands

Year	World	Japan	North America	US	Europe	Other
2004	125.7	59.8	55.9	54.0	8.1	1.9
2005	175.2	43.7	109.9	107.9	18.8	2.9
2006	185.6	48.6	109.0	107.0	22.8	5.3
2007	281.3	58.3	183.8	181.2	32.2	7.0
2008	285.7	73.1	163.3	158.6	41.5	7.7
2009*	404.2	208.9	144.3	139.7	42.6	8.4

(Source: greencarcongress.com, TMC)
* Japan's 2009 statistics is cumulative of Prius II and III sales

European sales of Prius began in September 2000. But from 2005 and after the introduction of Toyota Prius II, European sales increased dramatically. In other words, Europe became the third largest market for Prius. In 2006, Toyota came up with the idea of Camry Hybrid (model XV40), although this vehicle has never been available for purchase in its home market, Japan (Abuelsamid, 2009). Figure 14 shows the US hybrid market share in 2007, before the introduction of Toyota Prius III and Honda Insight II. It should be noted that Altima hybrid, Nissan's first hybrid car started its sales from 2007.

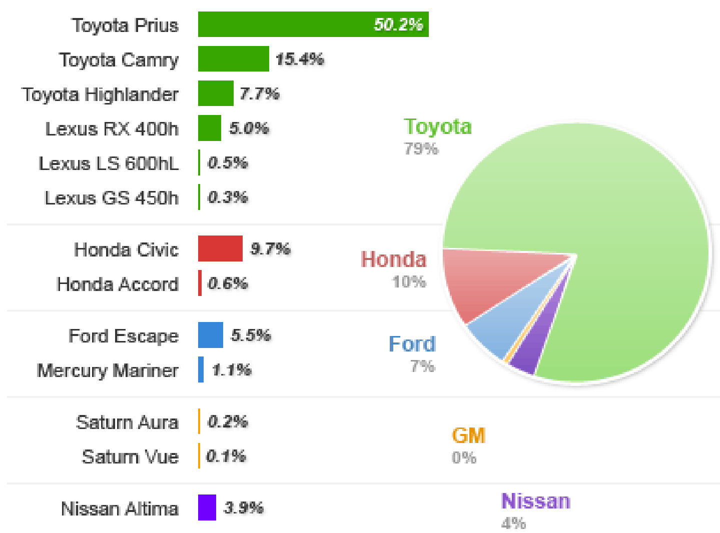


Figure 14, US hybrid market share in 2007 (source: hybridcars.com)

Indeed, after the introduction of Prius II, the golden ages of hybrid vehicles started for Toyota. Just between 2004 and 2008, Total hybrid vehicle sales in US became quadruple and of this huge increase in sales (Figure 15), Toyota had the greatest bite of the fruit. Between all of the known automakers, Toyota had the most hybrid vehicle sales as a percentage of total light vehicle sales (Figure 16). By 2008, Toyota had more than 10 percent reported hybrid vehicle sales as a percentage of total light vehicles sales, while for Honda, the closest competitor of Toyota in hybrid vehicles, this share remained hardly at 2 percent.

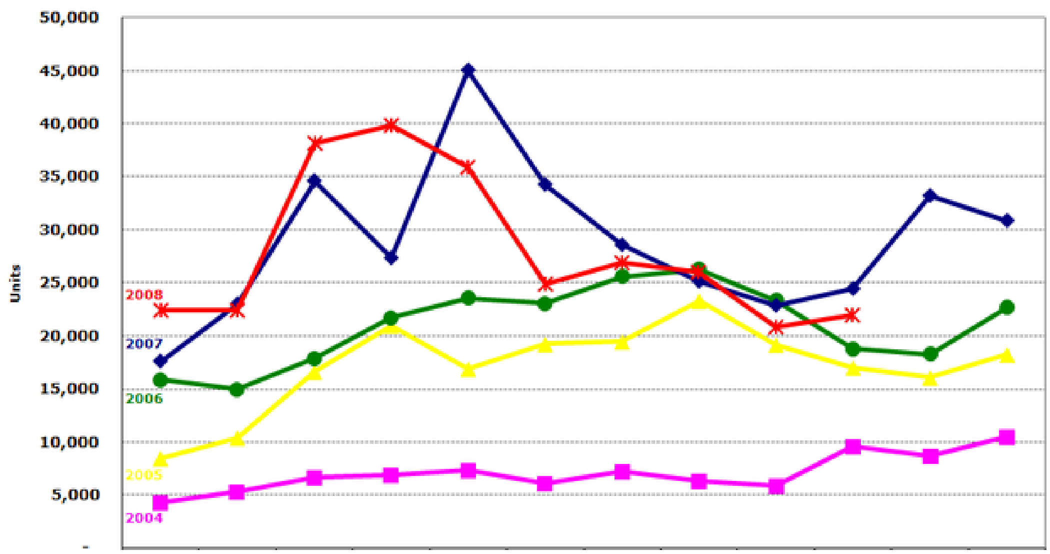


Figure 15., Total monthly reported US hybrid vehicle sales 2004-2008 (source: greencarcongress.com)

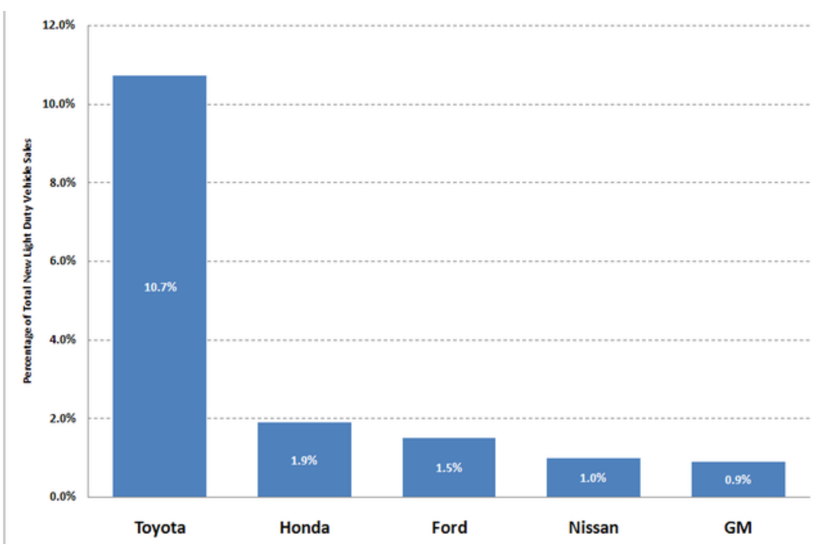


Figure 16., Reported hybrid sales as a percentage of total new light vehicle sales in 2008 (source: greencarcongress.com)

In 2009, Honda introduced the second generation of Insight. Compared with 2-seat Insight 1999, Insight 2009 was a 5-passenger hatchback, designed to compete with Toyota Prius. Toyota also debuted the new third generation of Prius (model NHW30) in the same year, but as far as the mass production is concerned, Toyota Prius III started one month later than Insight II. Toyota cut the price of the Prius from 2.33 to 2.05 m¥ to better compete with the Insight II (price between 1.89 and 2.21 m¥). Table 6 shows the annual worldwide sales of Toyota Prius III by region. Toyota Prius is sold in more than 70 countries. In May 2008, Toyota announced that the Prius worldwide sales had passed the 1 million vehicles, and this number reached 2 million units in September 2011 (Greencarcongress, 2010). Figure 17 and 18 show the main markets of Prius up to Sep 2010.

Table 6.,
Prius III annual worldwide sales by region – in thousands

Year	World	Japan	US	Europe	Other
2009	404.2	208.9	139.7	42.6	8.4
2010	NA	315.7	140.9	42.9	5.8
2011	NA	252.5	128.1	26.4	NA
2012	NA	279.0	126.0	16.7	NA
total	2,805	1,243	1,209.2	256.7	39.8

(Source: greencarcongress.com, TMC)

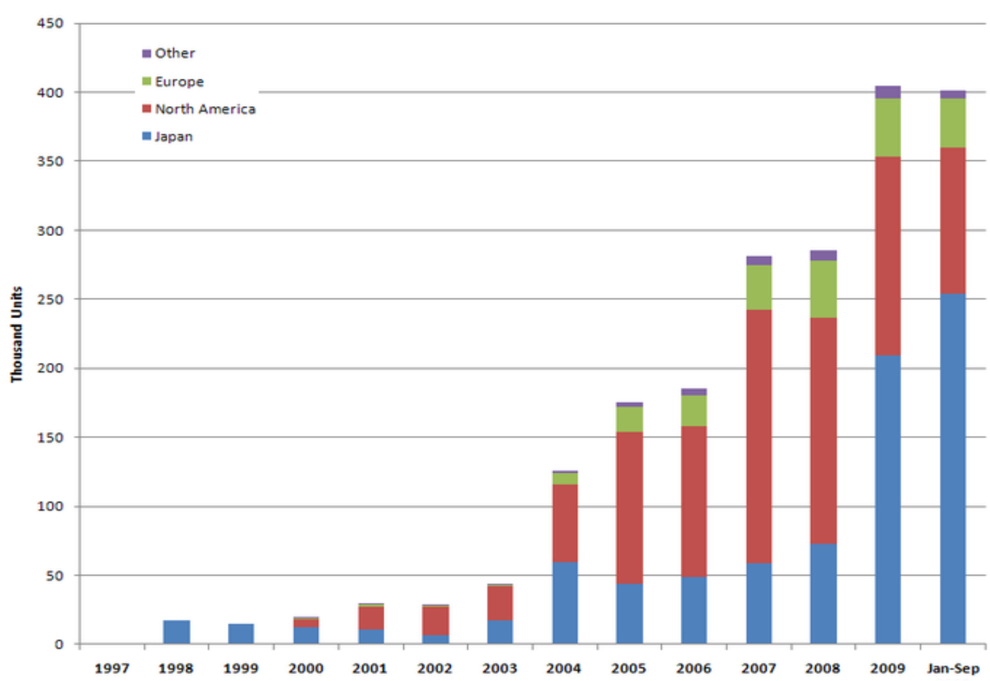


Figure 17., annual worldwide sales of Toyota Prius (source: greencarcongress.com)

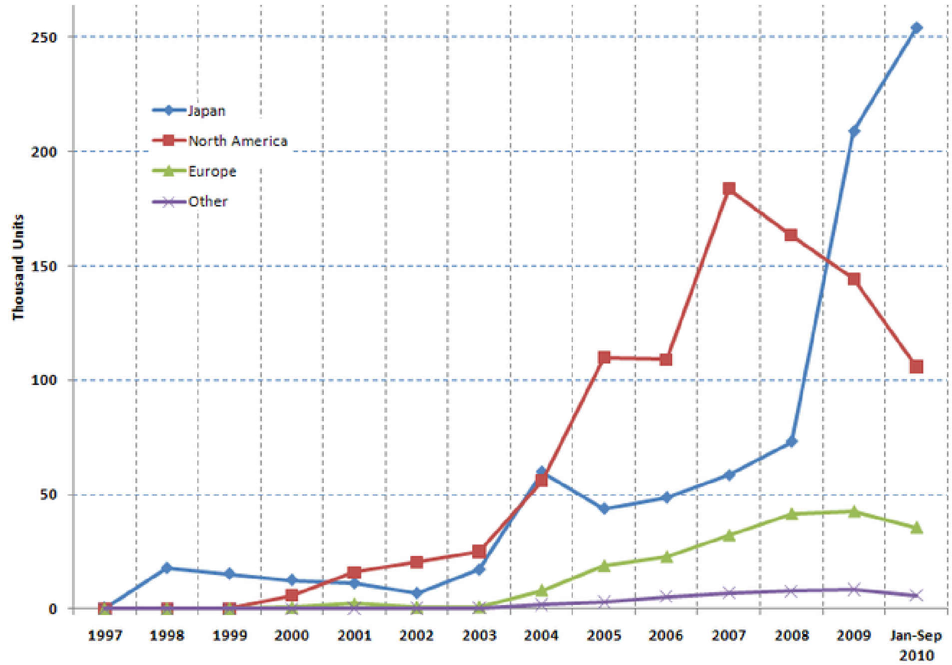


Figure 18., Worldwide annual sales of Prius by region (source: greencarcongress.com)

As it can be seen, Prius II sold very well in the American market. Of course, the World Financial Crisis that started in 2008 affected the sales of all automakers. In this sense, American sales of Hybrid vehicles were totally affected. But in Japan's auto market and from 2009, the new generation of Prius made the situation even better for Toyota. Toyota Prius became Japan's best selling vehicle in 2009 for the first time since its debut in 1997 as its sales almost tripled to 208,876 in 2009 (Jones, 2010).

As far as the latest generations of Prius are concerned, Toyota debuted the Prius C hatchback in 2011 (Tokyo Motor Show as Prius Aqua, North American International Auto Show in Detroit as Prius C). It was launched in Japan in December 2011 and in US in March 2012. Schmitt (2012) stated that initial demand has been high in both countries. Toyota cut the price of this car to 1.69 m¥. Toyota introduced Prius V minivan in 2011 (North American International Auto Show in Detroit as V). It was launched in Japan in May 2011 as Prius α, in US in October 2011 as Prius V, and the European version will be out in mid-2012 as Prius + (plus). This car uses NiMH battery pack and the sales price is 2.35 m¥. Also, Toyota produced Prius plug-in hybrid in 2011 (unveiled in 2011 in Frankfurt Motor Show). Sales began in Japan, US and Europe by early 2012 and the US retail sales price starts at US$32,000. In spite of the Tohoku earthquake and tsunami in 2011, again Toyota's Prius brand became the best selling vehicle in Japan in 2011.

Figure 19 shows the Prius I and II marketing strategies. It will be intriguing to note that Toyota focused on innovators and early adopters of innovation as the main marketing strategy for Prius I, while for Prius II, the focus was mostly on the early majority group of customers.

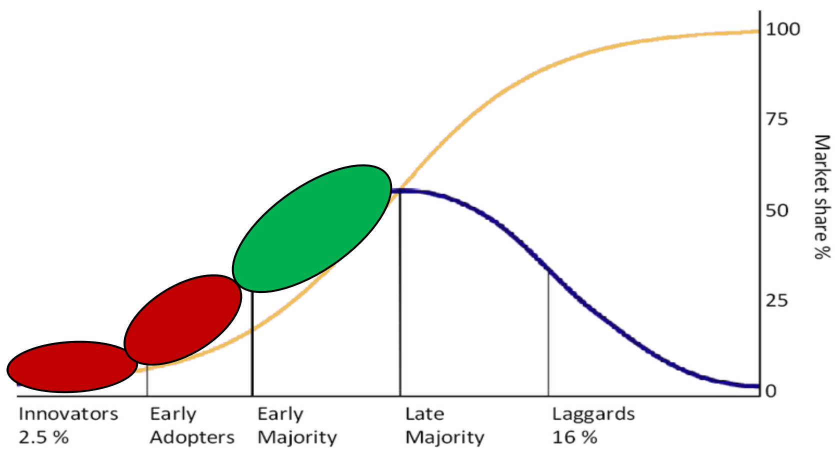


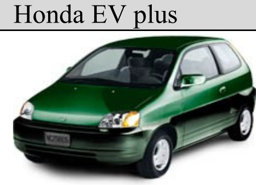
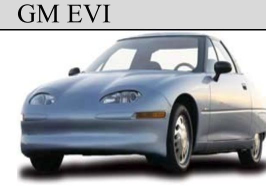
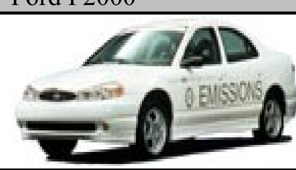
Figure 19. Toyota Prius I and Prius II marketing strategies

Coming back to 1997, while Toyota started its experience with hybrid vehicles, it was supposed to devote 2% of its sales to zero emission vehicles. In 1997, Toyota launched RAV EV I (first generation) on a limited lease basis in California and then, due to a shift in corporate policy, it sold them to the general public. During production years, 328 were sold with the final price of 29,000$. After six years and in spite of waiting lists of forthcoming customers, in 2003 RAV EV production was terminated by Toyota.

Between 1997 and 2003, major Japanese car companies wanted a piece of the Electric Vehicle market share. Toyota RAV4 EV was the first commercial electric vehicle to be powered by nickel-metal hydride batteries and was only offered for public sale for about seven months from 2002 to 2003 in very small quantities and just in California. Nissan Motor's Prairie Joy EV, introduced in 1995, was the world's first production electric vehicle powered by lithium-ion batteries. Nissan Prairie was a test model and only 30 vehicles were produced and mainly sold to labs. Nissan later introduced Altra EV in 1997, while only about 200 vehicles were sold. Honda EV Plus, unveiled in April 1997, was an electric vehicle of totally original design. Again only 340 vehicles were designed and produced. All of these vehicles productions stopped due to lack of demand or change in the company's strategy. Table 7 shows the comparison between the first mass produced hybrid and electric cars, Honda Insight I, Toyota Prius I, RAV4 EV I (Toyota's first experience with EVs), Honda EV plus, General Motors first generation's EV1, Nissan Altra EV, Ford Ranger EV, Chevrolet S-10 EV, Nissan Prairie Joy EV, Nissan Tino Hybrid, Nissan FCX EV, and Honda Civic hybrid I, Nissan Hypermini EV, Mitsubishi FTP EV sport car, and Ford FC5 and P2000 (world's first Fuel Cell powered vehicles).

Aside from hybrid vehicles, the destination of all mentioned electric vehicles was the same. In spite of the growing demand and positive feedback for some of the EVs in the market, their production stopped and the vehicles were crushed by their companies (Toyota RAV4 EV, General Motors EV1, and Honda EV plus), while the production of some of them stopped due to lack of demand (Nissan Altra EV). In other words, from 1999 to 2004, all of a sudden auto manufacturers pulled all their leased electric vehicles from the market or decided to stop producing more EVs. For almost a decade, the market didn't hear about any mass produced electric car. The most important EV development in this blank timeline was Tesla Roadster, developed by Tesla Motors in 2006 and mass produced from 2008 with the price of 109,000 US$. Of course because of the expensive price, this car wasn't something that everyone could afford.

Table 7.,
Comparison of first generation EVs and HEVs

Honda Insight I HEV	Toyota Prius I HEV	Honda Civic I HEV	Toyota RAV4 I EV
			
1999 - 2006 3-door hatchback Sale ($18,880) NiMH	1997 - 2003 4-door sedan Sale ($19,995) NiMH	2001 - 2005 4-door sedan Sale ($20k) NiMH	1997 – 2003 4-door SUV Lease, sale ($29k in Cal) NiMH
Nissan Altra EV	Honda EV plus	Nissan Tino HEV	GM EVI
			
1997 - 2001 5-door CUV N/A Li-ion	1997 - 1999 4-seat sedan Lease (455$/mth) NiMH	2000 4-door sedan N/A Li-ion	1996 - 1999 2-door Coupe Lease Lead-Acid
Ford Ranger EV	Nissan Prairie Joy EV	Honda FCX EV	Chevrolet S-10 EV
			
1998 – 2002 Compact truck Lease NiMH	1996 5-door CUV Test, Lease (2500$/mth) Li-ion	2002 2-door hatchback Test, Lease Fuel Cell	1997 – 1998 Compact truck Lease, sale Lead-Acid & NiMH
Nissan Hyper mini	Mitsubishi FTO EV	Ford P2000	Ford FC5
			
1999 – 2001	1998	1999	1999
3-door hatchback	Sport car	3-door sedan	4-door sedan
Sale ($36,500)	Test	Test	Concept
Li-ion	Li-ion	Fuel Cell	Fuel Cell

It should be noted that between 2002 and 2008, world economy dealt with a major oil crisis. Due to tensions in Middle-east and worries over oil speculations, price of crude oil increased from 30$ in 2002 to 147$ in 2008. From 2008, major automakers in the world, turned their attention again to electric cars. For example, Honda FCX Clarity manufactured by Honda from 2008 (production cost between 120,000$ and 140,000$), Th!nk City manufactured by Think Global from 2008 to 2011 (sold 1045 units worldwide), i-MiEV manufactured by Mitsubishi from 2009 (price from 29,000$ in US to 63,000$ in Australia), Leaf manufactured by Nissan from 2009-10 (world‘s best selling EV), Ford Focus Electric by Ford Motors Company from 2011 (price of 40,000$), RAV4 second generation manufactured by Toyota from 2012, and Smart ED third generation manufactured by Smart from 2012 (price of 22,400$ plus monthly battery rental fee) are said to be or will be the most successful EVs. Of course because of the limitations, it is not possible to deeply explore all of the mentioned electric vehicles.

From May 2010, Toyota Motor Company and Tesla Motors started their cooperation to develop the second generation of RAV4 EV. Tesla is providing the Lithium Metal-oxide battery pack and Toyota has come with the platform and body. The US market launch was in late-2012 (49,800$). From the first generation of RAV4 (1997) until the second one (2010), Toyota’s mainly eco-cars have been hybrid vehicles (such as Prius and Camry) and there wasn’t any pure electric vehicle from this company in the market. In spite of the oil price increase in the 2000s, why did Toyota stop its investment on electric cars? It is very interesting, because the same thing happened for almost all automakers; they all stopped electric car production and they all had their own strategic reasons for giving up on electric vehicles. In the next section, Toyota‘s reasons for stalling the production of electric car will be discussed.

6.1.1. Toyota Prius and RAV4 EV co-relation

This study was undertaken to explore why Toyota did not continue its electric vehicle production until 2012 (mass production time of RAV4 EV II). Figure 20 presents the timeline of Toyota's green car productions from 1997 to 2012 (electric and hybrid cars; eco-cars with ICE and low emission are excluded). Toyota introduced its RAV4 EV and Prius I hybrid in the same year, but RAV4 EV was available in the American market and only for lease. In 2002 and 2003, it was sold to the general public with the price of 29,000 $ on a limited basis and only 328 units were sold. Toyota suddenly stopped RAV4 EV production, removed its EV program website and called all of the leased vehicles back.

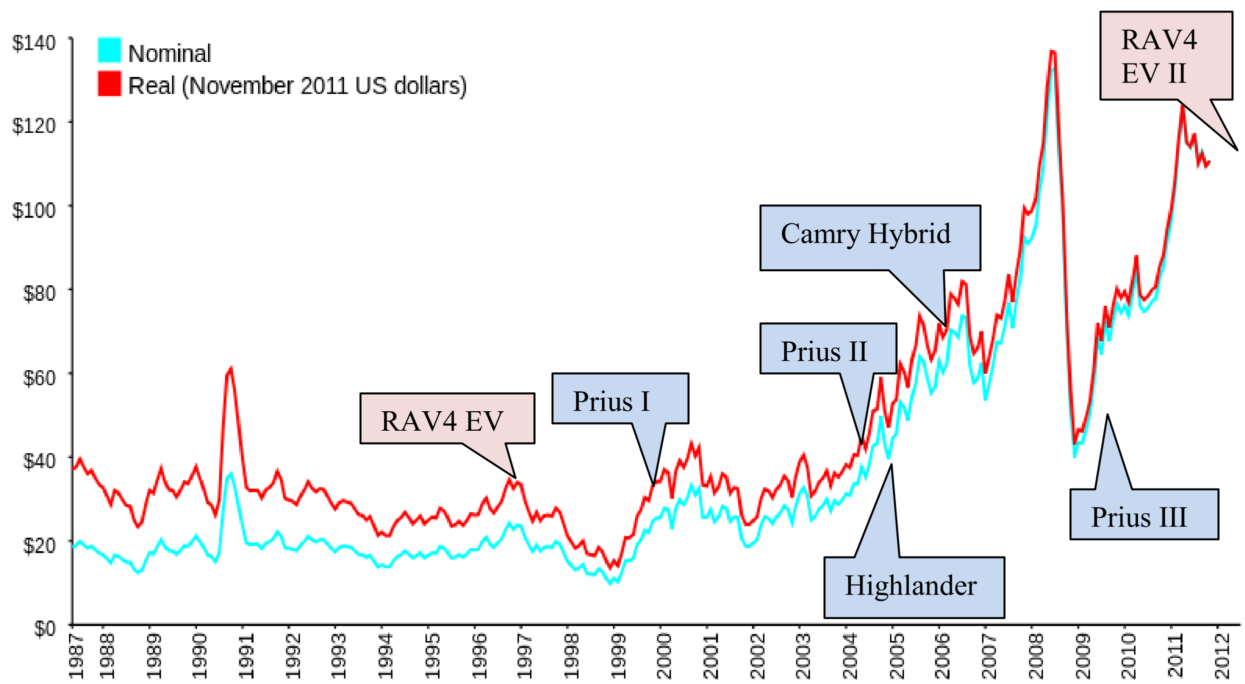


Figure 20., Toyota Hybrid (blue) and Electric vehicle (pink) introduction in US market along with oil price increase (compiled from: Energy Forum, 2011)

As far as Prius is concerned, the first generation wasn't available in the US market until 2000. From 1997, Prius hybrid extended its share in Toyota sales portfolio and the sales increased year by year. From 1997 in Japan, from 2000 in US and later in Europe, Prius family sold more than 3 million units (by June 2013). While Prius and RAV4 EV started their sales at the same year, why was it only Prius that gained importance by Toyota Company and the market? Why wasn't Toyota's electric vehicle successful in that period of time? Did Prius's success affect the sales of RAV4 EV?

One of the reasons that Toyota decided not to continue commercializing the next generation of EV or not to produce RAV4 EV after 2003, is that based on the previous Marketing researches findings, "for all of us, environmental advantages were able to arouse a certain conceptual interest but ultimately it was not the driving choice" (Beauchamp, 2006). It means that at the time of introduction of green vehicles, insisting just on environmental friendliness as the main message of the campaigns wasn't a good strategy for both RAV4 EV and Prius I. Toyota noticed this matter very early and it helped them to gain a huge profit out of their hybrid vehicle. In case of Prius, researchers recommended that as hybrid technology of Prius (or engine size and fuel type) is not a key selling point, the Prius should be positioned as a stylish, innovative vehicle offering fun to drive. Later on and especially from Prius II, Toyota changed this strategy and focused mainly on technology and Innovation.

For example, take a look at Figures 21 and 22, where it compares two generations of Toyota Prius campaign advertisements. In consistent, Tran et al. (2012) found that the largest influence on early adoption is financial benefit rather than pro-environmental behavior.

Figure 21., Toyota Prius I advertisement (compiled from: John’s stuff blog, 2003, 2004; Yoshiro, 2009)

It should be emphasized that Toyota’s first campaigns didn’t add enough perception of the technology and drive distinction. However, later on they were replaced by advertisements that give customers enough details about innovation dominance, remarkable idea and technological advancement.

In addition to the above finding and argument, in 2004, a survey was conducted by Thun (Basis-Kontakt and Maritz Research Deutschland) that was commissioned by the Strategic Research Division of Toyota Motor Marketing in Europe, on the positioning of a green technology in consumers consciousness ended up with an interesting result. This research found notably that fuel type is not a decision making motivation in the early stages of green vehicle sales. Unlike the aforementioned attribute, price, brand, segment, body type, design, in short innovation and technology, which they are far more relevant. The research further concluded that awareness of Green technology and knowledge of the hybrid system was low.

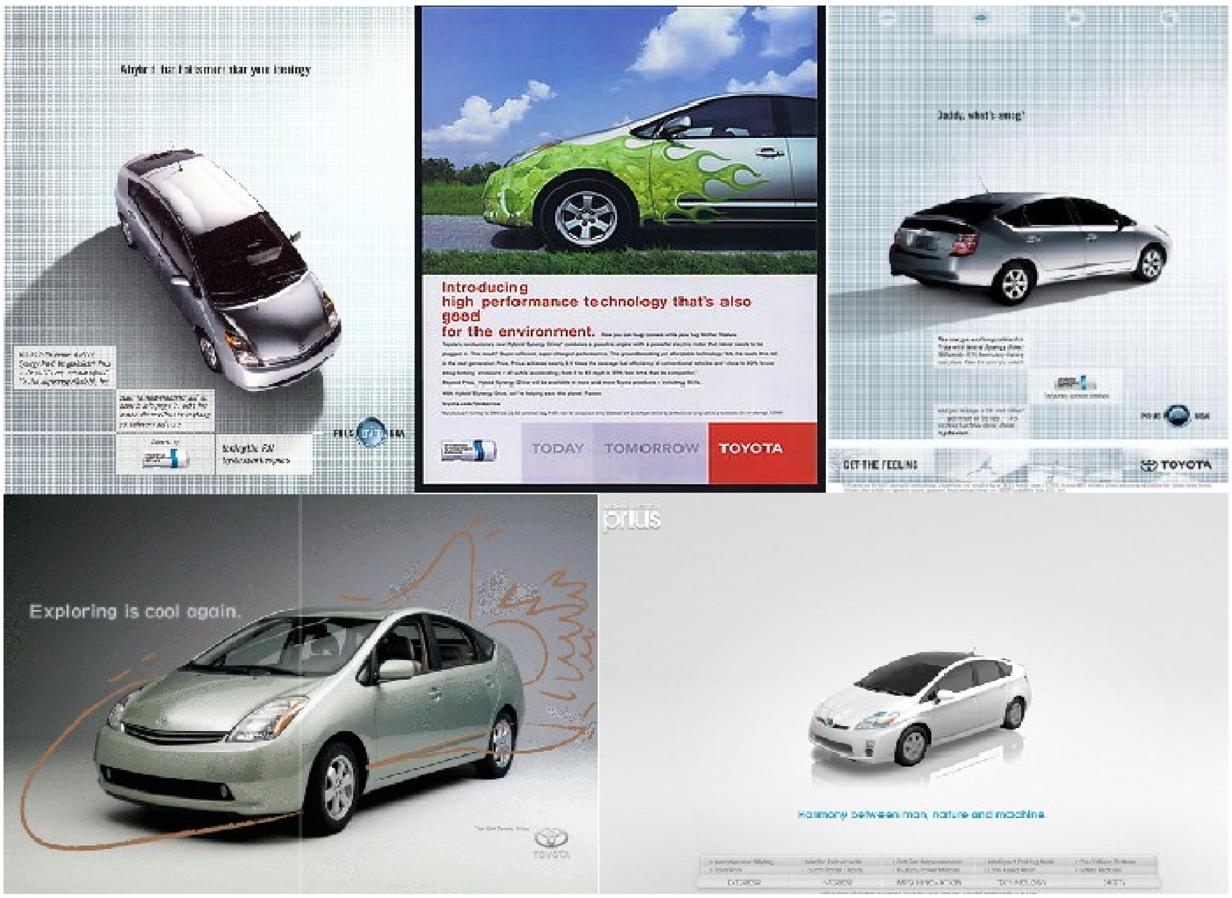


Figure 22., Toyota Prius II and III advertisements (compiled from: John's stuff blog, 2005; Coloribus, 2004)

Therefore, our study brings to the attention of specialists the importance of first marketing orientation. In spite of the rising oil price between 1999 and 2008, an opportunity that opens market doors for green technologies, one of the reasons that Toyota RAV4 EV couldn't find its right position in the market was the wrong sale and marketing strategies.

Another reason that Toyota decided not to continue the production of RAV4 EV after 2003, is that in the marketing campaign of Toyota Prius, the company found that the other products within Toyota's portfolio will benefit from the extra Toyota exposure and from Toyota being portrayed as a technologically advanced brand. In other words, Toyota sacrificed RAV4 EV in favor of Prius I and this practice helped Toyota to increase its sales not just only for Prius, but also other brands in its portfolio. In marketing literature, this is called Cannibalism (e.g. Traylor, 1986). If a company has two brands offering similar or close characteristics that are competing for the same customers, one will get eaten by the other or one will be removed from the market by its own company: the brand cannibalism.

Toyota stopped RAV4 EV production to help Prius sales and as a result, Prius sales increased and benefited other brands within the company's portfolio. For example, Reingold (1999) and Pohl and Yarime (2012) stated that the Prius, it is argued, is likely to attract customers to Toyota showrooms, even if the sales of the car are slow. The Toyota brand was probably developed in a positive direction, as HEVs contribute to an innovative and environmentally conscious profile of the firm and HEVs have been intimately associated with Toyota (Ibid). Figure 23 describes the battle between Toyota and General Motors in the car market.

In 2000, General Motors was the world top car manufacturer and on the list, Toyota was number 3 after Ford. It is clear that after the introduction of the Prius family, Toyota's vehicle sales increased significantly and in 10 years, Toyota Company became the world top car manufacturer and General Motors became number 2 on the list.

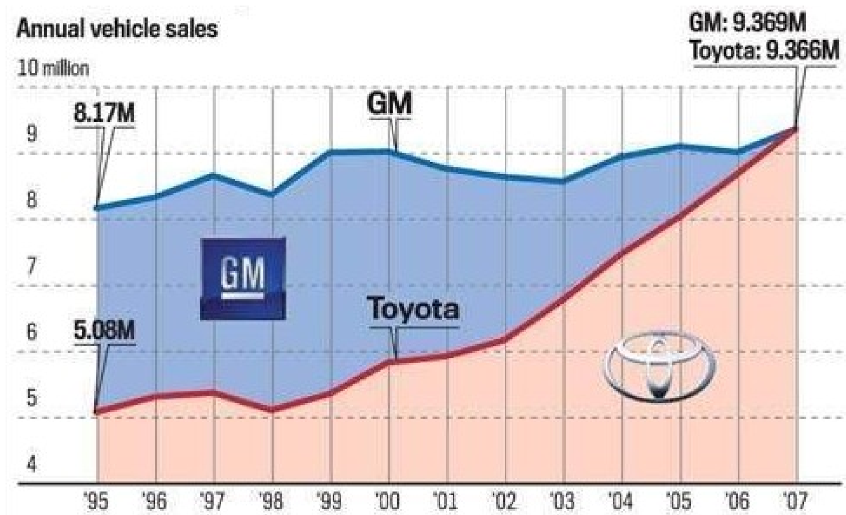


Figure 23., Toyota vehicle sales after the introduction of Prius (source: Global Insight: General Motors, Toyota)

The final argument is the Toyota RAV4 EV's Rebound Effect. Rebound effect or Take-back effect is a behavioral response to the introduction of a novel innovation. Rebound phenomenon is a tendency in the market that happens with the introduction and discontinuation of new technologies. In other words, if a sudden stall or stop in the production of a special innovation happens, the market gets hungry and thirsty and the signs of this enthusiasm will be even more than the time that the introduction first began (e.g. Grubb, 1990). Rebound effects are very difficult to quantify, and their size and importance under different circumstances is hotly disputed (Sorrel, 2007).

In 2003, when Toyota decided to stop its EV production, the company still had waiting lists of prospective customers. Near the end of this product's life time, Toyota was caught off guard by the market demand because the retailers had outsold their RAV4 EVs way faster than the vehicles could be supplied. Suddenly, Toyota started to crush its off lease EVs, from 2003 to 2005, a viral campaign with the support of DontCrush.com (now is PlugInAmerica.com) started to stop Toyota from crushing the remaining RAV4 EVs (see Greencarcongress, 2005). This campaign gave green vehicles more importance in the market and between academics and manufacturers. In this sense, RAV4 EV's rebound effect acted like a catalyst in Prius sales. Customers felt that in the absence of EVs, it is Prius who can serve them as a heroic green vehicle. It should be noted that RAV4 EV owners showed a great loyalty and most of them didn't want to replace their own cars. In the Internet, they even made an owners group and supported each other (ex, evnut.com RAV4 EV group), In contrast, researches didn't find any Rebound effect in the case of Prius (Haan et al., 2006), that means, any stall in Prius production won't necessarily cause any boost in other green vehicles sales.

In addition to the above findings, we shall not forget that Toyota RAV4 EV was a few years ahead of its time as far as market acceptance, but mainly because of the prohibitive cost of the battery pack (NiMH or nickel metal hydride) and self discharge disadvantage. The battery would have cost more than the car was worth at the time of replacement, so most of them were retired once the battery would no longer hold a charge. On the other hand, with the absence of electric vehicles in the market and along with the rising price of oil, Toyota introduced Prius II, Camry hybrid and later on Prius III that all had a great sale success.

Finally, the role of EV infrastructure must be considered too. Compared to the current time, a decade ago, EV charging points and battery swap stations weren't that available. For example in US, from 1996 to 2008, the only available charging station was General Motors EV1 with 500 charging points in California; A project that started in 1996 and was cancelled in 2001. But from 2008 to 2012, more than fifteen different companies have their own charging points in most of the important cities in US. Right now, with too many charging points and battery swap stations in most of the advanced countries, it has made it possible for EV owners to travel long distances and not have range anxiety.

Since electric cars are at least four times more energy efficient compared to ICEs, they are sustainable innovations. However, in this great transition from ICE to EV, hybrid vehicles played an important role. When the first generations of HEVs and EVs were introduced in Japan and US, there was an unavoidable skepticism in the mind of customers; especially not only where the battery pack was concerned, but also the vehicle‘s general reliability was highly in doubt. Many stated that hybrids were too risky, because it has two power sources and one of them is a new technology. As far as EV is concerned, for a long time, it was viewed as a particular technology for the short distance travels. The fact is that hybrid technology functioned as a transitional technology that prepared the minds of customers for the current generations of electric vehicles. In consistent, Franken et al. (2004) stated that HEV can function as a transitional technology that enables car manufacturers to experiment with innovations in various subsystems within the constraints of the current internal combustion engine regime. Currently, there are more than a hundred electric vehicles from different companies subjected for production, and out of them twenty eight EVs are being produced and sold in the market. Also, there are more than forty vehicles planned for future production.

It is rather interesting that green car technologies have shown a considerably growing variety in electric vehicle development. In the current state, electric vehicles can’t fade the importance of hybrid vehicles, nor can hybrid vehicles become the dominant technology in the market and both are developing along one another. During the period 1996 – 2008, a major policy shift caused manufacturers to become heavily involved in R&D and as a result, there was a sudden rise in patent listing of major car companies. The children of this R&D involvement were EVs, FCVs and HEVs. The previous stage in the transition from traditional gasoline cars to green cars mainly started by Toyota and its successful product Prius. The growing competition between automakers was considered as a positive factor of this transition between 1996 and 2003. However, of all the green vehicles developed in that period, Prius's success didn't happen out of the blue and indeed, Toyota had to sacrifice its own electric vehicle project. At production time, Toyota managed to communicate Prius similarly to the end values of the customers. The marketing and sales strategies surely have been the biggest influence in the success of Prius and failure of RAV4 EV. Toyota used its electric vehicle's market failure as an opportunity to feed the hungry market with another innovation. This is what Toyota does: Toyota's way of production and Toyota sales strategy.

6.2. Honda Environmental Leadership and sales follow up

In this section the Leadership dilemma and Product cannibalization of Honda Motor Company will be discussed. We will show that same as Toyota, Honda chose a strategic plan to promote HEV rather than EV. The same time that Toyota started its Prius family production, Honda came forward with Insight Hybrid and followed Toyota in HEV production. After 1990, both of the companies were focused on both HEV and EV development. Toyota introduced RAV4 EV in 1997 and Honda introduced EV Plus in the same year. Later, with the introduction of hybrid technology, Toyota and Honda pulled their EVs from the market and stopped further production. After that, Honda also produced Civic Hybrid and Accord Hybrid which both got a huge acceptance in the market. Honda is known as a strategic follower of Toyota.

Prior to the arguments in the next section, we would like to differentiate two terms that sometimes are mistaken in the literature: Market Leadership and Environmental Leadership. Based on Rouse (2007), Market leadership is the position of a company with the largest market share or highest profitability margin in a given market for goods and services. Market share may be measured by either the volume of goods sold or the value of those goods. In contrast, the Environmental Leadership concept of Dechant and Altman (1994) put the emphasis on getting a competitive advantage through approaching environmental issues. Figure 24 shows a schematic diagram of environmental leadership.

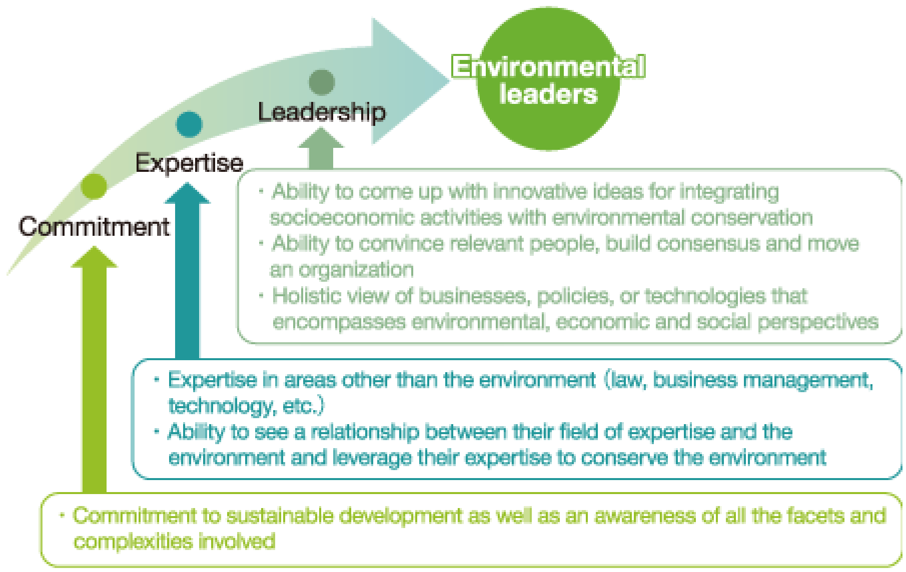


Figure 24., Environmental leadership (ELIAS, 2007)

This section tries to explain whether Honda Motors chose to become a market or environmental leader in green vehicles' race. In other words, as far as market penetration for green vehicles is concerned, can we still say that Honda is lagging behind or ahead of other companies?

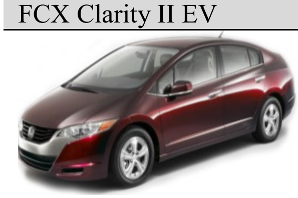
6.2.1. Honda's historical background, a leap from motorcycle to vehicle

Honda Motor Company was founded by Soichiro Honda in 1948 and since 1959 it has been the world's largest Motorcycle manufacturer. As a result, Honda has gained large benefits of economies of scale in internal combustion engines because of its motorcycle and power product businesses. Currently, it is the largest engine manufacturer in the world, with annually eleven million units for its product line and to sell to other companies. As far as the main markets, it should be mentioned that total automobile demand in Japan is declining and it is not just the vehicle market, but the market as a whole. Some reasons for that happening is that the Japanese market is affected by declining birthrates, aging population and shifting consumer preferences. The United States is one of the advanced countries with a growing population, and it is expected to have a stable growth in the automobile market. This makes sense when we found out that in 2001, North America accounted for 57.3% of the total revenue of Honda.

Honda's green production (electrification) started in the early 1990s and the starting cause was the Californian law makers. California Air Resource Board's (CARB) regulations were issued in Sep 1990 in the US, state of California and it was to take effect in 1998. A law, called ZEV mandate I which required car companies to sell a certain percentage of zero emission vehicles each year (initially 2 percent of the total number of car sales). Same as other auto manufacturers and even more importantly, to be able to keep its main market, Honda responded to CARB ZEV I by starting its green transition and R&D investments on EV development projects. The first practical outcome of Honda's hasty projects was EV-X which was the first EV of Honda. The company initiated this project in 1991, and exhibited the concept model in 1993 at the Tokyo Motor Show. This work made the base for all of Honda's future green vehicles.

Table 8 shows the main green vehicles of Honda, produced in the past two decades. From the early 90s until present, Honda has produced five models of EVs as well as seven models of HEVs. The difference is that none of Honda's EV projects ended up with mass production or any success in the market. For example, EV-X (1993) was a test model; only 340 units of EV Plus (1997 - 1999) were made and leased; only 30 units of FCX EV (2002) were made and were only for lease. In fact, FCX EV was the base technology for FCX Clarity EV (2009 - present), and based on the reports, only 200 units of Clarity were made and are currently leased. Honda announced that its mass production is scheduled to start from 2018. Also, Honda has produced 1100 units of Fit EV (2013 - present) only for a limited lease.

Table 8.,
Green vehicles of Honda from 1990 - 2012

Insight I HEV	Insight II HEV	Civic I HEV	Accord I HEV
			
1999 - 2006 3-door hatchback Sale ($18,880) NiMH	2009 – present 5-door hatchback Sale (~$19,800) NiMH	2001 - 2005 4-door sedan Sale ($20k) NiMH	2005 – 2007 4-door sedan Sale ($32k) NiMH
FCX Clarity II EV	EV plus	FCX EV	EV-X
			
2008 - present 4-door sedan Lease (600$/mth) Fuel cell	1997 - 1999 4-seat sedan Lease (455$/mth) NiMH	2002 2-door hatchback Test, Lease Fuel Cell	1993 - 1994 2-door hatchback Test NiMH
Fit HEV	CR-Z HEV	Accord II PHEV	Fit EV
			
1998 – 2002 Compact truck Lease NiMH	1996 5-door CUV Test, Lease (2500$/mth) Li-ion	2013 – present 4-door sedan Sale ($40k) Li-ion	2010 - present 4-door hatchback Lease (260$/mth) Fuel cell

On the other hand, most of Honda's produced HEVs such as Insight I (1999 - 2006), Civic (2001 - present), Accord (2005 – 2007), Insight II (2008 - present), Fit Hybrid (2010 - present), and CR-Z (2010 - present) have gained a huge reputation and market acceptance. This condition even caught the scholars' attention, as Burgelman and Schifrin (2008) wrote Honda, the large Japanese manufacturer and hybrid EV evangelist appears uncommitted to pursuing an EV strategy and does not plan to roll out mini-EVs until 2015. Meanwhile, Honda has continued its commitment in HEV production until recently, which it took EV more seriously and has invested hugely on EV technology R&Ds.

Motoatsu Shiraishi, Honda's director in charge of environment, confirmed that "Honda will pursue higher efficiency in internal-combustion engines, which are today's mainstream engine technology and as such represent the greatest near-term opportunity for reducing our environmental impact on a global scale" (Honda environmental report, 2006).

Honda started its EV development project with EV-X (1993) in US, California. Kenji Matsumoto, Honda's Large Project Leader (LPL) said: "Honda has a very big presence in the US, and in terms of market share in individual states, Honda ranks first in California" (Korzeniewski, 2008). And of course to keep the company's presence in the US, Honda had to follow CARB regulations. The company produced EV-X as a test vehicle. This new technology of Honda got a promising positive reaction from the test drivers. As the next project and certain of its success, Honda developed EV Plus. It is rather interesting that despite all the positive and hopeful feedbacks to EV-X, in reality, EV plus wasn't successful.

One reason is as Honda turned away fleet customers for the EV Plus, it played pick and choose as to whom it considered an acceptable retail consumer (Hollander, 2000). Honda produced 340 units of EV Plus and they were only for a limited lease. After two years, Honda pulled them out of the market and crushed them (same as Toyota and RAV4 EV I). The company defended the move claiming that the EV Plus was a car that no one wanted (Hollander, 2000). In fact, Honda was the only company that clearly shown evidence of stopping its EV production in favor of hybrid technology. In 2002, Honda produced FCX EV, which was the world's first Fuel cell EV. Only 30 units were produced in Japan and US for a limited lease and ground testing. Honda believes that this vehicle was the base technology for the next improved version, FCX Clarity EV 2008. Out of all mentioned EVs manufactured by Honda, none made it successfully through the market. They were all for a limited lease or test purposes. Car companies usually want to provide lease for their new models. There are a number of reasons for this, the most important being reliability. The car companies simply do not know how reliable these cars will be, especially their battery packs (Moore, 1998). Besides, the families leasing the cars are not only early adapters, but they also help the company with a real market test. Figure 25 shows Honda's eco-friendly vehicles from 1990 to 2012, along with the historical trend of oil price.

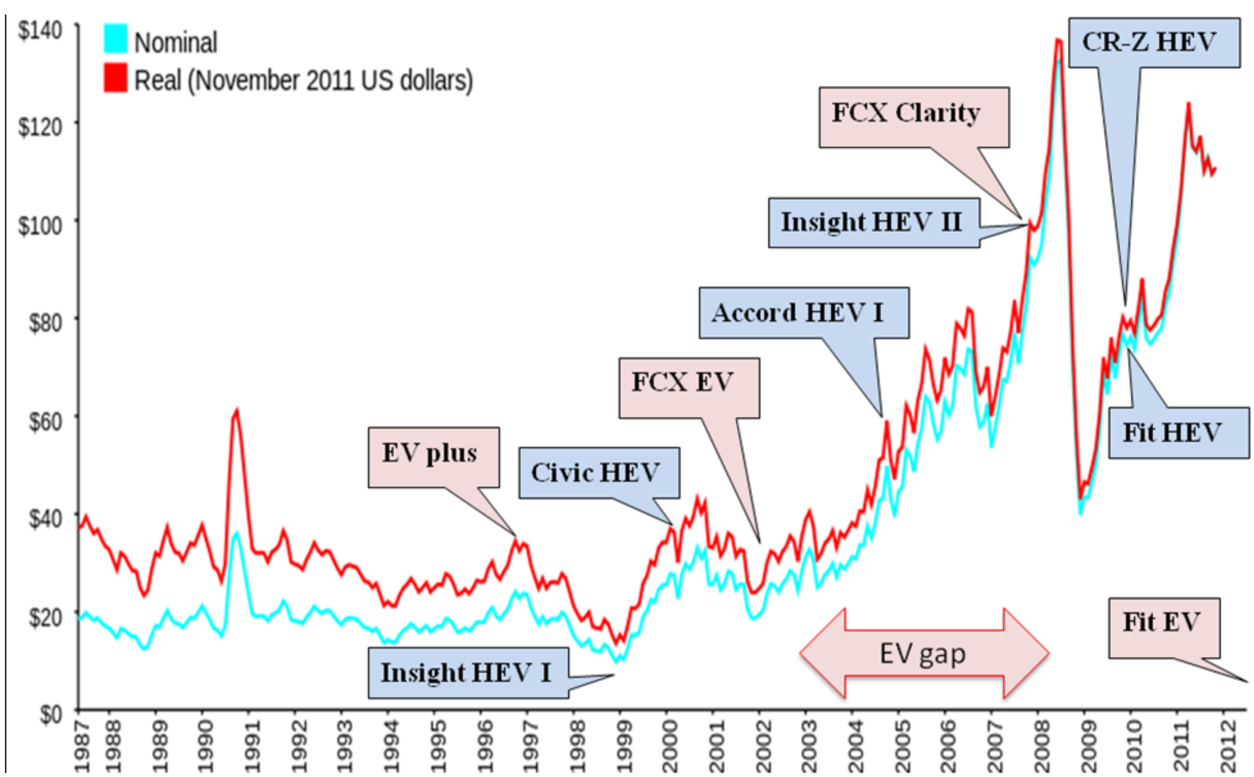


Figure 25., Honda's eco-friendly vehicles, 1990 to 2012 (compiled from: Energy Forum, 2011)

During the weak presence in the EV market, in 2012, cumulative sales of Honda HEVs reached one million units worldwide. Figure 26 shows the share of Honda's HEVs in US hybrid sales by model. Honda's share is shown inside the curved lines.

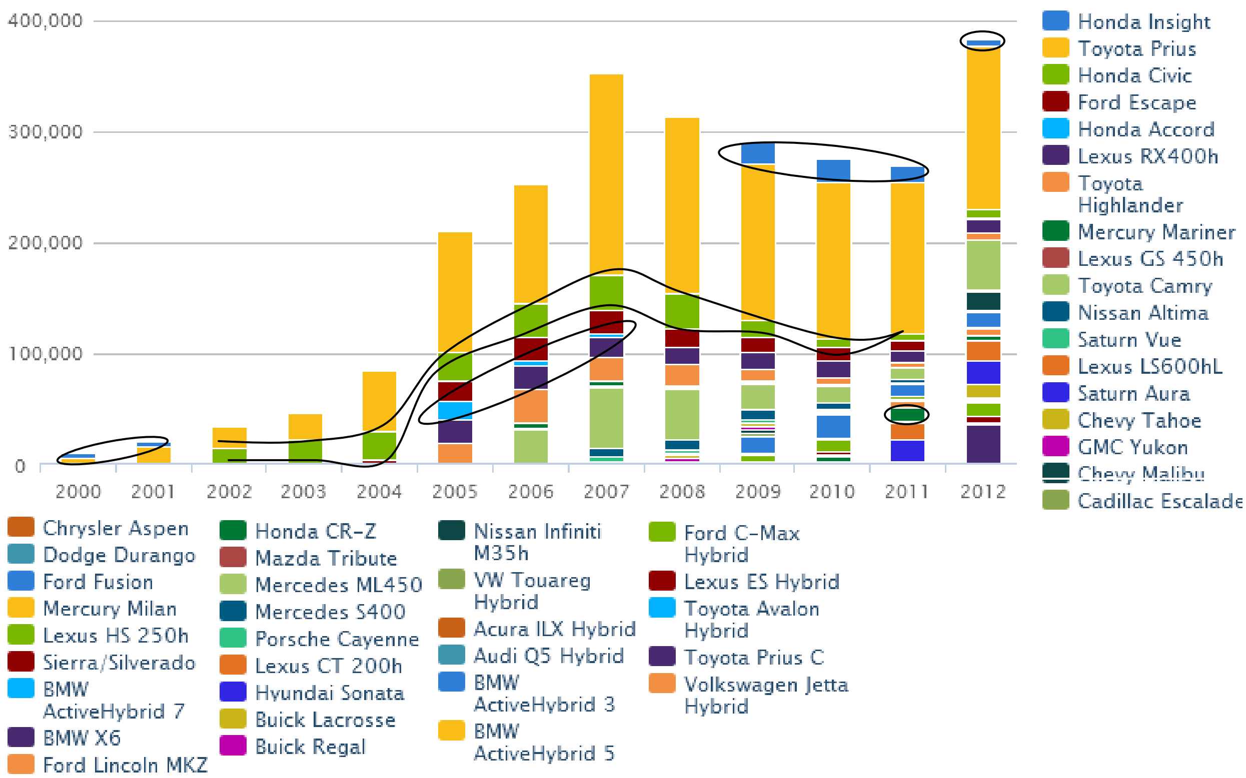


Figure 26., US HEV sales by model (source: Alternative Fuels Data Center)

Table 9 and figure 27 show Honda's net income from 1997 to 2012. Same as Toyota, from the early 90s, Honda's net income increased rapidly and in 2008 set a record of highest net income in Honda's history. At this moment, there are two important questions to ask. Did Honda want to become a Market Leader in green car production? (Tendency to Market Leadership) In addition, did Honda have a vision of Environmental Leadership in the green vehicles market? (Tendency to Environmental Leadership) The answer to both of these questions is yes.

Table 9.,
Net income of Honda between 1997 and 2012

Year	1997	1998	1999	2000	2001	2002	2003	2004
Net income	221	305	262	232	362	426	440	464
Year	2005	2006	2007	2008	2009	2010	2011	2012
Net income	486	597	592	627	150	282	563	222

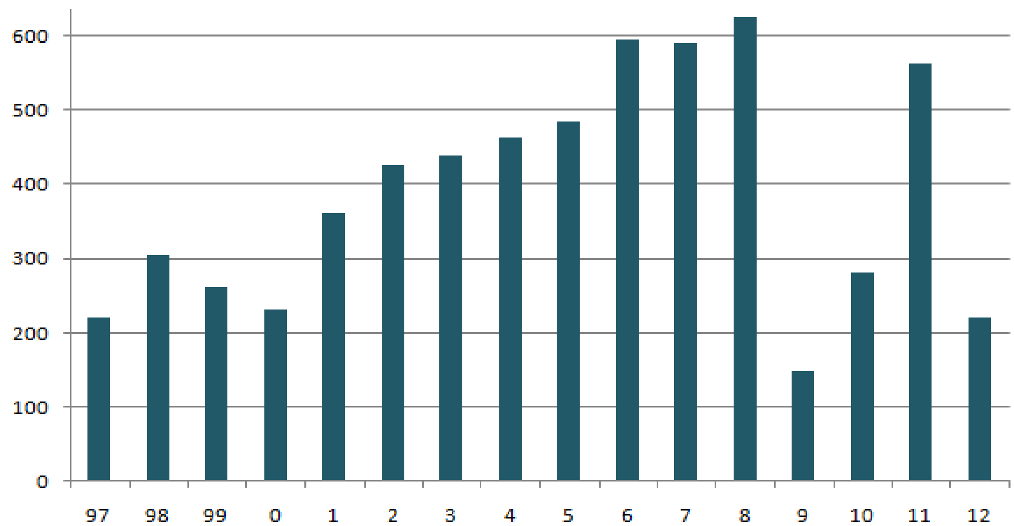


Figure 27., Financial condition of Honda between 1997 and 2012

Kazuhiko Tsunoda, chief engineer of Honda R&D, said: “Honda's strategy has been to lead the process of developing new environmental technology” (Tsunoda, 2000). In case of Insight he said: “our goal was to make Insight the world’s most fuel efficient mass production car” (Ibid). Consistent with the above argument, Hamel and Prahalad (1989) state Honda’s success was due to its focus on leadership in the technology of internal combustion engines. In both the Japanese and American markets, Toyota and Honda were competing against each other to gain the market leadership. Fontanelle (2007) notes Toyota and Honda’s competition in Green vehicles benefit both of the companies, especially in US, in terms of tech and popularity.

Why did Honda lag behind in EV production? Why would Honda neglect the growing market for a radical innovation called electric vehicles, and push hybrid technology instead? The answer, according to Thad Malesh, senior analyst and alternate-fuels specialist at J.D. Power and

Associates is: "Nobody wants to give up this huge investment in the combustion engines". Insight is essentially still powered by a conventional combustion engine. Only 6 percent of its power comes from battery technology (e.g. Hollander, 2000). In addition, Robert Bienenfeld, advanced environmental vehicle marketing manager for American Honda said: "Demand [for EV] was very, very tepid; we never had a waiting list of customers" (Hollander, 2000). Honda argues that selling thousands of the ultra-low-emissions hybrids and gasoline cars will do more for the environment than the leasing of a few hundred zero-emission electric cars. Bienenfeld continued: "Ninety-nine percent of cars are gas, so for the biggest bang, we have to solve that problem".

Honda's main concern in the past few decades has always been the superiority of its engines in terms of environmental friendliness, being pollution and noise free, and cleanness. Kazuhiko Tsunoda, chief engineer of Honda R&D, said: "Honda's strategy has been to lead the process of developing new environmental technology. More recently, our commitment to develop low emission vehicles has focused on developing advanced internal combustion technology." (Tsunoda, 2000). Before Prius took over the Hybrid vehicle market in the early 2000s, Tsunoda emphasized "our goal was to make Insight Hybrid the world's most fuel efficient mass production car" (e.g. Tsunoda, 2000). Years later, Motoatsu Shiraishi, Honda's director in charge of environment, repeated the same and said: "Honda will pursue higher efficiency in internal combustion engines, which are today's mainstream engine technology and as such represent the greatest near-term opportunity for reducing our environmental impact on a global scale" (Honda environmental report, 2006). As a result, Pohl and Yarime (2012) concluded that Honda's main motive behind the introduction of HEVs was to maintain a leadership in fuel efficiency.

This strategy of Honda is not only limited to Hybrid technology, but it also caused a huge transition in the fuel economy of Honda's ICEs. Figure 28 shows the transition in Honda's fuel economy from the mid-90s to the mid-2000s. In 1983, Ikuo Kajitani who was an engineer of Honda at the time developed an engine technology in house called "VTEC engine (dream engine)". The E (economy) version of the engine was introduced in 1992 and soon became the foundation for many of Honda's breakthroughs in environmental technology (Anderson and Zaelke, 2003). Later from 2001, Honda evolved VTEC-e into i-VTEC, k-VTEC, and R-VTEC. This evolutionary technology of Honda has been used in different types of vehicles such as Civic HX Coupe, Civic VX, Accord, and CR-V; and it also has been used for engine swap operations, especially in the US. VTEC series have the highest fuel economy in their class, with the air/fuel ratio of 65:1, while normally, gasoline engines have the air/fuel ratio of 14.7:1.

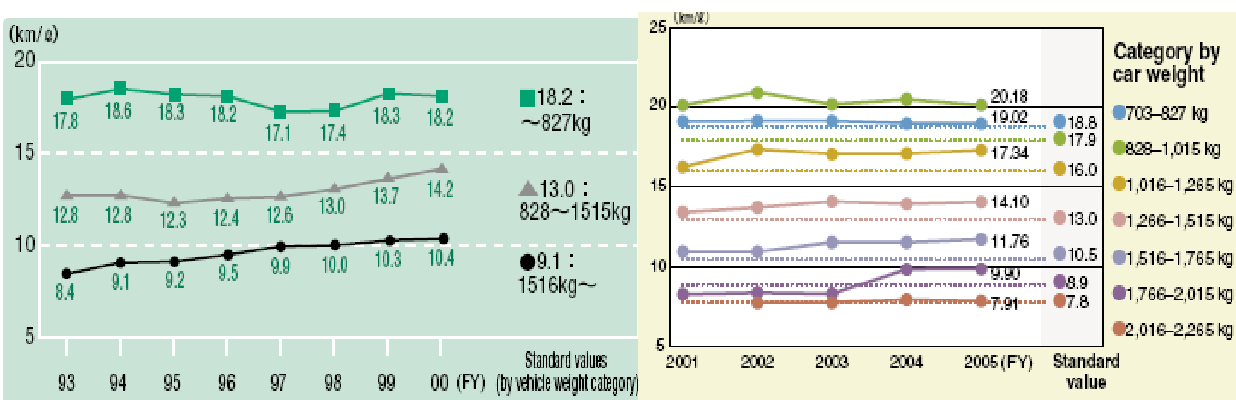


Figure 28., Transition in fuel economy of Honda gasoline vehicles – categorized by weight (source: Honda environmental annual report 2001, 2006)

Based on Honda's environmental annual report (2001), this system made it possible to achieve both a high fuel economy and a high level of exhaust gas cleanliness at an "Excellent" level. Considering the financial condition of Honda between 2001 and 2008 (Figure 27), it has been argued that Honda's success was due to its concentration on environmental leadership in the technology of gasoline engines (e.g. Hamel and Prahalad, 1989). Honda wanted to repeat its "being leader" strategy of engine technology, with focusing more on fuel efficiency rather than innovation and design, something that may cause Honda to fail in being a HEV *market leader*. Honda's gasoline vehicle fuel economy guaranteed the sales trend for Honda during the 2000s.

Honda's system of innovation is also a fact that shouldn't be ignored. Honda's innovation orientation was mostly around evolutionary innovation. In this sense, Honda mostly focused on improving the existing technology. Revolutionary technology is entirely new and represents a breakthrough in environmental performance. Evolutionary technology fine-tunes existing technology to further increase power and fuel efficiency and to reduce emissions (Anderson and Zaelke, 2003).

Tomohiko Kawanabe, who served as Honda's managing director, confirmed this and said: "Revolutionary breakthroughs like the CVCC were continuously improved until we reached the limits of emission reduction. When we couldn't go any further, we jumped to a new revolutionary technology and then continuously improved that" (Ibid). VTEC to i-VTEC improvement and the development of the exhaust filter (Perovskite 3-way Catalytic Converter System for Automobiles) are examples of Honda's evolutionary innovation system. In this regard, Toyota introduced its first Prius in the late 90s as a revolutionary vehicle, while Honda Insight was introduced as an evolutionary improvement. The hybrid Insight two door coupe looked like something out of a science fiction movie, was small and impractical, demanding that its buyers sacrifice space, comfort, and appearance in exchange for high gas mileage which customers were unwilling to do. Roy (2009) states its size and Spartan interior limited the car's general appeal and it required too many compromises. For marketing Insight I, Honda used a small budget for Internet and TV ads in local media, while Toyota used video clips sent to over

44,000 people, as well as a test drive option through 900 dealers. Toyota also dedicated a special website to Prius two years before the introduction of the product. Figure 29 shows Prius I and Insight I model comparison and early sales in US.

Figure 29., Prius I (left) and Insight I (right) model and early sales comparison – units (compiled from: DOE, 2008; photos from Mixed Power, The auto channel)

In the late 2000s, Honda changed Insight completely: A 4-door sedan with maximum safety, high fuel mileage, driven by aerodynamics. Roy (2009) wrote Honda insight II features were never even considered for the original Insight.

6.3. Nissan and late entrance into eco-friendly vehicles market

As one of the successful cases in this way, Nissan Motor Company Ltd. has always been famous for its environment friendly cars. In Nissan annual report 1998, it says “We are the only Japanese automobile manufacturer to provide environmental notes on the environmental specifications of all new models since June 1997”. Nissan always tried to show itself as an environment friendly company. It has been the industry leader in lithium-ion battery development for nearly two decades; it has produced the world’s first electric vehicle equipped with Li-ion batteries; and even now, Nissan has made a big leap in the electric vehicle world with its recent product Leaf 2010. In the hybrid vehicle production and compared to its rival Toyota Motors, until recently Nissan had never been much of a pioneer. Until 2007, Nissan has in total produced two hybrid vehicle models and both of them didn't fulfill the company's expectations in the market. As a result, their production stopped due to lack of customers.

In contrast with Chan's (2002) anticipation of "EVs and HEVs will still be coexistent", between 2002 and 2007, all major car companies didn't mass produce any electric vehicle. In these five years, because of a shift in major auto manufacturer's policies and other factors, there is a gap in green vehicle's production. For Nissan, this period of absence in the green vehicles market marked a great transition to true zero-emission mobility, a transition with five new EV models from 2009 to 2012. This chapter seeks to explain the reasons why this production gap in Nissan's green car production from 2002 to 2007 happened. In other words, compared to other auto manufacturers, did Nissan get benefit from this gap for its green vehicles production?

6.3.1. History and technological background

For understanding the EV and HEV development of Nissan trough time, it is important to consider the historical background of the company, as well as the nature of its political shifts. The company was founded in 1911 and it marketed vehicles under the Datsun brand name. In 1934, as a result of integration and later separation from Tobata Casting, a new company Nissan Motor was established. Until the 90s, Nissan was famous for its high quality, high commitment and environmentally friendly products. In the 90s, the company demonstrated its fragility. The first financial decline came in 1991 and the company's operating profit declined 64.3 percent. In 1992, Nissan registered its first pre-tax loss and this trend still continued. From 1991 to 1999, Nissan had been losing its market share continuously. Table 10 shows the Nissan annual net loss from 1992 to 2001.

Table 10.,
Nissan’s annual Net income and loss– in billions Yen

Year	1991	1992	1993	1994	1995	1996	1997	1998
Net income	101	(55.9)	(86.9)	(166)	(88.4)	77.7	(14)	(27.7)
Year	1999	2000	2001	2002	2003	2004	2005	2006
Net income	(684.3)	331	372.2	295	503.6	512.2	518	460
Year	2007	2008	2009	2010	2011	2012		
Net income	482.2	(233.7)	42.4	319.2	341.4	342.4		

(source: Nissan annual reports 1996, 1999, 2003, 2007, 2012)

In spite of the cost cutting measures (like reducing the materials and manufacturing costs) introduced by Nissan’s management for controlling the precipitous drop in the company’s income, this trend made Nissan downsize 12,000 of its employees in Japan, Spain, and the United States. Nissan was the first Japanese company to close a plant in Japan since Second World War. Before the 90s decade, Nissan was the largest Japanese automaker after Toyota, but this situation made Nissan’s share of Japan’s auto market fell from 34% in 1972 to 20% in 1997. Competition from Toyota and Honda played a major factor in this decline.

Nissan was also under a debt load and it threatened to bankrupt the company. The company's continued astronomical debt load as high as US$19.7 billion in late 1998. In other words, Nissan remained a troubled company. In 1999, world economic recession forced a decline in economic activities mainly in developed countries. As a result of this economic recession and the previous unfortunate situation of the company, in 1999, Nissan loss reached 684 billion Yen. Figure 30 shows Nissan’s annual income and loss from 1991 to 2012.

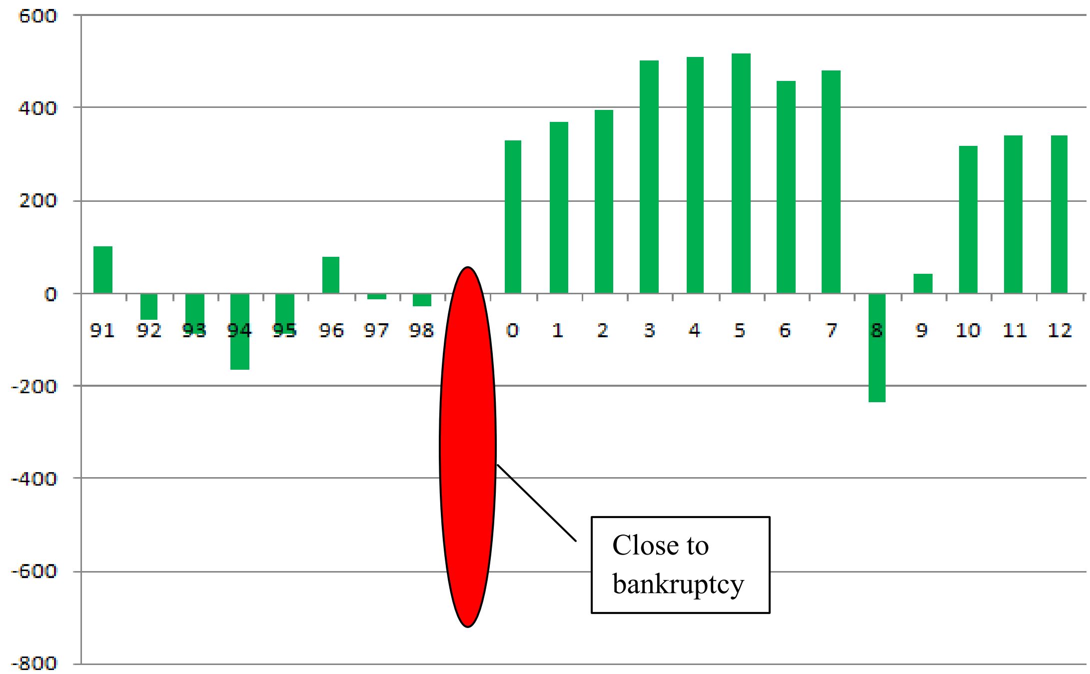


Figure 30., Nissan's annual Net income and loss– in billions Yen (Nissan annual reports 1996, 1999, 2003, 2007, 2012)

The late 90s was a period of strong consolidation and partnership in the auto industry. In 1998 the merger of Daimler-Benz AG and Chrysler Corporation formed DaimlerChrysler AG. At the same time, both Nissan of Japan and Renault of France were looking for a partner. They made a joint alliance in 1999.

Renault Car Company was owned by the French state from 1945, became a limited company in 1990 and was privatized in 1996. Right before the strategic alliance with Nissan, 55.8% of its share capital was owned by private shareholders and 44.2% by the French State. Renault was heavily dependent on the European market, responsible for over 90 percent of its revenues in 1998. In terms of geography, almost half of this revenue was from the company's home market and the remainder largely in Western Europe. In 1998, Renault sold about 2.2 million units worldwide, making it number ten within the industry. The problem was that Renault did not have a dramatic presence in Asia and it would have been very difficult to enter this market on its own. By the mid-1980s, however, Renault's performance began to falter. Although revenues remained strong, the company was losing money due to the high costs of a bloated workforce and inefficient manufacturing operations (IMD, 2003). From 1985 to 1995, by using cost cutting measures and downsizing, Renault began to improve its performance. The company steadily increased its revenue and returned to profitability. Figure 31 shows the performance of Renault from 1986.

Like many other companies Renault has been looking to expand into Asia for its large market potential, and North America. They felt that the best way to do this was through a strategic alliance. Renault has been looking for another automobile manufacturer to peruse a possible alliance with since the early 90's. In 1998 Renault did not sell cars to ASEAN or the Association of Southeast Asian Nations and North America. Renault was mainly present in Europe (in 1998 over 90% of its revenues), especially in France with 57% of the revenues generated there. Nissan would give Renault a powerful presence in Asia as well as in the United States. Renault could in turn provide Nissan with a strong base in Europe, where it currently has little market share, as well as in Latin America (Andrews, 1999).

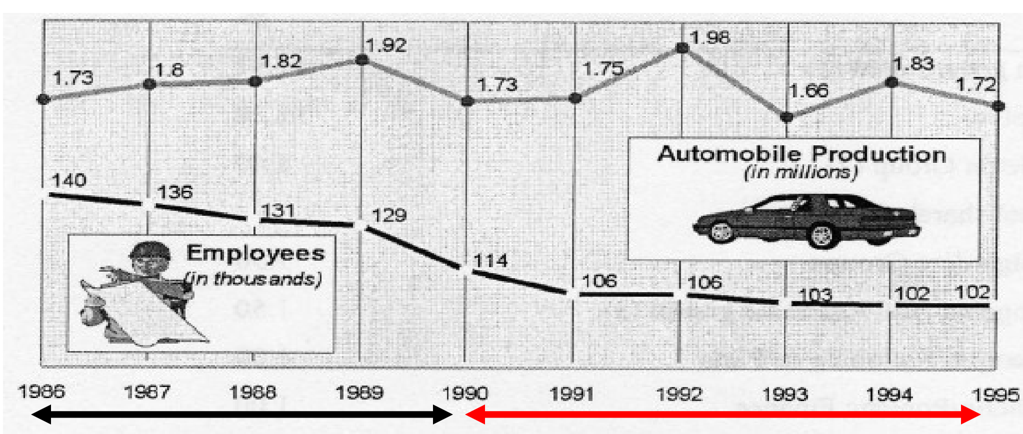


Figure 31., Renault's production and workforce from 1986 to 1995 (source: L'Express, March 13, 1997, p.32)

In the period of ten years from 1985, Renault downsized about 38,000 of its workforce, modernized its manufacturing plants, invested in new technologies, offered more attractive cars, and emphasized simplicity in production more than before. As a result and compared to Nissan, before the strategic alliance between the two companies, the Renault situation in the market was far better than Nissan. In Table 11, some selected financial data of Renault is shown.

Table 11.,
Selected consolidated financial data 1986 – 2012 (in billion FRF)

Year	1986	1987	1988	1989	1990	1991	1992	1993	1994
Net income	(5.8)	3.2	8.8	9.2	1.2	3	5.6	1	3.6
Year	1995	1996	1997	1998	1999	2000	2001	2002	2003
Net income	2.1	(5.2)	5.4	8.8	3.5	7.1	6.9	12.8	16.2
Year	2004	2005	2006	2007	2008	2009	2010	2011	2012
Net income	18.6	22.1	18.8	17.5	3.2	(20.3)	23	13.7	(9.8)

(Source: Renault annual report 2000, 2004, 2008, 2012)

Nissan and Renault started their talks in July 1998, and approximately 200 staff members conducted joint studies for several months to explore the possibilities of creating synergies by taking advantage of each other's strengths. In vehicle sales, Nissan was strongest in Japan and other parts of Asia, the United States, Mexico, the Middle East, and South Africa, while Renault concentrated on Europe, Turkey, and South America (International Directory of Company Histories, 2000).

In March 1999, Nissan and Renault signed a global alliance via cross-shareholding; that means in exchange for a 36.8% stake in Nissan Motor and a 22.5% stake in Nissan Diesel Motor Co.; Renault would inject US$5.4 billion into Nissan. Figure 32 shows an updated version of this strategic alliance.

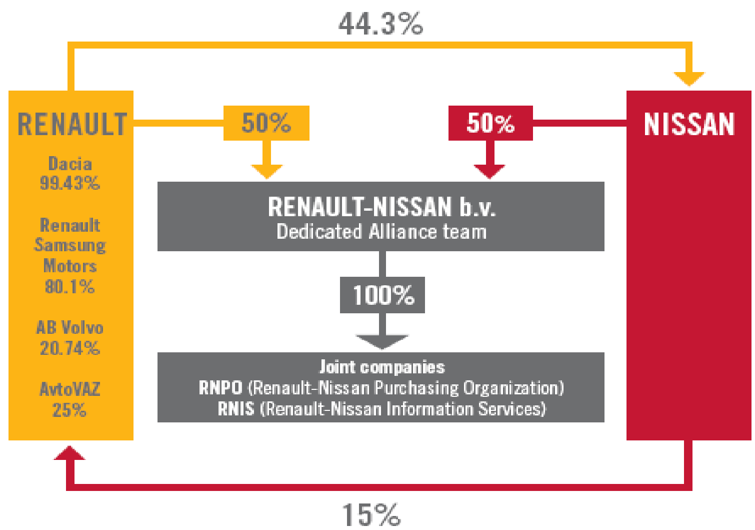


Figure 32., Nissan-Renault strategic alliance (Source: Nissan facts and figures, 1999)
*Renault-Nissan BV (RNBV) is a strategic management company to oversee areas like corporate governance between the two companies

The alliance was based on these principles: respecting their own corporate, keeping their own brand, and combining the strengths of both companies. Later, when Nissan's financial situation improved, it bought a 15% stake in Renault and Renault then increased its stake in Nissan to 44.3% and its stake in Nissan Diesel to 26%.

The Brazilian born Carlos Ghosn became the CEO of Nissan in 2001 and CEO of Renault in 2005. He rapidly began establishing a massive restructuring and re-engineering of Nissan. Because Nissan was billions of dollars in debt, it wanted a partner that could provide cash injections. As part of the agreement, Renault pumped US$5.4 billion into cash-hungry Nissan. The capital injection from Renault quickly reduced Nissan's debt load to ¥1.4 trillion (US$13 billion). In addition, Ghosn's cost cutting and restructuring of Nissan decreased the debt to US$6.5 billion. Because of his efforts in revitalizing Nissan, he became the most influential CEO of 2001 by Time magazine. Ghosn's efforts didn't stop there and Nissan offered new models and new replacements to find its position back in the market. The result of these changes shows itself in Nissan's annual financial reports. Figure 33 illustrates yearly improvements over the net income of the company. Before the strategic alliance, Nissan was close to bankruptcy but in five years since the alliance, the net income became more than five hundred million Yen.

Nissan wasn't the only one who benefited from this partnership. By accessing Nissan's know-how and expertise, Renault also improved its position in the market. By 2009, Renault-Nissan was the fourth largest auto-manufacturer in the world.

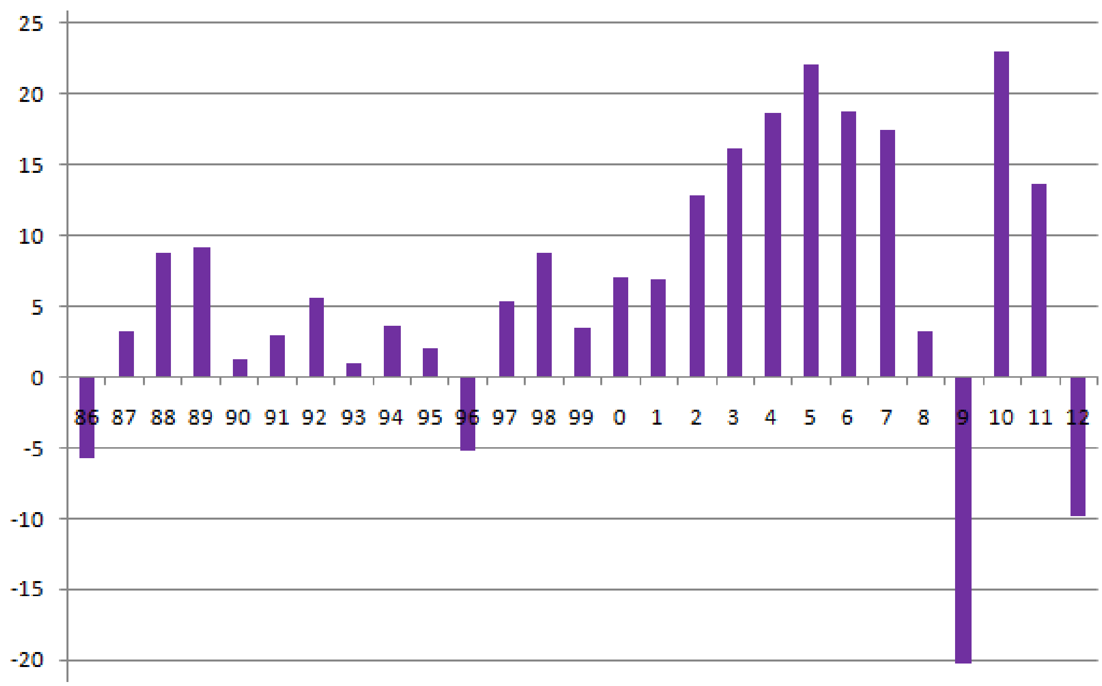


Figure 33., Renault net income improvement after the partnership, in billion FRF (Source: Renault annual report 2000, 2004, 2008, 2012)

Obviously, the Nissan-Renault alliance increased the economies of scale and market share for both companies as well as sped up their research projects using mutual synergies. By this partnership, each company could use and borrow the best practices of one another in a time of necessity. Figure 34 compares the net incomes of both companies during their alliance. 1999's World Economic Recession and 2009's World Financial Crisis affected all global companies' income as well as Nissan and Renault. In 2009, Nissan had to suspend its "GT 2012" business plan and announced a series of emergency measures. The GT 2012 plan will be discussed in the next sections.

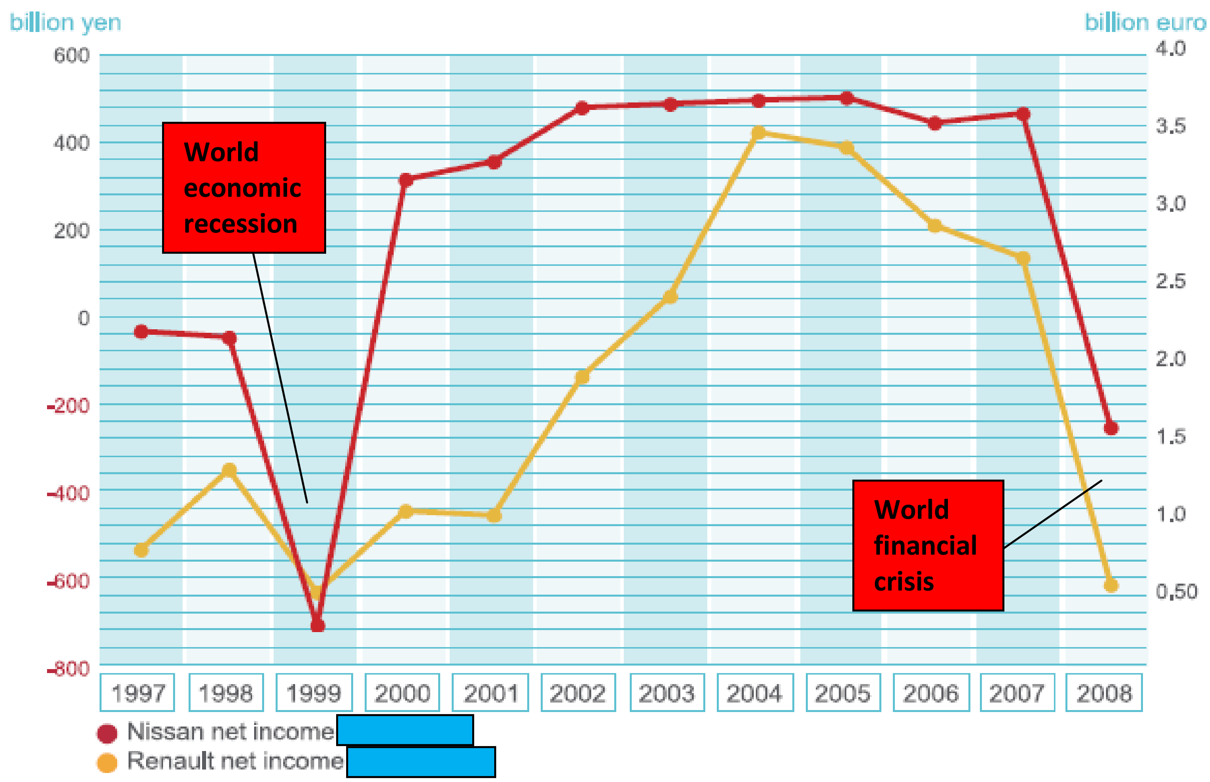


Figure 34., Nissan and Renault net income comparison during their alliance (Source: Nissan facts and figures 2009)

6.3.2. Failed cases

After World War II and because of the oil price fluctuations, Nissan has been paying special attention to green vehicles; and when we're talking about green vehicles, its mainly Electric Vehicles and Hybrid Electric Vehicles. Just after 1990, Nissan has introduced more than twenty EV and HEV test and concept models. Until 2012, of all the introduced models, there are only seven vehicles that went into mass production and of all these seven mass marketed vehicles, only one model gained real success in the market (success in terms of sold units).

As far as green vehicles are concerned, the first serious attempt of Nissan's after 1990 was called Nissan Prairie Joy EV. As the company claims, it was the first electric car equipped with Li-ion battery. A total of 30 units of this EV were sold mainly to scientific labs. Nissan always calls this vehicle as the basement of the company's future electric vehicles and as a symbol of their pledge to the environment. Table 12 shows the main green vehicles produced by Nissan.

Table 12.,
Nissan mass produced green vehicles from 1990

Prairie Joy EV	Altra EV	Hypermini EV	Tino Hybrid
			
1996 5-door CUV Lease (2500$/m) Li-ion battery pack Lab test Model	1997 - 2001 5-door CUV N/A Li-ion battery pack Failed	1999 – 2001 3-door hatchback $36,500 Li-ion battery pack Failed	2000 4-door sedan N/A Li-ion battery pack Failed
Altima Hybrid	**Leaf EV**	**Fuga Hybrid**	**Pathfinder Hybrid**
			
2007 – 2011 4-door sedan $33,000 NiMH battery pack Failed	2010 – present 5-door hatchback Japan ($44,600) Li-ion battery pack Auxiliary Lead-acid Successful	2010 – present 4-door sedan ~ $54,000 Li-ion battery pack ?	2014 - 5-door SUV ~$36,000 Li-ion battery pack ?

In 1997, Nissan produced Altra EV (introduced as R'nessa in Japan) and without any doubt, it was Nissan's first mass produced electric vehicle. This car gained a high reputation and it became an award-winning electric car, honored as one of the "greenest cars" by Green Guide to Cars and Trucks in 1999. Again, this car used a Li-ion battery pack, but only about 200 vehicles were sold in US and Japan and the production stopped in 2001. In US, its production was at the same time as Toyota RAV4 EV and Honda EV plus. All of the mentioned EVs were introduced in 1997 and all of them faced failure in the market.

In 1999, Nissan introduced Hypermini EV which again, got a lot of popularity and won the fourth annual "New Energy Grand Prize", sponsored by the New Energy Foundation of Japan (Nissan press release, 1999). One interesting aspect of this EV was its charging time that was less than all other EVs available in the market. Because of the high performance of Li-ion batteries, it took just about four hours for the car to get fully charged. Like before, the unfortunate destination of this vehicle was the same as the other ones. Only 220 units were sold in Japan and only 15 units went on lease in US. The production stopped in 2001.

Nissan didn't stop its efforts in the green vehicle movement; it introduced Tino Hybrid in 2000. This car was Nissan's first actual experience with HEVs and the company produced it in response to Toyota Prius I and Honda Insight I. Tino used a Li-ion battery pack and Nissan's in-home made NEO hybrid system. Internet sales started in Japan, while the company announced that based on the public's reaction to the Tino Hybrid, Nissan then will consider whether to increase the production volume (Nissan press release, 2000). About 100 vehicles were sold only in Japan and later, Nissan stopped the production due to low sales and the deterioration of the company's bottom line (e.g. The Asahi Shimbun, 2011). There were some car recalls from the company due to control problem.

In 2002, Nissan and Toyota reached an agreement aimed at actively developing hybrid cars. Based on this agreement Nissan could install Toyota's hybrid system, which features a gasoline engine as well as electric motors, in its vehicles that would be sold in the United States from 2006. It was obvious that Nissan had lagged behind Toyota in the development of hybrid vehicles, partially because of prioritized rehabilitation after its alliance with Renault. But Akihiko Saito, Toyota's Executive Vice president said that "(But) it is important for us to spread (our) environmental technology as long as (the cooperation) is profitable" (The Japan times, 2002). As a result, Nissan introduced Altima Hybrid in 2007. A car that used Hybrid Synergy Drive licensed from Toyota. It should be noted that Nissan has been producing Altima model (gasoline engine) from 1993 and until 2012, five generations of this car have been produced. Alongside Altima forth generation in 2007, Nissan produced its second hybrid vehicle, Altima Hybrid. Both cars had the same shape and from the outside it would be impossible to recognize them from one another. Altima Hybrid was only available in the US market with the price of US$33,500. Critiques said that its quality is as per as Toyota Camry. Nissan axed the hybrid model from its new Altima lineup in 2013 (e.g. Healey, 2012). As a result, Altima fifth generation 2013 would be gasoline only.

Nissan stopped the production due to poor sales. Based on Hybridcarblog.com (2009), a significant percentage of Altima hybrid owners had complaints about dead battery, poor dealer service, lights, etc. The Altima Hybrid only sold in a few selective markets and the total sales of this model from 2007 until 2012 was about 36,500 units. This vehicle was a failure compared to the other hybrid models. In other words, the *Toyota-Nissan-built* Altima's success is not even close to the mainstream hybrid competition from Toyota, Honda and Ford, so Nissan decided to kill it off. Maybe one of the reasons is that the Altima Hybrid came to the market at the same time as the gasoline engine Altima IV in 2007. Altima forth generation used VQ35DE and QR25DE engines. They have low gasoline consumption and are very close to being called eco-friendly engines. Table 13 compares top hybrid cars sales in 2007.

Table 13.,
Hybrid vehicle sales of 2007

EV	Nissan Altima	Toyota Prius	Toyota Camry	Honda Civic	Toyota Highlander	Lexus 400h	Ford Escape
sales	8,827	158,884	46,272	31,297	19,391	15,200	19,522

(source: Electric Drive Transportation Association)

6.3.3. Successful cases

In 2007, Nissan executives decided that Nissan's future likelihood must be EV, a dream that soon came true. Ghosn believes that by 2020 purely electric zero-emission vehicles will represent 10% of the global car market, and plans to make Renault-Nissan the first big manufacturer of zero-emission vehicles (economist, 2009). As a result, Hidetoshi Kadota was appointed as Chief Vehicle Engineer for the first truly practical zero-emission electric car. A car designed for the mass market and later to be named "Leaf". Kadota had worked on a number of electrification projects such as Infiniti M35h (Nissan Fuga Hybrid System).

Table 14.,
Nissan Leaf annual sales in the world

Year	2010	2011	2012*	2013	Total
sales	38	21,733	26,178	45,874	93,823

* as of September 30, 2013

Nissan introduced Leaf EV in 2010. Leaf uses a Li-ion battery pack and the company claims that the car is 90 percent recyclable. Until now, the top markets of Leaf have been Japan by 33,230 and US by 42,122. Right now it is being sold in 16 countries. Nissan leaf received a high reputation and lot of awards: the 2010 Green Car Vision Award, the 2011 European Car of the Year award, the 2011 World Car of the Year, the 2011-2012 Car of the Year Japan, EV.com's 2011 EV of the Year, 2011 Green Fleet Electric Vehicle of the Year, and 2011 Eco-

Friendly Car of the Year by Cars.com. Table 14 shows the annual sales of Leaf in the world from 2010 until present.

For a better understanding of Nissan's strategy for Leaf, again we have used Rogers Diffusion of Innovations to describe the marketing strategy for Nissan Leaf. According to Rogers (1962) definition, with successive groups of consumers adopting the new technology (shown as a bell curve in Figure 35), its market share (yellow line) will eventually reach the saturation level. Figure 35 shows the Nissan Leaf marketing strategy. Ghosn believes that the trend that started in the market will lead Innovators, Early Adopters and the Early Majority groups of customers (shown in the pink oval) to green vehicles sooner or later: A trend that is caused by the high fuel prices and environmentally-friendly products. The only matter is time and to be patient and prepared for the right moment. For the Late Majority and Laggards (shown in the blue oval), Nissan will focus on some practical tools like education, advertisement, presentation of fine information, zero emission tours, test drives and training cab drivers.

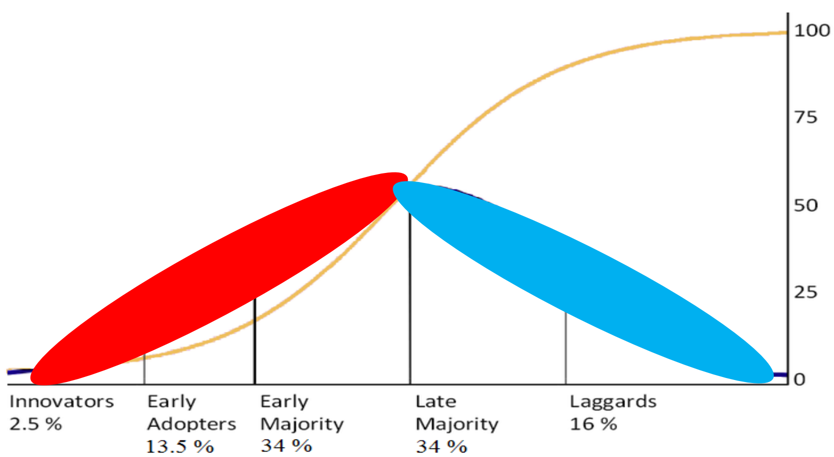


Figure 35., Nissan Leaf marketing strategy

Nissan's green cars legend is still ongoing. In 2010, Nissan introduced its first in-house developed hybrid electric technology: Fuga Hybrid. A car that the company claimed would double the fuel economy of its previous version. It's rather interesting that Toyota and Honda had the hybrid technology in 1997. Similar to the Altima Hybrid, Nissan was producing Fuga from 2004 as a gasoline engine vehicle. For the second generation, Nissan produced Fuga under the brand of Infiniti M56. The car uses a Li-ion battery and currently, together with Leaf, they make Nissan’s flagships toward green vehicle production.

Nissan Fuga Hybrid got a high reputation as well as awards. For example, 2010 Ward's Auto Interior of the Year, 2011 Popular Mechanics Automotive Excellence Award, 2011 Insurance Institute for Highway Safety Top Safety Pick, are some of them. In 2011, Infiniti M35h sets an official Guinness record for world's fastest hybrid (a quarter mile in 13.9031 seconds). Well, Infiniti M35h sold 324 units in 2011 and it is too soon to judge its success in the market. Figure 36 shows Nissan’s green vehicle production’s timeline that is from the company’s first serious attempt for entering the market in 1996 to the current and its only successful case, Leaf 2010. From 2000 to 2007, there is no green vehicle introduced by the company.

Why wasn’t Nissan successful in any case of electric or hybrid vehicle before Leaf 2010? In other words, compared to other green car manufacturers like Toyota, Honda and Ford, why did Nissan’s successful track start so late? It should also be emphasized that Nissan started its efforts as early as the other car manufacturers. From 1996 to 2000, the company could just introduce four green vehicles to the market. So in terms of being up-to-date and keeping the pace with the trend of the market, Nissan’s responses were excellent, but at the same time unsuccessful. In other words, the problem is while other manufacturers were enjoying the fruits of their green vehicles, Nissan lagged behind them for more than a decade.

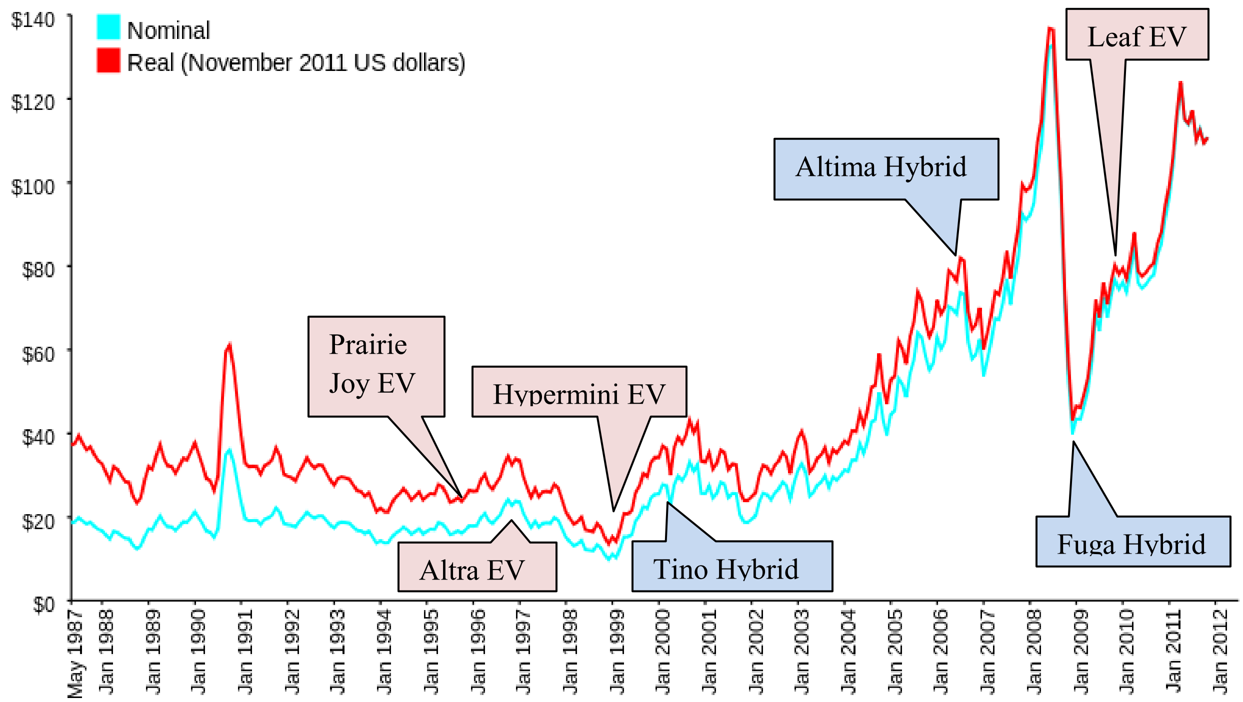


Figure 36., Nissan HEV and EV introduction along with oil price – EVs shown in pink (compiled from: Energy Forum, 2011)

There are four major reasons that Nissan couldn't find its place in the green car market. One reason is the battery breakthrough of Nissan. The greatest hinder in EVs development is the battery pack needed to run the electric vehicle. Weight and cost of batteries are two big disadvantages compared to gasoline engine. That's the reason why it has been the main obstacle in the EV's fight for consumer market share. As far as Nissan is concerned, Nissan's main leap toward battery development happened later than other main rivals. Mark Perry, Nissan's director of product planning and advanced technology strategy said (see SAEinternational, 2012):

> "*Our battery breakthrough happened in 2003, and after that it allowed us to achieve an energy-density packaging, size of the battery pack and chemistry. The architecture actually changed completely and once we found that nexus of all those variables, then we felt we could actually go to mass production*".

It should be noted that it took Nissan another four years to practically mass produce the first after breakthrough vehicle; that was Altima 2007.

Another reason that Nissan's green vehicles couldn't fulfill their manufacturer's expectations in the market is the company's other vehicle's high technologies. This could be explained by the fact that other vehicles of Nissan have consistently been on the forefront by optimizing their gasoline engines, especially when it comes to developing Eco-cars[4]. An Eco-car is a leading automotive technology that aims at minimizing the environmental impact of personal transportation. By this definition, all gasoline engine vehicles that cope with some standards in gas emission and environmental factors are considered as Eco-cars. In other words, without worrying about the rising competition in the new green vehicle technologies, Nissan had a guaranteed path for its sales. For example, Nissan Sentra CA model received California Air Resources Board (CARB) super ultra low emission vehicle (SULEV) certification and obtained zero emission credits. Also, Nissan 350z was certified as an ultra-low emission vehicle (ULEV) under the low-emission vehicle certification system of the Ministry of Land, Infrastructure and Transport in Japan. It should be noted that other vehicles of Nissan such as Elgrand, Skyline and Infiniti G35 received a lot of reputations and their high sales strengthened Nissan's position in the market (from 1991 to 2007).

In addition to the above finding and argument, Nissan's high technology engines also should be reminded, and that makes it the third reason: advanced engines technology of Nissan. For decades, Nissan's vehicles were at the top of the list in terms of engine power, noise and

[4] Eco-car means Eco friendly car and shouldn't be mistaken by Ecocar that means Economic car

vibration level, technology and lower emission. For example, VQ and VK series engines have improved Nissan vehicles performance compared to other company's vehicles.

VQ series engine was introduced by Nissan in 1994 and from that time it was used in dozens of the company's vehicles. By 2008, the VQ series engine was honored by Ward's 10 Best Engines list (Ward's AutoWorld magazine) almost every year from the list's inception, making it the 14th straight year a VQ series engine has earned that distinction. Vehicles such as Cefiro, Elgrand, Leopard, Cedric, Teana, Maxima, Cima, Pathfinder and Fuga were some of Nissan's successful gasoline vehicles in the market that have used VQ series engines. After the strategic alliance with Renault, the French company also benefited from this technology. Safrane, Escape and Vel Satis are some of Renault vehicles that have used Nissan's VQ engine. Because of the high performance, Nissan used this engine along with an electric motor in Infiniti M35 Hybrid to introduce its first in-house developed hybrid technology.

Coming to the forth reason, Nissan started its Electrification plan called GT 2012 in 2007 (G stands for Growth and T stands for Trust). Carlos Ghosn, CEO of Nissan, unveiled the five years plan which outlines the company's goals to enter the race of developing environmentally friendly vehicles. Ghosn said that Nissan was determined to achieve zero-emission-vehicle leadership. In May 2008 issue of The Economist, Ghosn said, "We must have zero-emission vehicles. Nothing else will prevent the world from exploding." In this sense, in that moment Nissan executives decided that Nissan's future likelihood must be EV. As a result, Hidetoshi Kadota was appointed as Chief Vehicle Engineer for the first affordable zero-emission electric car, later to be christened "Leaf". Kadota worked on a number of electrification projects before, including Infiniti M35h (Nissan Fuga Hybrid System). The question is: what about Nissan's strategy before the GT plan? It is rather interesting that before 2007, Nissan's top management mainly believed that the internal combustion engine (gasoline engine) will continue to serve as the main power source for vehicles.

John O'Dell, senior editor at Edmunds.com, wrote in a New York Times article: "It wasn't long ago that Carlos Ghosn was a big naysayer about the role of electric vehicles. Obviously, something has opened his eyes. For the past few years, Ghosn has consistently called gas-electric hybrids "niche products" and "not a good business story." In 2005, he said, "We do not want to build or sell cars that do not make a profit" (hybridcars.com, 2008). Ghosn also believed that California's greenhouse measures are the only legitimate reason for moving toward electric cars. Hakim (2002) wrote about Ghosn which stated: "Nobody believes in it, but you have to do it. It's a huge cost, but its part of the cost of doing business". Dominique Thormann, senior vice president of administration and finance for Nissan in North America, confirmed this view: "Hybrids are not a very viable economic proposition, there's got to be a reason why people are going to buy hybrids" (Calcars, 2006).

After the shift in the management mindset about the future tendency of the company, in an interview in May 2008, Ghosn said Nissan decided to accelerate the development of battery-powered vehicles because of high gasoline prices and environmental concerns, not just because of the need to meet stricter fuel-economy standards (Vlasic, 2008). It is interesting that years later in a speech to the National Automobile Dealers Association, he called electric hybrids "niche products" useful only to meet strict fuel-economy and emission standards in states like California (Ibid). Based on the previous arguments, Nissan's shift in the strategy didn't appear until 2007 and by that time, Toyota, Ford and Honda had already made their moves in the green vehicle market. Based on World Watch Institute, in 2007, a total of 541,000 hybrid vehicles were produced and Nissan's share was only 8,800 from Altima.

The current stage of technological transition in the automobile industry started from the mid-90s with the introduction of Electric Vehicles and Hybrid Electric Vehicles. This strong shift caused by environmental factors, oil increasing price and auto manufactures' strategies mainly was responsible for all the new models of EVs and HEVs that came to the market. This shift caused an electrification wave to occur. From 1996, car companies became involved in electric battery R&Ds and introduced the first generation of Electric and Hybrid vehicles. Of these models only a few such as Toyota Prius and Honda Insight and Honda Civic were sold successfully in the market. Similar to other manufacturers, Nissan Motor Company also introduced its first generation of EVs and HEVs.

Marketing theory states that it is easier to penetrate a market in growth, since the competitive situation is less hostile and sales growth can be achieved without affecting competitors' revenue (Johnson, Scholes & Whittington, 2005, p. 344). As it is obvious from Figure 36, from the end of the 90s decade until 2009, oil price had an increasing trend and this made it an opportunity for car manufacturers to come out with their own strategies. Toyota as the leader of green vehicle development (Cumulative Prius sales 3 million until June 2013), Honda, Ford and later GM could use this period of time well. In contrast, Nissan's electric and hybrid sales still continued to be a small part of the overall picture. Even in the future, the race to market for green cars will soon become more and more. Currently, the entire industry from China and India (companies like BYD, Tata), Europe (Benz, BMW, Peugeot), USA and Japan (Ford, GM, Nissan, Honda and Toyota) has joined the movement to develop and market affordable EVs. Indeed, Nissan strategies surely have been the greatest hinder in the success of its green vehicles. But after the change in Nissan's echelon's mindset, it took time and money to change the global car perception and support infrastructure, a process that took at least 2 or 3 years and millions of dollars in investment.

6.4. Mitsubishi's electrification strategies

In this chapter, we will investigate Mitsubishi's eco-friendly vehicle manufacturing trend and the company's position in the global automobile market. We will show that Mitsubishi's technological choice in terms of green vehicles is somehow similar to Nissan. They both started later than other companies and declared EV production as their core electrification strategy in the late 2000s. It should be mentioned that Mitsubishi has always been known as a committed company to EV development. Between all of the Japanese auto manufacturers, Mitsubishi has produced different test EVs and HEVs models, with more than 19 different vehicles from the 1970s, more than any company in the world. They have mainly been for test purposes, but only three of them went through mass production phase from 2009. Why didn't Mitsubishi come with a mass produced eco-friendly vehicle between 1996 and 2008? It is interesting to see with all the technological experience, why Mitsubishi lagged behind other companies in introducing an earlier successful eco-friendly vehicle.

6.4.1. Mitsubishi's thirty years history of electrification

Mitsubishi group is a conglomerate of independent companies accomplishing a range of businesses which share the same brand name such as Mitsubishi Electric, Mitsubishi Chemicals, Mitsubishi Cable industries, Mitsubishi Heavy Industries, Mitsubishi Chem, etc. Mitsubishi's R&D on the electric vehicles started from 1966. At that time Mitsubishi Motors still belonged to Mitsubishi Heavy Industries, Ltd., but Mitsubishi Motors had already been developing electric vehicles mainly for the electric power company's use in its power-generating stations or sales divisions up to the early 1990s (Yoshida, 2009). Mitsubishi Motor Company (MMC) was formed in 1970. As an independent entity, MMC designed its first actual EV, called Minica EV, in 1970. MMC continued to develop EVs in response to the oil crisis and air pollution (e.g. Hosokawa et al, 2008). In the 1990s, demand grew for protecting the ozone layer and addressing global warming. In this period, MMC developed EVs which were delivered to a Japanese electric power company (Ibid). MMC developed its first in-house hybrid vehicle Chariot HEV in 1994, a year before Toyota launched G21 project that resulted in the Prius family. This means MMC had the hybrid technology, or something similar to it, earlier than other main industry actors. Later in the mid 2000s, MMC became serious in making eco-friendly vehicles as its main green manufacturing strategy and mass produced its first successful EV called iMiEV in 2009. As far as the financial situation of MMC in the past two decades is concerned, the company until recently was dealing with a serious financial crisis and at one moment, the company was close to bankruptcy. Table 15 and Figure 37 show the MMC's net income from 1994 to 2012.

Table 15.,
Net income of MMC between 1994 and 2012

Year	1994	1995	1996	1997	1998	1999	2000
Net income	12,6	12,7	11,6	(101,8)	5,6	(23,3)	(278,1)
Year	2001	2002	2003	2004	2005	2006	2007
Net income	11,2	37,3	(215,4)	(474,7)	(92,1)	8,7	34,7
Year	2008	2009	2010	2011	2012		
Net income	(54,8)	4,8	15,6	23,9	38		

(source: Mitsubishi annual reports, 1999, 2003, 2008, 2011; Mitsubishi Motors press release, April 2013)

From 1997, MMC faced a very challenging decade ahead, with losing it's market share, political scandal and ending a profitable partnership with Daimler Chrysler. Mitsubishi Motors President, Katsuhiko Kawasoe, in 1998 stated that "in 1997, the company recorded the worst losses in its history, dividend payment was cancelled, and our share price was scraping rock bottom." (Mitsubishi annual report, 1999). In 1999, he said "Mitsubishi Motor Company has lost money for most of the 1990s" (Chandler, 1999). But compared to the early 2000s, MMC still had its German partner and key foreign based executives. In response, MMC announced Renewal Mitsubishi 2001, a mid-term three years management plan, to recover at the earliest possible time. In 1999, Mitsubishi cut 15% of its production line due to lack of sales in Japan (Mitsubishi annual report, 1999). The results improved the sales for a short time. It was mainly to reduce cost and liabilities, but with no focus on innovation. In its annual report 2003, published on March 2003, Mitsubishi stated that it was satisfied by the results of its three years cost reduction plan. The result was a substantial increase in their operating profit. In 2000, MMC was implicated in a cover-up scandal that resulted in the belated recall of about 600,000 cars and trucks, but company officials blamed poor maintenance by the trucks' owners. It has been said that since the 1980s, the automaker systematically hid defects involving 800,000 vehicles. The scandal shocked Japan. At least 40 prefectures and local governments banned the purchase of Mitsubishi vehicles, and the Japanese press was issuing almost daily reports on fires and accidents involving Mitsubishi cars and trucks. Mitsubishi sales were plummeting, and analysts said the company may not survive. (Faiola, 2004).

Mitsubishi started its alliance with American Chrysler in 1971. After the merger with Daimler and as a part of injecting cash into MMC, in a two step deal, Daimler Chrysler purchased a 37.3% stake in MMC. But in 2004, its stake was sold back to Mitsubishi Group. DC share decreased to 23% and one year later it decreased to 12.4%. As a result, the situation got worse and MMC was very close to fileing for bankruptcy. The company cut 22% of its global work force, closed an assembly plant in Japan, and received a $4 billion infusion from the Mitsubishi group and other investors (Associated Press, 2004). At this moment, some of the critical heads of MMC's foreign offices left the company. In 2004, Mitsubishi group for the second time financed $4.6 billion to help MMC. Again in 2005, Mitsubishi group financed $2.9 billion to help MMC.

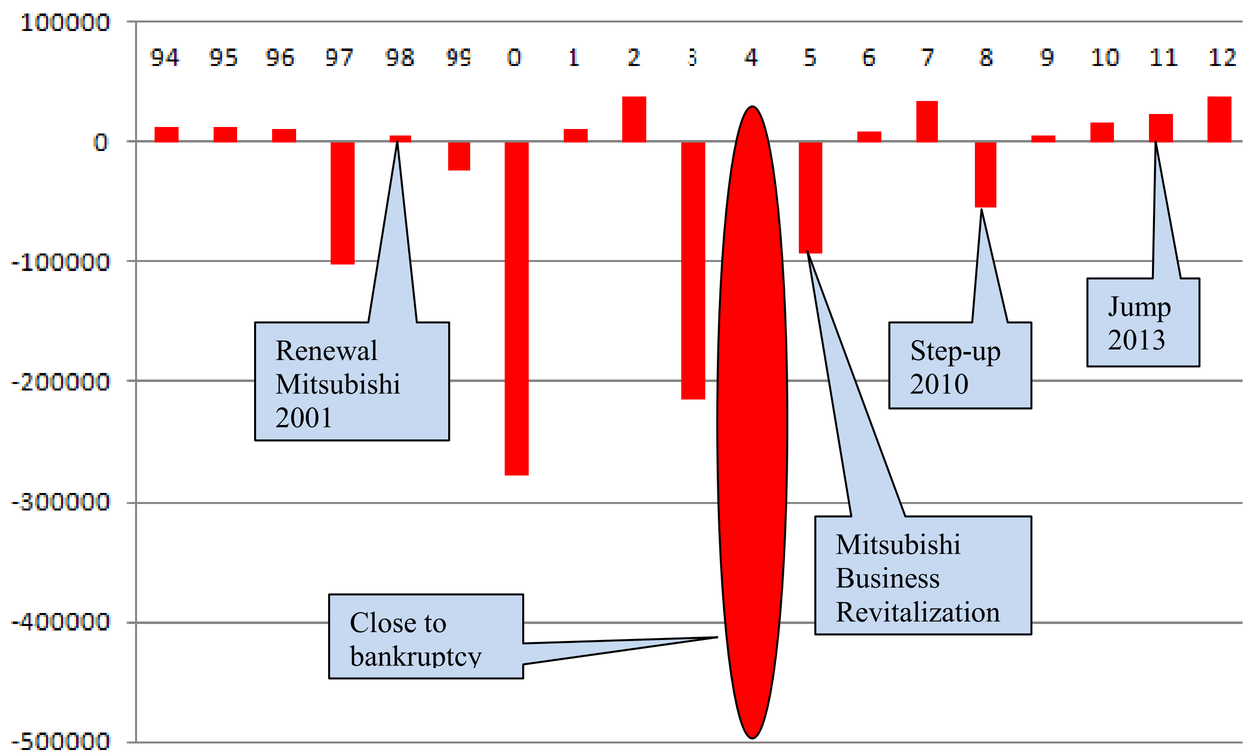


Figure 37., MMC financial crisis

Mitsubishi Group continuously supported sinking MMC through cash injections. From 2005, MMC initiated a few mid-term and long-term projects to recover such as Mitsubishi Motors Business Revitalization Plan 2005 (2005- 2007), the step up 2010 (2008 - 2010), Jump 2013 (after Tohoku earthquake) (2011 - 2013), and The Mitsubishi Motors Group Environmental

Vision 2020 (focus on eco-friendly automobiles from 2013). It should be noted that without the financial help from Mitsubishi Heavy Industries, Mitsubishi Corp, and Mitsubishi UFJ Financial Group, MMC couldn't become profitable again.

6.4.2. Mitsubishi's eco-friendly fleet

Along with Nissan, Mitsubishi also broke new grounds of developing EVs and HEVs in Japan. Historically, Japan established its first agency of environmental affairs, the Environment Agency of Japan in 1971, to address air pollution at the time. At the height of Japan's rapid economic growth, EVs were considered the solution to air pollution and automakers competed to develop EVs (Hosokawa et al, 2008). As a pioneer, Mitsubishi's efforts for commercializing EVs in Japan made it easier for other companies to do the same. Yoshida, general manager of EV and Power train System Engineering at Mitsubishi Motors, stated that "I had the privilege of clearing the path for the future" (e.g. Yoshida, 2009). Mitsubishi first developed Minica EV in 1970 and Minicab EV in 1971. It was provided for power companies and the government, and more than 1000 units were delivered (e.g. Mitsubishi fleet history, -). In a period of twenty years from 1971 to 1991, MMC developed four models of EVs, Delica EV 1979, Minica Econo EV 1983, Libero EV 1991, and Lancer Van EV 1991. Except Libero EV, which 36 units of them were sold in total to the electric power companies, not for public use, other models were only concept and test models (e.g. Hosokawa et al., 2008). Even Libero had a lot of problems with performances and cost, and it was not a car that could be used normally. Only 36 units of Libero EVs were sold in total for the electric power company's use only. MMC then started its practice with hybrid technology. MMC developed the first test Hybrid vehicle in the world, called Chariot HEV in 1994. Mitsubishi already removed all the information about this vehicle from its website, but it is the first vehicle in the world that used Li-ion batteries and it is one of the important factors that caused CARB to loosen its strict ZEV regulations. Mitsubishi then developed Chariot HEV further into Expo PHEV in 1994, the first plug-in hybrid vehicle in the world, and later into Mitsubishi Hybrid in 1995. It is interesting to know that both Chariot and Expo were originally MMC's gasoline vehicles. While before Chariot was sold in North America as the Mitsubishi Expo. Table 16 shows a historical timeline of Mitsubishi developed eco-friendly cars so far.

Table 16.,
Mitsubishi's historical trend of eco-friendly vehicles

Year	Vehicle	Battery	Condition
1970	Minica EV	Lead-acid	Limited sale
1971	Minicab EV	Lead-acid	Test/concept
1979	Delica EV	Lead-acid	Test/concept
1983	Minica Econo EV	Lead-acid	Test/concept
1991	Libero EV	Lead-acid	Test/concept
1991	Lancer Van EV	Lead-acid	Test/concept
1994	Chariot HEV	Li-ion	Test/concept
1994	Expo PHEV	Li-ion	Test/concept
1995	Mitsubishi Hybrid	Li-ion	Test/concept
1998	FTO EV	Li-ion	Test/concept
2001	Eclipse EV	Li-ion	Test/concept
2005	Colt EV	Li-ion	Test/concept
2005	Lancer Evolution EV	Li-ion	Test/concept
2009	iMiEV	Li-ion	Mass produced
2009	PX MiEV I	Li-ion	Test/concept
2011	Minicab MiEV	Li-ion	Mass produced
2011	PX MiEV II	Li-ion	Test/concept
2013	Outlander PHEV	Li-ion	Mass produced
2013	Global Small EV	Li-ion	Test/concept

From 1996 to 2003, which was the first generation of serious EV production for main auto manufacturers in the world, Mitsubishi continued its test practices with EVs again, as well as putting Li-ion batteries into use. The company developed FTO EV in 1998 sports car and Eclipse EV in 2001. From 1998, Mitsubishi admitted that in the first generation of EV production (1996 - 2003), the company was not among the automakers active in EV development, instead, the company was improving its EV technologies (e.g. Hosokawa et al, 2008).

Mitsubishi in 2005, developed Lancer Evolution MiEV (Mitsubishi innovative electric vehicle) which is regarded as the base for iMiEV 2009 - the most successful eco-friendly case of the company so far. In the same year MMC developed Colt EV, which was originally being produced as Mirage in Japan. In 2006, Mitsubishi developed the first concept model of iMiEV, but it didn't go to production until 2009. Also, a few more concept models that were the same as iMiEV, but with slight changes in the design were introduced such as CT MiEV and EZ MiEV.

From 2008 which is the second generation of EV development, Mitsubishi produced iMiEV 2009, Minicab MiEV 2011, PX-MiEV I 2009 and PX-MiEV II 2011 and Global Small EV 2013 concept vehicles. Mitsubishi has sold more than 27,000 units of iMiEV and more than 4500 units of Minicab MiEV mainly in US and Japanese markets. The company also produced Outlander PHEV 2013, which has sold more than 5,800 units so far. Due to battery overheating, Mitsubishi recalled 4,313 Outlander PHEVs in June 2013. Figure 38 shows the HEV and EV introduction of Mitsubishi along with oil prices.

According to the above, Mitsubishi has always been engaged with electrification practices and compared to other auto manufacturers, introduced more models of electric vehicles. But, why didn't it mass produced an EV until recently? While the company introduced its hybrid technology in 1994 and 1995, why didn't it pursue eco-friendly vehicles production more seriously? In the late 90s, Mitsubishi didn't believe EVs as a feasible option for the future. In Mitsubishi annual report (1990), it has stated "Electric vehicles are virtually pollution free, but are handicapped by restricted cruising range and high prices due to low production volumes".

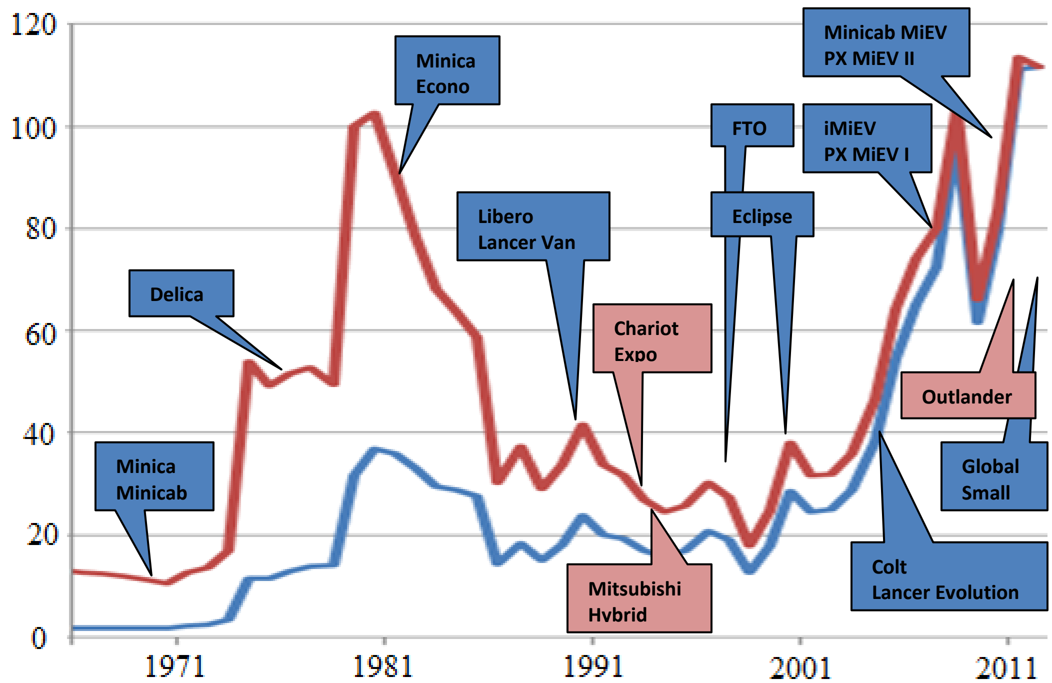


Figure 38., Mitsubishi's HEV and EV introduction along with oil price (HEV and PHEV is in pink color, EV is in blue color)

In the late 2000s, Mitsubishi changed its view on EVs and announced that EV production is the core strategy of the company for electrification: "Mitsubishi views EVs as central to their business activities over the medium and long terms, and as the driving force behind the Environmental Vision 2020. MMC's target for EVs is to account for at least 20% of total production volume by 2020" (e.g. Mitsubishi annual report, 2009).

One main reason is that the Mitsubishi's main markets had mostly been Japan and ASEAN countries, which it didn't cause any burden in terms of CARB regulations on emission control for the company (Figure 39). Recently, Mitsubishi started to focus on the emerging markets such as India, Indonesia, Russia, Bangladesh, China, Vietnam, Thailand, and Brazil.

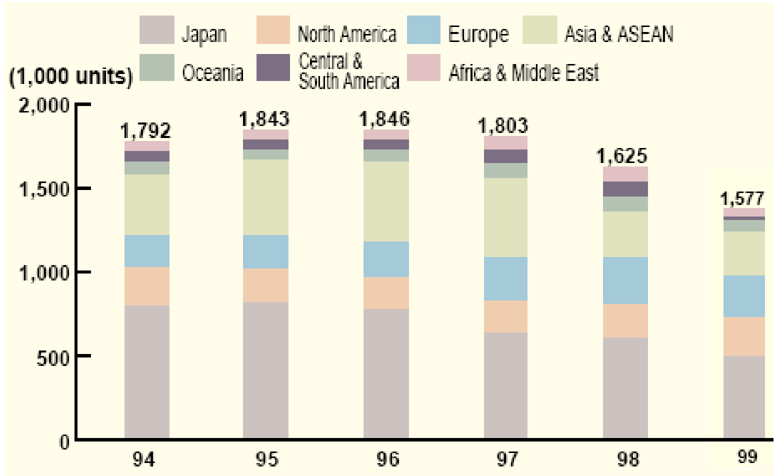


Figure 39., Mitsubishi Motors main markets in the 1990s (source: Mitsubishi annual report, 1999)

Another reason is that Mitsubishi didn't consider the possibility of EV mass production until the development of iMiEV. Hiroaki Yoshida, general manager of EV and Power train System Engineering at Mitsubishi Motors confirmed this view and stated: "at the timing of starting the development of the iMiEV, we already had prospects for the possibility of mass-production" (Yoshida, 2009). Furthermore, in December 1999, for the first time Mitsubishi felt sure that EVs can be put into practical use. It was because of a driving range test on FTO EV at the Mitsubishi Motors Okazaki testing circuits (Ibid). It should be noted that the main Japanese actors in the American market already produced their EVs and HEVs and started selling them (for example, Nissan Altra in 1996, Toyota RAV4 in 1996, Honda EV plus in 1997, Toyota Prius in 1997, Honda Insight in 1999, and US rivals such as GM EV1 in 1996, Ford ranger in 1996).

Beside the financial crisis in the early 2000s, until recently, Mitsubishi waited for the other companies to pave their way. Greg Adams, vice president of marketing for Mitsubishi Motors North America, confirmed and said: "Nissan and Chevrolet have basically done the work for us in a lot of ways. They've educated people, and now we're offering an alternative…at \$5,000, \$6,000, \$7,000 less" (Schweinsberg, 2011). When the i-MiEV project was mooted in

May 2005 by Hiroaki Yoshida, the automotive industry had absolutely no established infrastructure to produce EVs (Cheong, 2012).

Mitsubishi is selling its electric car to corporate customers in Japan first to allow more time for local governments and businesses to set up recharging stations around the country (Murphy, 2009). Mitsubishi didn't want to invest for infrastructure set-up, education of customers, huge advertisements, etc. Even now, Mitsubishi doesn't spend anywhere near the hundreds of millions of dollars that Nissan reportedly is putting into marketing their eco-friendly cars. Greg Adams continued: "I used to work for Ferarri, and Ferarri spends zero money on advertising, absolutely nothing. They spend all that money on events or public relations. And both of those two venues become your advertising if you effectively use it. So, that could be brought into Mitsubishi" (Schweinsberg, 2011). In this regard, Mitsubishi has had Internet-based remote driving, participating in record setting for Guinness, and several appearances in The Wall Street Journal, The New York Times and USA Today. This is Mitsubishi's new way to sell its HEVs and EVs.

7 – Results and findings

This chapter presents the statistical results of our patent analysis for EV and HEV core technology assets of four Japanese auto manufacturers, over a period of 33 years from 1982 to 2012. Our study results are not a recipe for organizational success. In fact, this study's results are based on pure logic and statistics and exclusive factors such as the Historical background of the company, Political awareness of technology, and social and environmental forces also play an important role in a real technological journey. For example, the appearance of eco-friendly vehicles in the early 90s was due to a shift in Californian regulations.

Considering the nature of technological competition between the four Japanese automakers, at the outset, the descriptive comparison of companies regardless of technological classification is investigated. As a result, we will be able to assess the amount of technological innovativeness between the companies. Here, the total cumulative patent data of Toyota, Honda, Nissan and Mitsubishi Motors is compared.

Figure 40 shows the historical trend of patent data from 1980 to 2012. As the figure shows, Toyota and Honda are stronger in terms of technological investments. Especially, from the late 2000s, they account for more than ninety percent share of cumulative patents between the four companies. One issue worth mentioning is that from 1990 to 1995, there was a major decline in the R&D investments of Japanese auto companies. Based on Shimokawa (1995), this was due to the burst of the Japanese economic bubble and the start of a standardization trend to control costs in the automobile sector. In this regard, companies such as Toyota and Honda decreased their automation investments and car categories, while Nissan acted differently and increased its product line and production capacity.

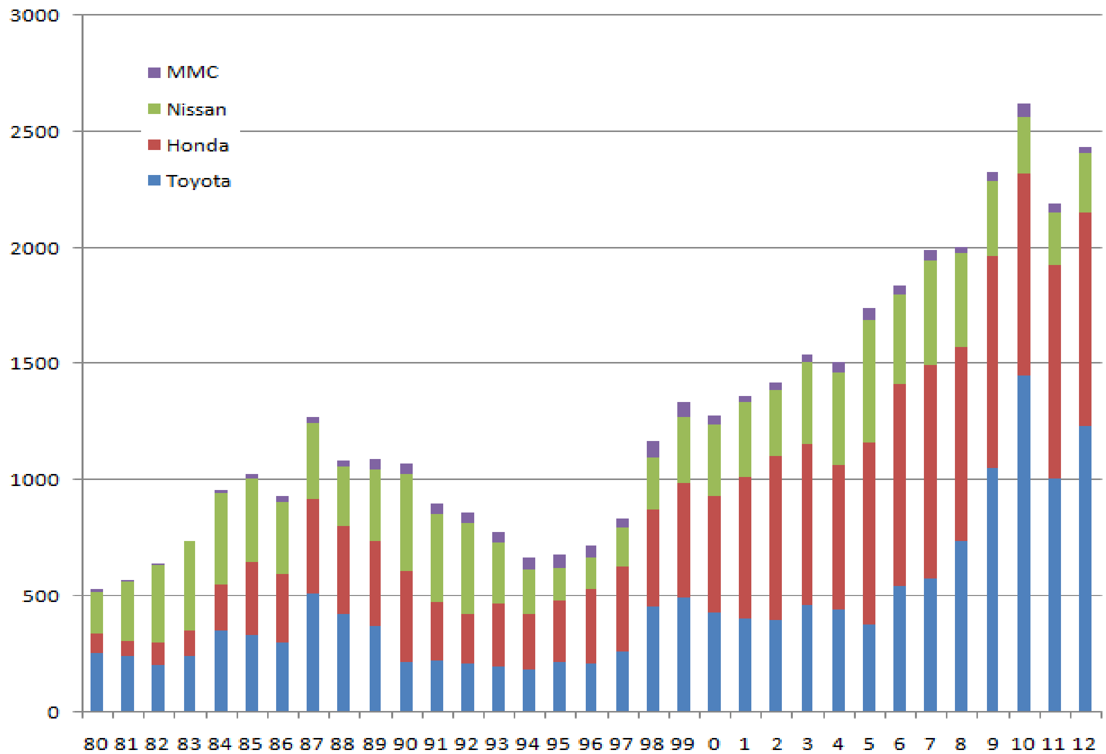


Figure 40., The cumulative patent data of four Japanese car companies from 1980 to 2012

Figure 41 shows that from the late 90s, Toyota and Honda's technological asset had a dramatic increase, while Mitsubishi stayed the same and Nissan declined from the mid-2000s. It also shows a cumulative technological comparison between the main US rivals of Japanese companies in eco-friendly vehicles from 1985 to 1995. Between all the companies, General Motors (GM) started its electrification earlier than others. The company invested on Solar Vehicles and Electric Vehicles R&D in the late 80s and introduced its first practical EV in 1989. So basically, upon the CARB regulation of ZEV act I in 1990, GM had already initiated the practices.

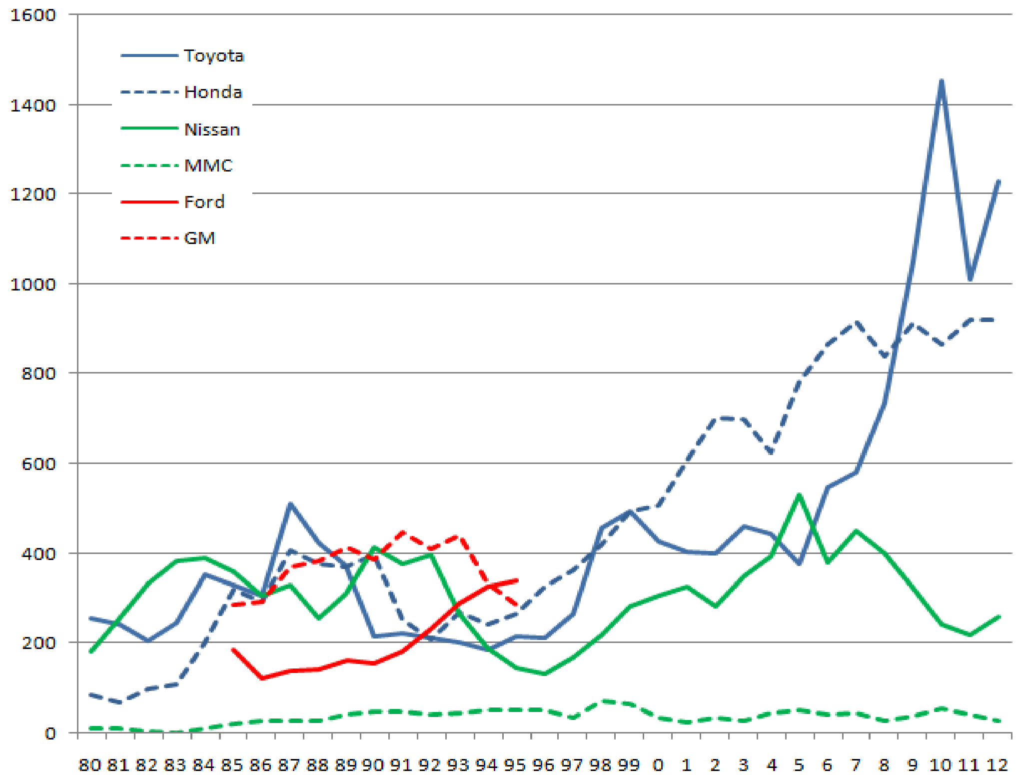


Figure 41., A cumulative technological comparison between four Japanese car companies from 1980 to 2012 and comparison with US competitors

Figure 42 compares the cumulative HEV and EV technological assets of Toyota and Honda with GM and Ford. These findings suggest that in terms of EV technology advancements, Japanese companies already had a strong rival in the market. Before 1995, General Motors, a company that started at least a decade earlier, had a competitive advantage in EV technology and that could be another cause for Toyota, the Japanese pioneer of HEV technology, to avert from EV and put more focus on HEV as its core competitive electrification strategy.

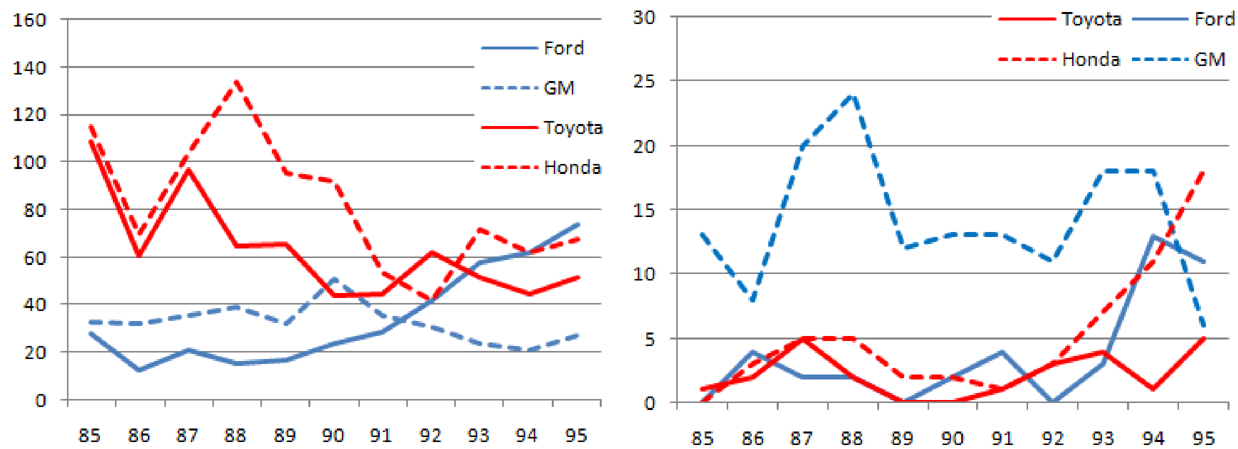


Figure 42., A comparison between US market competitors of eco-friendly vehicles between 1985 and 1995 – A cumulative HEV (left) and EV (right) technological asset comparison

Next, we will demonstrate Toyota's and Honda's technological trend, using the patents on EV and HEV core technological asset. It should be reminded that the main question which has been investigated here is "why Toyota and Honda pursued HEV development as their main electrification strategy, while Mitsubishi and Nissan pursued EV development?" In other words, is there any technological evidence that Toyota and Honda were locked-in to their historical experience with HEV core technologies? Figure 43 shows Toyota's patent data on Engine, Generator, Fuel economy/Emission control, and Hybrid Drive System technological asset between 1980 and 2012. As it is mentioned before, Toyota started its G21 project in 1993, and two development projects of Hybrid and EV technologies were progressing in parallel at the time. The year 1995 is the key moment which Toyota chose its in-house HEV technology over EV and made it as the main environmental strategy of the company. Based on Itazaki (1999), at the end of 1994, G21 project engineers from the Electric Vehicle Division, Hybrid vehicle Project and BR-VF (Business Reform – Vehicle Fuel) team were ordered to prepare a superior design for Tokyo Motor Show 1995, and in early 1995, Hybrid technology was nominated for the show.

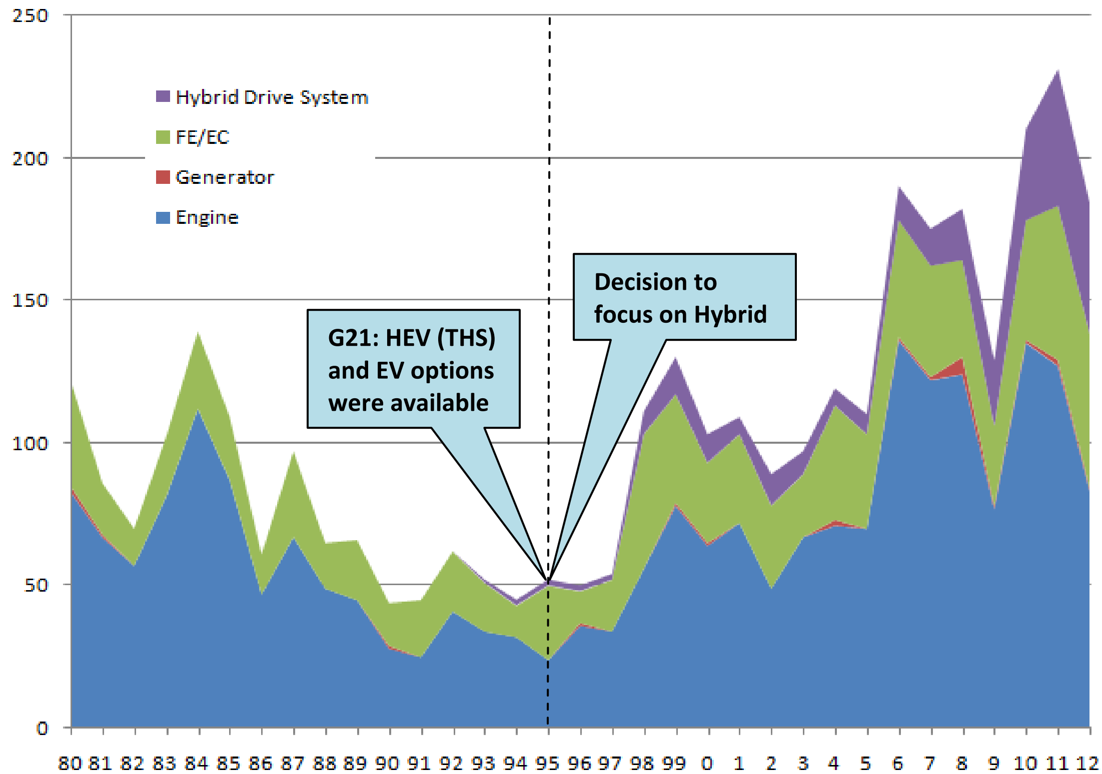


Figure 43., Toyota HEV asset between 1980 and 2012

Figure 44 shows Toyota's patent data on Electric battery, Electric motor, Electric Drive System, and Fuel cell between 1980 and 2012. As it can be seen, before 1995 in which Toyota made its technological choice to focus on its Hybrid technology and to make HEVs as its main environmental strategy, the company lacked EV core technological asset and the diagram is somehow flat. While at the same time, the company had a strong technological portfolio of HEV technological asset. From 1995 to 1997, Toyota developed an in-house technological system called Toyota Hybrid System I (THS) which later evolved into the famous Hybrid Synergy Drive (HSD).

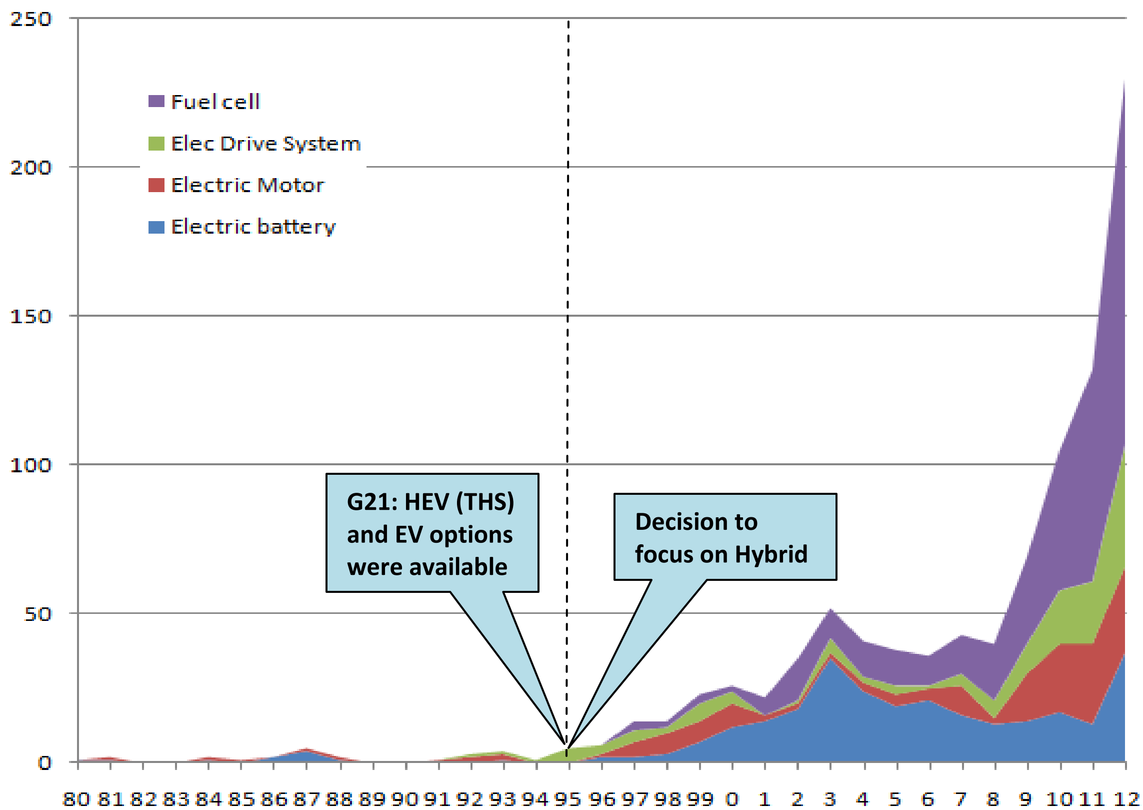


Figure 44., Toyota EV asset between 1980 and 2012

Figure 45 shows Honda's patent data on Engine, Generator, Fuel economy/Emission control, and Hybrid Drive System technological asset between 1980 and 2012. Similar to Toyota, Honda started its Hybrid technology project in the mid-90s. In 1996, the year in which Honda made its technological choice and chose its famous in-house developed HEV technology called Integrated Motor Assist (IMA) over EV and announced it as the main green strategy of the company, two development projects of Hybrid and EV technologies were available at the same time. Based on Figure 45, in 1996, Honda had a strong technological portfolio of HEV asset, which is even slightly stronger than Toyota.

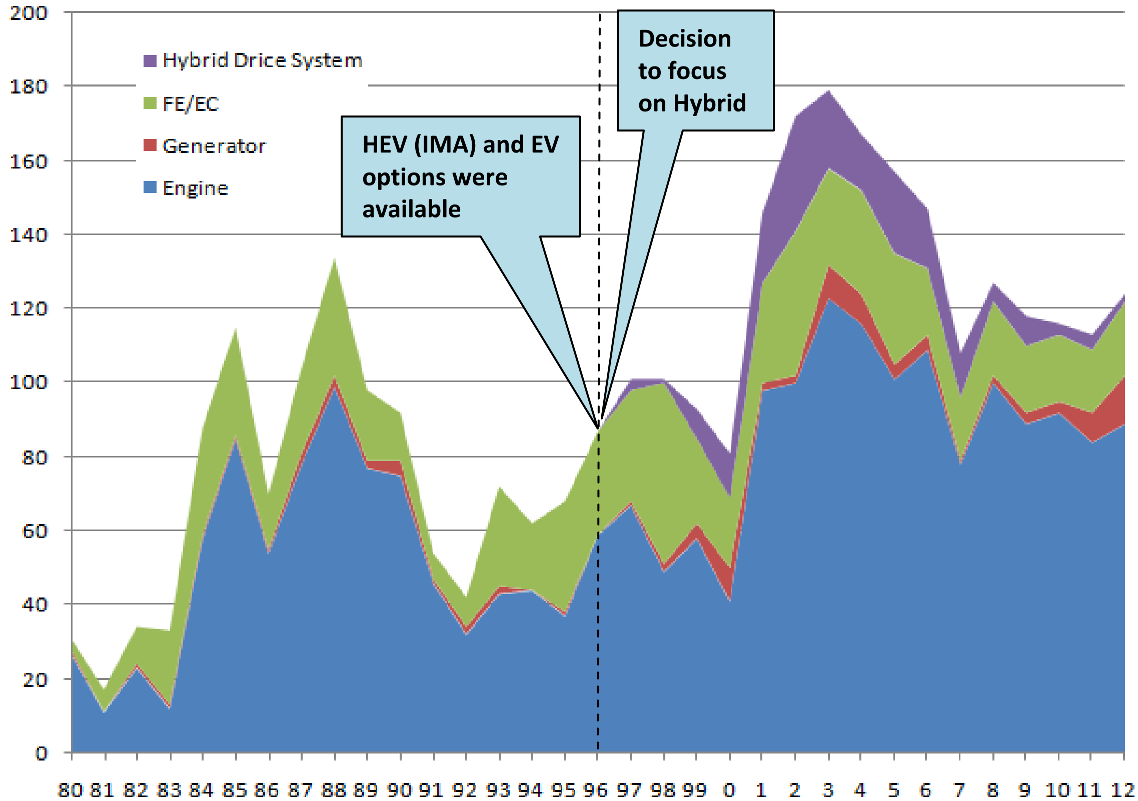


Figure 45., Honda HEV asset between 1980 and 2012

Figure 46 shows Honda's patent data on Electric battery, Electric motor, Electric Drive System, and Fuel cell between 1980 and 2012. Somehow similar to Toyota, before 1996 in which Honda chose to focus on its Hybrid technology, the company's EV core technological asset wasn't strong enough, while at the same time, the company had a strong technological asset of HEV technologies. It should be noted that Honda was the only company that clearly announced the halt of its EV project in a favor of HEV development. In 1999, Honda finally announced that the company sacrificed its EV technology for hybrid technology[5].

[5] Based on Netcarshow report "Honda EV Plus (1997)"

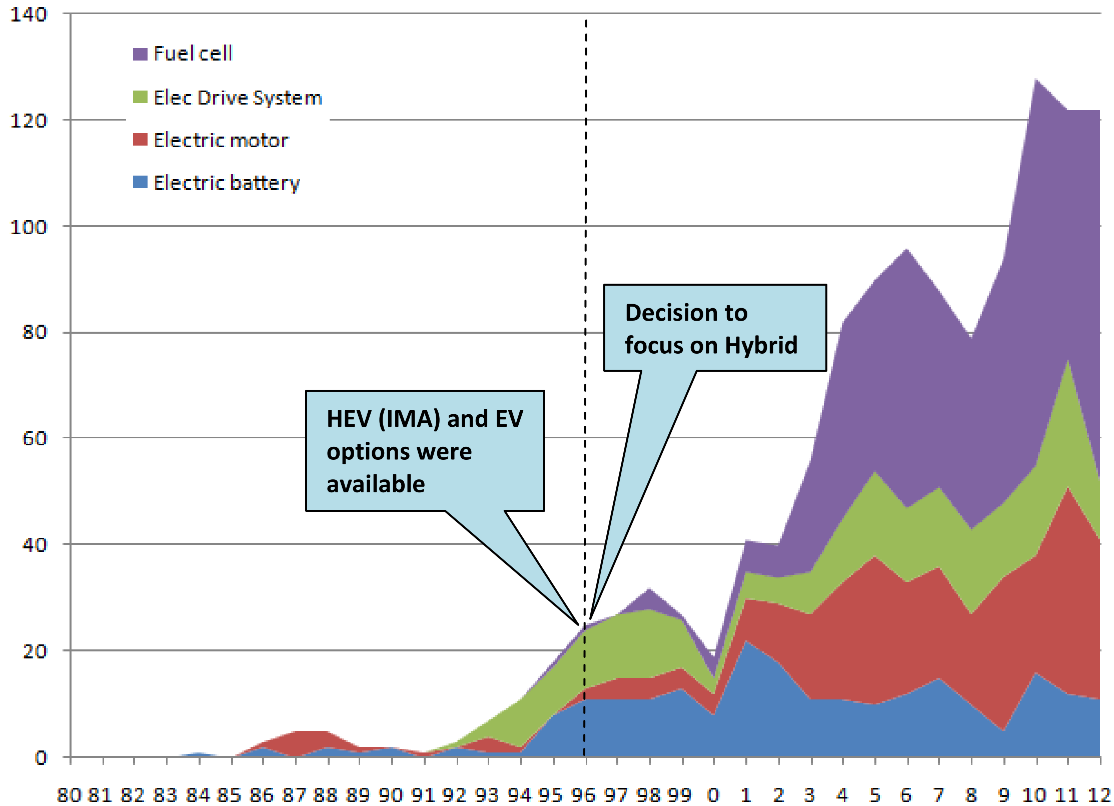


Figure 46., Honda EV asset between 1980 and 2012

Path Dependency explains technology adoption processes and industry evolution. Organizational Path Dependence has been linked to various factors that explain persistence of organizational choices and that emphasize the importance that past events bear for the future orientation of organizations (e.g. Sydow et al., 2009). Paul David (1985, 1987) and Douglas Puffert (2010) specified three conditions which may work together to give rise to processes of technological change path dependent: the technical interrelatedness of system components, quasi-irreversibility of investment (durability of capital equipment or more generally, switching costs), and positive externalities or increasing returns to scale. These conditions lead agents to coordinate their choices and also lend persistence to the resulting allocation.

Brian Arthur (1989, 1990, & 1994) stated that positive externalities could appear in the demand or supply side of the market. Considering the patent data of Toyota and Honda, switching cost of HEV to EV development wasn’t already paid for. It needed a huge amount of fresh R&D investments, while the amount of R&D and technological advancement for HEV assets was already done before. Technological interrelatedness of ICE and HEV comes through gasoline engine, fuel economy and emission control advancements. For both systems, the core technologies are the same and the companies already had a full patent portfolio of them. Furthermore, as it has been discussed in the Case studies chapter, Toyota and Honda emphasized on the evolutionary breakthroughs through the improvement of their previous technologies.

As far as increasing returns, Toyota and Honda pushed HEV technology, so they could make it a standard for the future. They then started a huge patenting from 1998 to protect this emerging technology from other competitors. This means more technologies of the same portfolio appeared, while until recently, the EV asset of mentioned companies has had a minority share.

Before analyzing Nissan’s and Mitsubishi’s patent data, we would like to discuss the companies’ view on HEV and EV technologies in the past two decades. It has been shown that Nissan and Mitsubishi experienced a shift in their view of eco-friendly vehicles, with a tendency to invest on and commercialize EVs more than HEVs. For example, in the early 2000s, Carlos Ghosn, CEO of the Renault and Nissan, didn’t believe in EV as a realistic product, but as a forced mandatory project by Californian regulators. In 2002, Ghosn said: “Nobody believes in it, but you have to do it. It's a huge cost, but it is part of the cost of doing business” (e.g. Hakim, 2002).

In the late 2000s, Nissan’s view of EVs shifted to a more positive practical product. In May 2008, Ghosn stated on Nissan‘s website that “We must have zero-emission vehicles. Nothing else will prevent the world from exploding” (Brain, 2013). One year later, he again confirmed this and stated "A new era is beginning in the global automotive industry. At Nissan and Renault, we are working together to lead the way to mass-market zero-emission mobility" (Ghosn, 2009).

Figure 47 shows Nissan's patent data on Engine, Generator, Fuel economy/Emission control, and Hybrid Drive System technological asset between 1980 and 2012. In contrast to Toyota and Honda, which made their technological choice in the mid-90s and centered HEV as their core environmental strategy, Nissan's technological choice didn't appear until the late 2000s. The moment of technological choice for Nissan was in 2007, when the company executives decided to seriously focus on electric vehicles as a core product for their electrification strategy.

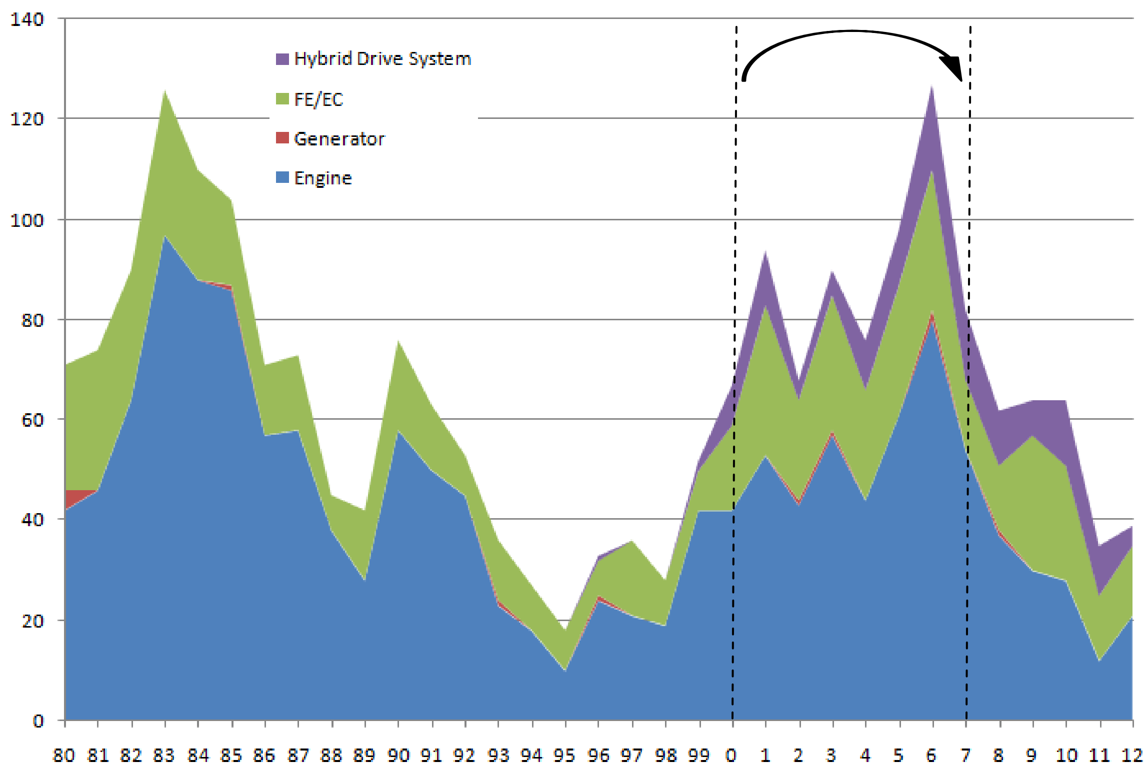


Figure 47., Nissan HEV asset between 1980 and 2012

Meanwhile, the company’s view on HEVs remained the same. For example, Dominique Thormann, senior vice president of administration and finance for Nissan in North America, said “Hybrids are not a very viable economic proposition. There's got to be a reason why people are going to buy hybrids” (Calcars Initiative, 2006). In Figures 47 and 48, the decision moment is moved from early 2000s to 2007.

Figure 48 shows Nissan’s patent data on Electric battery, Electric motor, Electric Drive System, and Fuel cell between 1980 and 2012. Again, the technological choice moment is changed and in that instant, the company already had both HEV and EV core assets under development.

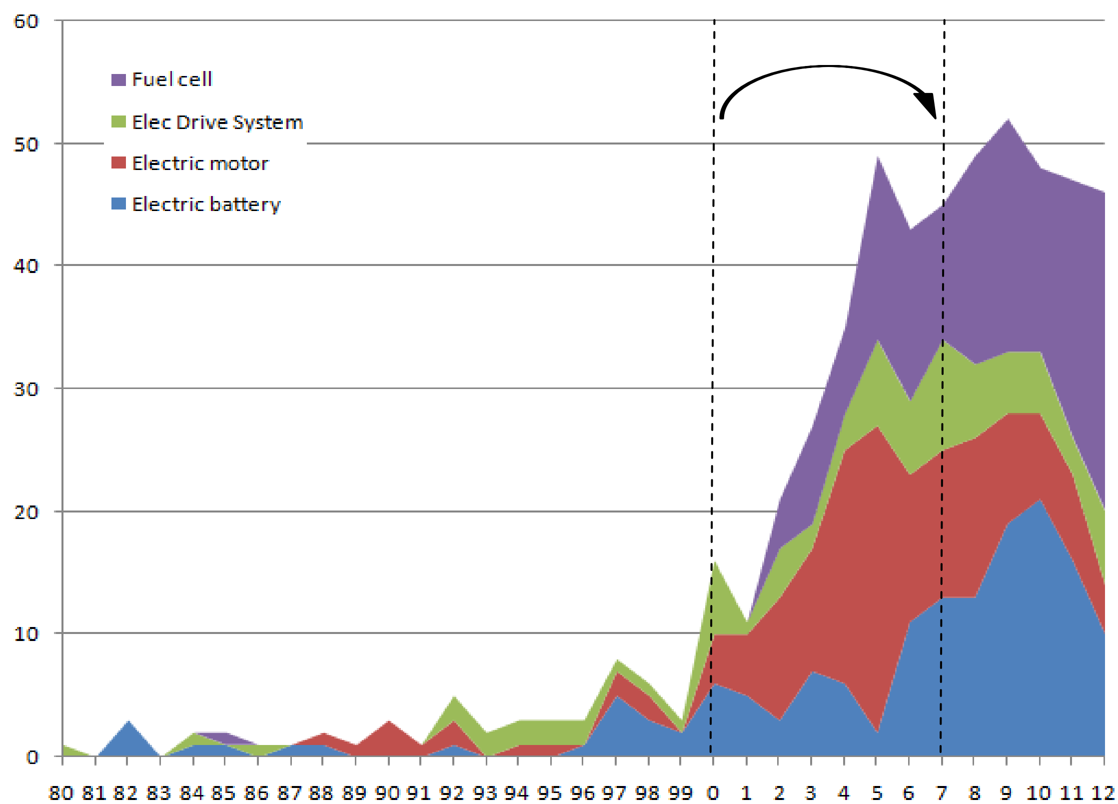


Figure 48., Nissan EV asset between 1980 and 2012

Similar to Nissan, Mitsubishi also experienced a shift in its view of eco-friendly vehicles, but with a slight difference. Mitsubishi has always been a pioneer in EV technological development, but not until 2009, could the company mass produce any successful eco-friendly vehicle. All of its previous efforts were for a test or limited lease purpose. Mitsubishi didn't consider the possibility of EV mass production until i-Miev development, which was after 2006. In this sense, Moore (1998) wrote Car companies usually want to provide lease (short or long term) for their new models.

There are a number of reasons for this, the most important being reliability. The car companies simply do not know how reliable these cars will be, especially their battery packs. It has been negatively written in Mitsubishi annual report (1999) that Electric vehicles are virtually pollution free, but are handicapped by restricted cruising range and high prices due to low production volumes.

In less than a decade, Mitsubishi's view shifted positively. In Mitsubishi's annual report (2009), it has been mentioned that Mitsubishi views EVs as central to their business activities over the medium and long terms, and as the driving force behind the Environmental Vision 2020. MMC's target for EVs is to account for at least 20% of the total production volume by 2020.

Figure 49 demonstrates Mitsubishi's patent data on Engine, Generator, Fuel economy/Emission control, and Hybrid Drive System technological asset between 1980 and 2012. It should be noted that along with Mitsubishi Motor Company, Mitsubishi Group patent data on HEV and EV core technologies are also investigated. The details of this selection and analysis are explained in the Methodology chapter.

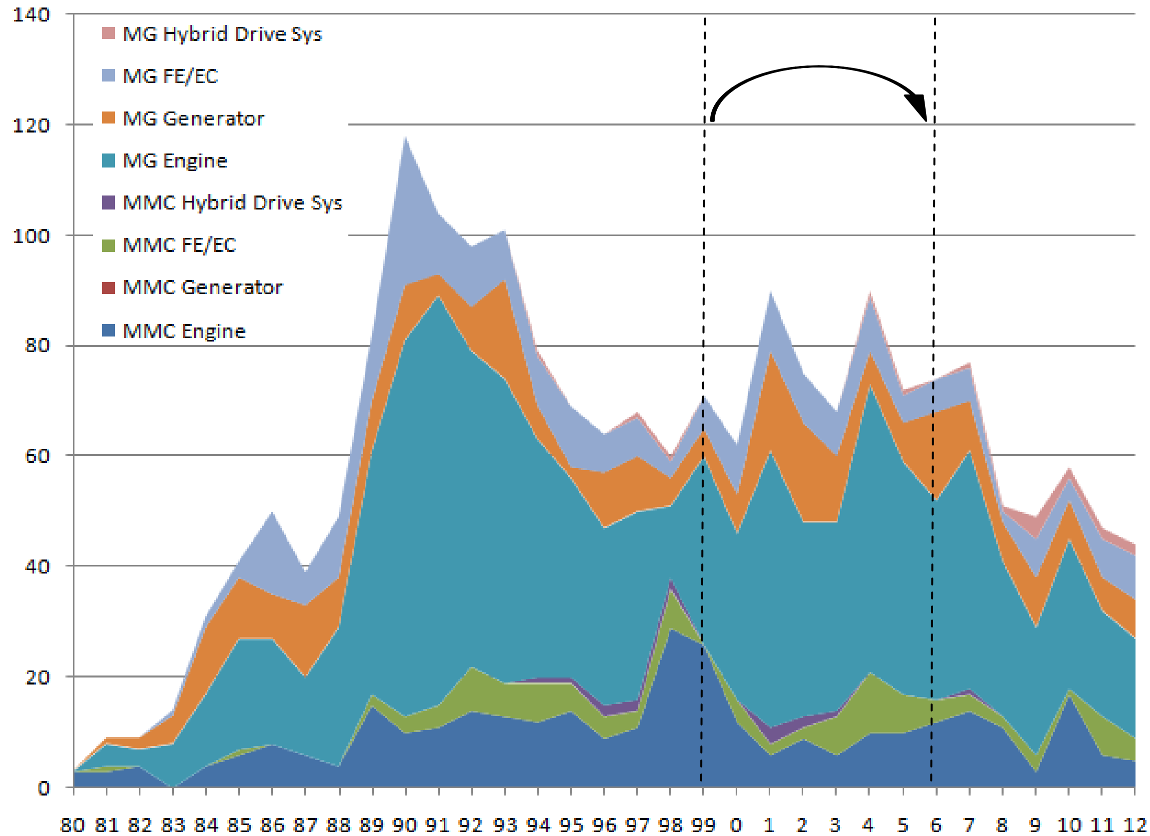


Figure 49., Mitsubishi HEV asset between 1980 and 2012

Figure 50 shows Mitsubishi's patent data on Electric battery, Electric motor, Electric Drive System, and Fuel cell between 1980 and 2012. Considering the patent data of Nissan and Mitsubishi on EV and HEV technological assets and based on the David (1985, 1987) and Arthur's (1989, 1990, & 1994) arguments, we express that it's not clear whether Nissan's and Mitsubishi's choice of EV over HEV technology in the late 2000s, was path dependent. First, the switching cost of HEV to EV development wasn't a main problem. Both companies had already a patent portfolio of HEV and EV assets and R&D was already done before. Basically, for both HEV and EV systems, the core technologies were available. In some cases, the core technologies were developed by other MG companies such as Mitsubishi heavy industries, etc. Also in the late 2000s, it is clear that none of the EV and HEV technological assets have the share superiority over the other. In other words, if any technological asset could benefit from the increasing return over time, another asset could neutralize this superiority trend.

It should be noted that For Honda and Toyota, the decision moment is choosing a technology between two available options. But for Mitsubishi and Nissan, the decision moment is not exactly a technological choice between HEV and EV options. Because in the 2000s and even earlier, they both had continuously developed EVs but none got serious in mass producing them and pursuing a leadership strategy of ZEV production.

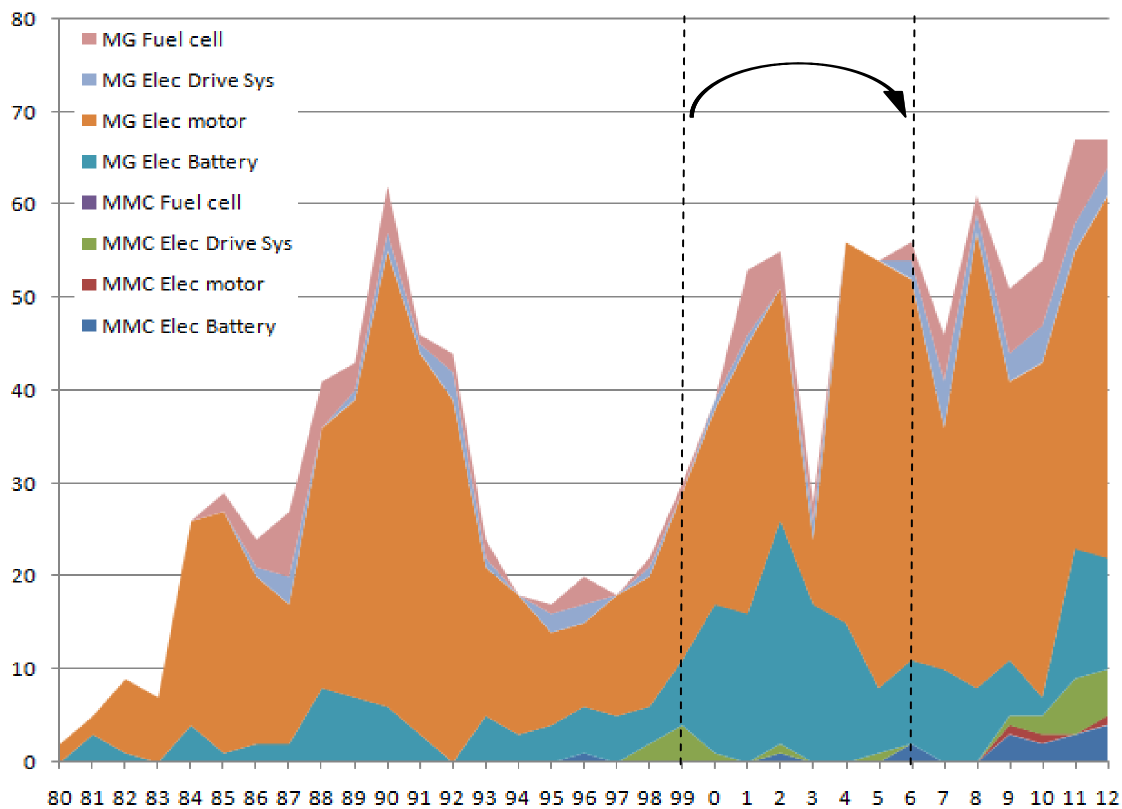


Figure 50., Mitsubishi EV asset between 1980 and 2012

Based on the previous Tables and Figures, it can be concluded that influenced by the other strategic factors, the decision made by Toyota and Honda for focusing on Hybrid technology could be a Path Dependent decision, while for Nissan and Mitsubishi's choice of EV technology, wasn't and other strategic and contextual factors may have been engaged. This finding is an opening step toward the configuration. As David (2001) states path dependence does not imply sub optimality but it can lead to it. Although all of the necessities for the emergence of Path Dependency may exist, but granting a certain conclusion is not a rational way to do.

8 - Conclusion and discussion

A critical challenge is how to bring promising innovations into a stream of economic positive returns for their stakeholders. In other words, today the main issue is not so much the invention of technology, but commercializing it. In this regard, the objective of this study is to investigate the strategic and technological motives behind the technological choice of four Japanese auto manufacturers. Broadly defined, we want to find out why some companies such as Toyota and Honda pursued HEVs while other companies like Nissan and Mitsubishi pursued EVs? This interest has been expressed in the literature, but conducting it is mainly left out and the bulk of the studies have researched the eco-friendly vehicles as commercial products, not as a technology.

In this thesis, we have addressed a range of issues, from eco-friendly vehicles development in Japan's auto industry, an argument on the technological choice of the firms, and historical Path Dependence. This thesis makes a few contributions to the literature. First, as we have discussed, the barriers and bottlenecks in front of eco-friendly vehicles development are not only technical. While the literature has largely focused on the battery hindrance and range anxiety, we have shown that each manufacturer could have a different set of strategic and technological limitations which could have influenced the electrification process through time. In addition, comparing the car companies and their decisions, we have shown that these limitations are not similar in nature and while a company could be locked in to its historical trend, other companies' reason for not focusing on EVs and HEVs could have been based on the strategic decisions. In other words, each company has a different set of disputes for its approach toward the eco-friendly vehicles commercialization. For example, for Nissan we have demonstrated that for several years, the company's engine breakthrough made its vehicles the frontline of CO2 emission and environmental friendship, and as a result, the company didn't consider EVs and HEVs as a beneficial and strategic asset. Meanwhile, Toyota considered HEVs as a major breakthrough and a chance to increase its competitiveness in the market and started to strongly invest on them from 1995.

In this regard, a novel contribution of this study is the illustration of multi-dimensional social forces impact on the technological choices of the firms. Our case study analysis, along with the technological background analysis show that if we look at the eco-friendly vehicles as a technology, not only as a tool or commercial product, we will notice that there is no easy and simple way to describe the penetration of "green vehicles" in the society. In fact, this process is a complex one and a lot of other factors affect the situation. Technological choices are complicated multi-driven moments that by looking at them from a single point of view, we couldn't make a justified assumption for the future. As it is described in the historical chapter, many factors were engaged in the penetration of EVs in the early twentieth century, such as Lack of infrastructure, Political forces, Shift in the market structure, etc. Furthermore, for understanding the trends in recent years, we need to understand all engaging factors. It should be also noted that by considering all engaging forces at the same time and from a multi-dimensional point of view, technological choices are not always rational and acceptable. For example, when Toyota started the sale of its Prius hybrid in the late 2000s, it cost at least 32,000$, for the company to produce a unit, but the retail price of the car was less than 17,000$ (e.g. Bloomberg Businessweek, 1997). That moment, this choice was irrational for many. This study is a pioneer scholarly work that combines strategic and technological factors to draw a conclusion on the eco-friendly vehicles commercialization, historical barriers, as well as the role of technological assets for further breakthroughs. For example, it was previously shown that the engineering philosophy of the eco-friendly vehicles, namely battery, energy technology, or propulsion technology is the main factor in their penetration (e.g. Chan, 2002). However, the role of technological background and strategic choices of companies had not been characterized. Dobusch and Kapeller (2013) have also indicated that the main reason for the prevailing dissent in path dependence research methods is the futile attempt to capture "path dependence as a whole" within a single-method research design. Though, as it was explained in the Methodology chapter, in this study we have used a Mixed Method Paradigm to assure the capture of the technological Path Dependence. Our quantitative statistical factors, HEV and EV core assets, were adjusted by using both qualitative case study outcomes and electric and mechanical engineering dynamics (interviews and technical papers). In this regard, this thesis's findings are in line with Cowan and Hulten (1996) and Callon (1989) technological studies on eco-friendly vehicles, which illuminate that investment of time and money in a dominating technology, would bring unwillingness to switch technologies.

The second contribution of this thesis is that it offers a detailed systematic analysis of a technological Path Dependence. Path Dependence and Competitive advantage have a major share of economic literature. Methodologically, it is novel to approach this issue through an analytical point of view. Since one of the concerning issues today is how it can be measured by data and how it can be statistically backed up (see Jackson and Kollman, 2012). Freeman (2011) wrote we do not know how (if) path dependence is manifest in data and studies provide little guidance about how (if) certain statistical results connote path dependence. So far, the mainstream of political and social science in Path Dependence have been mostly based on the historical narratives, scholar insights, or merely assumptions. However, in this work, we have provided new knowledge and advances using a cleverer and better method. This thesis made an effort to identify the technological lock-in by scrutinizing the technological patent data. Using the measurable data has helped us to clarify the existence of Path Dependence in the automotive industry and how it may have shaped the recent trends of electrification in certain ways.

In a recent work on Irish patent data, Roper and Hewitt-Dundan (2011) have tried to investigate the emergence of Path Dependency by assessing the historical knowledge stock. They have shown that patent stocks have negative rather than positive impacts on business units' innovation outputs, reflecting potential negative path dependency or core-rigidities. Consistent with the above study, in this thesis, it has been shown that the technological assets of the company could shape a Path Dependent trend and could also limit the company's future openness to technological decisions. Is has also been shown that to what degree it can be measured (year the decision was made, shift in the commercialization strategy). This is in line with Farrell and Saloner (1985) and Cohen (1984) works on Path Dependency, which have explained the possibility of getting trapped in a historical standard.

The third contribution is an effort to study failed technological innovations. In the historiography of technology, a problem exists that concerns the asymmetric focus of the analysis. While Historians have a rich research site among the inventions that failed to develop into innovations (Hughes, 1989), scholars believe that there are not enough articles devoted to the study of failed technological innovations (Staudenmaier, 1985; Bijker et al., 1989). This trend did not change in the past two decades from early scholars of technology, and probably it gotten worse, since in a recent scholarly work, Coopersmith (2009) argued that even historians have not paid sufficient attention to this important subject, focusing on success. In consistent, Landry et al. (2008) also indicated that empirical studies on innovation failures are much less numerous than those on innovation successes. As a consequence, conceptualization and measurement of failures have received much less attention in the literature (Galia and Legros, 2004; Smith-Doerr and al., 2004).

In their recent study, Landry et al. (2008) provided some evidence that a better understanding of innovation failures would contribute to improve our understanding of innovation successes. This preference for successful innovations seems to lead scholars to assume that the success of an artifact is an explanation of its subsequent development. There is a need for a symmetric sociological explanation that treats successful and failed artifacts in an equivalent way. As we have seen, eco-friendly vehicles history, especially the first generation of EV development from 1996 to 2003, consists of many failed cases. In this thesis, we have discussed about the first generation of electric cars, which came along a massive failure for all EV producers. Failed EV projects such as Toyota RAV4 EV, Nissan Altra EV, and Honda EV plus were investigated in this study. It was concluded that the product cannibalization and strategic market positioning were some of the main reasons why in the early 2000s, Toyota and Honda pulled out their EVs from the market and sacrificed them for HEVs. Also, it was shown that the product design and models of HEVs were superior and easier to adopt by the customers. Later in this chapter, some of the political and economical implications, as well as limitations of this study will be discussed.

Throughout this work, we have shown over a period of one hundred years of eco-friendly vehicles history, from the earliest attempts to improve the technical ability of the vehicles and compete against other technologies, to recent commercialization and standardization efforts by major players. This study has demonstrated that for early ICEs, they continuously added value to their vehicles and continuously improved their production processes, while early EVs remained steady in their early stages. Even for the second wave of EVs (1965-85), produced EVs didn't offer anymore privilege than the early EVs (this subject was discussed in EV history). Therefore now, if EVs want to be the main portion of customers' attention, they have to sustainably add value and progress. EVs with the same performance and design as their rival ICEs won't show any sign of market dominance. Consistent to the above argument, Itazaki (1999) suggested that if an eco-friendly car does not provide all the conveniences of today's cars and is also consumer unfriendly, consumers will never support it. Meanwhile, it has been shown that the consumers with ecological and environmental concerns are widely documented as having a higher tendency to adopt eco-friendlier products (Gatersleben et al., 2002; Minton and Rose, 1997; Anable, 2005; Bamberg, 2003; Hansla et al., 2008; Maloney and Ward, 1973; Stisser 1994). Thus, increasing the environmental awareness of customers will also speed up the acceptance of eco-friendly vehicles in the society.

This study argued that Toyota pushed HEV technology, so it can make it a standard for the future. Then Toyota, followed by Honda, started a huge patenting from 1998 to protect its core technological asset (Murphy, 2009). This is in line with Lopperi and Soininen (2005) who stated technology, much like knowledge, is cumulative in nature - accumulation of technological capabilities based on the existing knowledge rather than clear-cut destruction and displacement. The type of technology and the knowledge embedded influence how companies can best benefit from protecting their inventions from imitation. In this regard, for further market penetration, the companies that will need engagement in this technology must go through the path that Toyota set up for them, such as Nissan and Ford which have sought licensing from Toyota. It is currently increasing Toyota's return in terms of licensing, shared product developments, etc.

One issue worth mentioning is that the patent expiration brings a challenge to the auto companies. One may argue that with the expirations of patents issued two decades earlier, how could patent accumulation bring competitiveness to the company? As of US Patent terms, for applications filed after June 8, 1995, the patent term is 20 years from the filing date of the earliest US application, while for before June 8, 1995, the patent term is either 17 years from the issue date or 20 years from the filing date (USPTO, 2013). Patent expiration causes revenue losses for the companies, and for Toyota and Honda, this is no exception. While the patents of the 1980s were getting close to the expiration edge, the companies continued to invest in distinctive science (EV core assets) from the early 2000s, meanwhile they tripled their patents in the 2000s to defend their HEV technology from inventing around, twists and imitations. But, this distinction didn't appear until 2001-2 and for a period of six to seven years, both Honda and Toyota were still investing on core HEV technologies.

As a result, later they could keep their competitiveness, while strengthening their EV core assets. This could be explained by Rowland and MacKenzie's (2006) demonstration on a few mechanisms that help companies to stay competitive and benefit from the previous success. Along with the (a) continuous innovation, (b) power of strong branding (as Toyota did for Prius and introduced it as highly innovative, with a unique design, and superior technology in the early 2000s), (c) increasing brand awareness through marketing channels (as it was mentioned in the case study chapter, both Toyota and Honda used the Internet and Mass media to increase their Hybrid awareness, while Mitsubishi and Nissan were late movers and waited for the other companies to pave the way), and (d) continuous improvement and modifications which even after the patent expirations can keep the competitors away (both Honda and Toyota continued their product improvements after the late 90s).

There were HEV and EV technologies available to the market. By using the HEV technology, people found it more comfortable, with a better design and model; they didn't need to change their behavior in order to use the product, and a variety of other reasons. By acquiring an EV, the customer needed to change his/her behavior, learn how to charge and deal with new technology, less comfort and lack of infrastructure. As a result, people bought more HEV rather than EVs. Furthermore, HEV development processes showed an increasing return to the scale and it could be called a Path dependent process. From the mid-2000s, due to the advancement of technology, R&D investments, and better infrastructure, switching cost of the technology declined and people also already had some experience with eco-friendly vehicles.

8.1. Implications and further research

This thesis raises a series of new academic interests, questions and trends. Any eco-friendly technology lends itself to study by many academic methods and approaches. Currently, there are studies being carried out into the technical characteristics and marketing techniques of eco-friendly vehicles, but the main issue for future researches must be rendering a technological approach. It would be interesting to re-study the technology diffusion of eco-friendly vehicles, as well as the technical limitations such as batteries, etc. from a technological point of view. It would be fascinating to see as a new life changing technology, how far can eco-friendly vehicles influence the driver community to accept this new technology? And will this technology be a replacement for the current system or something that could be used as the same time at the current system.

Something worth investigating is why fuel economy and replacing familiar ICEs with EVs is not a top concern to customers. Some scholars, such as Berman (2009); Hermance and Sasaki (1998), believe that HEV is a bridge to the next revolutionary technology (EV) and will be replaced eventually. Therefore, at the end of the day, a technology that won't need any gasoline at all will be dominant. Consistent with the above argument, in the previous chapter, it was shown that even Toyota and Honda which advocated HEVs for more than a decade; recently have started a Path Creation trend, and they are investing strongly on EV core technologies. This could be a sign of what will come in the next decade and the start of an important scholarly interest for academics.

This study has also shown with rising prices of fuel and worsening emission levels each year, it is possible that the necessary awareness of the current energy crisis hasn't nurtured within the public. Under the current structure and with more than 84 million global production of vehicles in 2012 (OICA, 2013), some argue that achieving sustainable energy policy requires rapid diffusion of new technologies i.e. smart grids, electric vehicles, photovoltaic, heat pumps, smart meters, etc. (World Energy Outlook, 2012; Beise and Rennings, 2005). Meanwhile, others suggest that paradigmatic shifts in technology are long and slow processes (Kline and Rosenberg, 1986) and the electrification of road vehicles is no exception (Pohl and Yarime, 2012). This technological paradox implicates that the role of transitional and bridge technologies is more important than we expected. Hybrid Vehicles, Plug-in Hybrids, and natural gas powered vehicles will help the society to prepare and will also help to speed up the infrastructure establishments.

8.2. Limitations

We acknowledge that there are few limitations to this research. In our attempt to analyze the patent database of the companies on HEV and EV core technologies, we have used simple patent counts to statistically measure the historical assets of the companies. While some scholars such as Griliches (1998) believes that using patent citations rather than unweighted patent counts can provide alternative "indexes" of differential quality. On the other hand, Trajtenberg (1990) has shown citation weighted patent numbers are more closely correlated with "output" measure, which are consumer gains from the development and diffusion of technology, while unweighted patent counts (as we have done in this research) are more closely related to "input", which are firm's R&D and core technological breakthroughs. In this sense, and with comparing different arguments, we believe that such limitations do not impose a major concern in this research.

It should be noted that in the definition of resource accumulation, Japanese companies supplier relations are also have a huge impact on the success of firms operations. In contrast to US, Japanese automakers work with a fewer suppliers, but in a long term and with a stronger cooperation. Aside from suppliers, Japanese automakers also work along their rivals to develop the products. These relations have a huge impact on the operational decisions in Japanese firms and in this thesis, due to limitations they weren't fully investigated.

We stress that our research illuminates the very reality of technological choice in the companies, something that doesn't happen by a singular mean, but by different social and technological forces which are engaged at each level. This kind of study wasn't addressed previously in detail by other scholars. Thus, by using eco-friendly vehicles as a mean to understand technology, we hope to absorb more academic interest in these topics and provide a better context for the emergence of environmental friendly technologies.

In the end, As Ruger (2013) states "Good research always opens up new questions, and a subsection about future work helps voicing thoughts on this", we believe that this research opened up vast areas of potential interest, for the researcher himself and for other academic scholars, to shorten the limitations of the study and contribute more to the society.

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Appendix I

Further Research proposal by the author:

Measuring Increasing return

For measuring the Path Dependence item of increasing returns by statistical data, we have used the Experience Curve Effect (Learning Curve Effect) as a tool to demonstrate the relationship between the experience and the probability of the technological tendency. By using the Power Law distribution function, Experience Curve Effect shows that each time a cumulative volume of a specific technology increases, the probability of its appearance in the next round will increase by a certain percentage. A curved power trend line uses data sets that compare measurements that increase at a specific rate. In contrast to Freeman (2011) which stated linear time series models illuminate early and outcome path dependence, we believe that due to the non-linear nature of the trend, linear time series do not provide a precise result. This is because the outcome of each level is not only dependent to its previous state, but also to all of its previous states. Power formula with the cumulative volume (Y) relation is:

$$Y = a X^b$$

or

Y = constant A * x ^-constant B (^ indicates that -constant B is an exponent)

The result of this equation will give you the average slope of the experience curve. We have used the statistical software that calculate the constants and gives the Y slope.

Results:

For measuring the Increasing return item, we have used the Experience Curve Effect. Based on Arthur et al. (1987) and Balmann et al. (1996), the Polya process provides a good analogy for our measurement. The Polya process can be illustrated as follows: Assume an urn containing one red and one blue ball in $t = 0$. In each of the following periods $t = 1, 2, \ldots$ one ball is randomly drawn from the urn. Then the ball is returned and another one of the same color is added to the content of the urn. This can be formalized as follows (Figure 51):

$$\text{Probability } (\mathit{Add\ Red}_t{+}1) = f\,(\mathit{Proportion\ Red}_t)$$

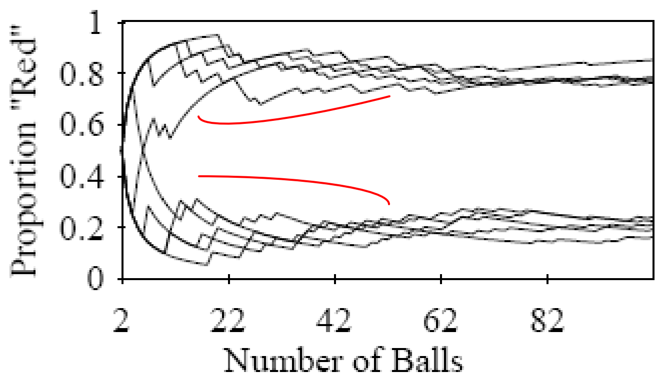


Figure 51., As the number of balls increase, the range of proportion varies (Balmann et al., 1996)

The behavior leads to a Path Dependence. Figures 52 to 55 show the results of ECE and Power trend line on EV and HEV assets of four investigated cases. Finding the average slope in the specific moment will give us the percentage as a suitable measurement of technological Increasing Return. The results of power trend function for the specific decision moment of the mentioned companies are shown in Table 17. It should be noted that for the statistical calculation of the cumulative patent volumes, for those years with zero patent application, the closest and the most applicable number to zero (0.01), but not the zero itself, was selected.

Table 17., ECE results for technological choices

Company	Toyota 1995	Honda 1996	Nissan 2007	Mitsubishi 2006
HEV asset	69.16	34.09	78.73	12.2
EV asset	0.06	0.01	0.11	6.64
claim	Lock-in HEV	Lock-in HEV	Lock-in EV	Lock-in EV
result	approved	approved	disapproved	disapproved

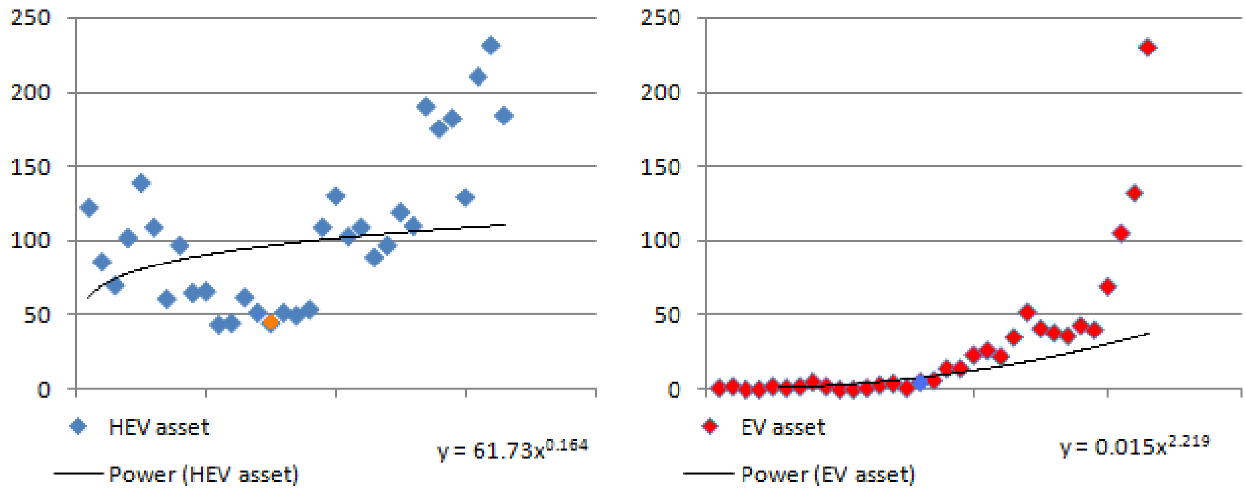


Figure 52., Result of ECE for Toyota's EV and HEV technological asset

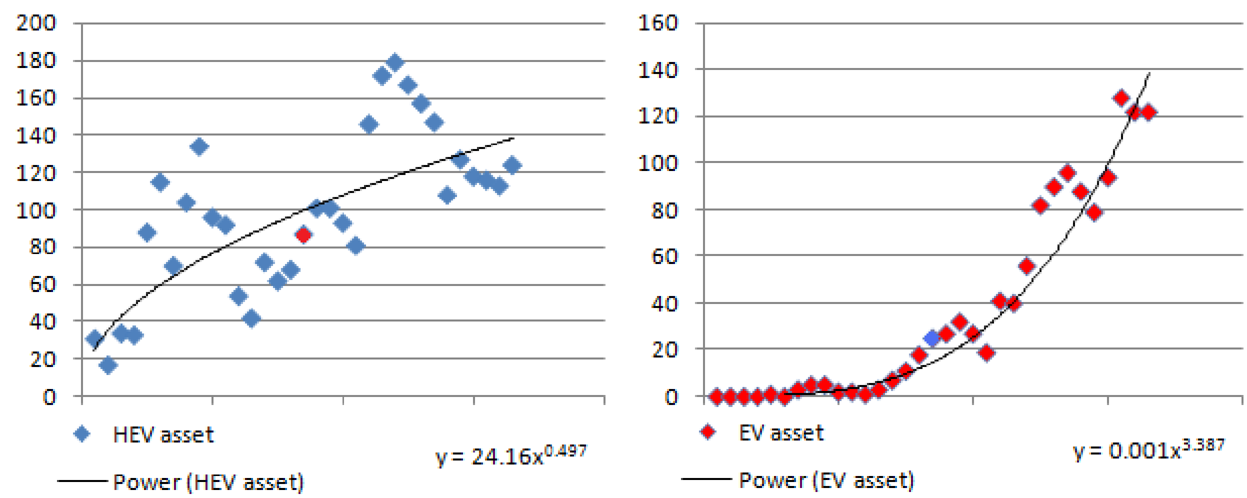


Figure 53., Result of ECE for Honda's EV and HEV technological asset

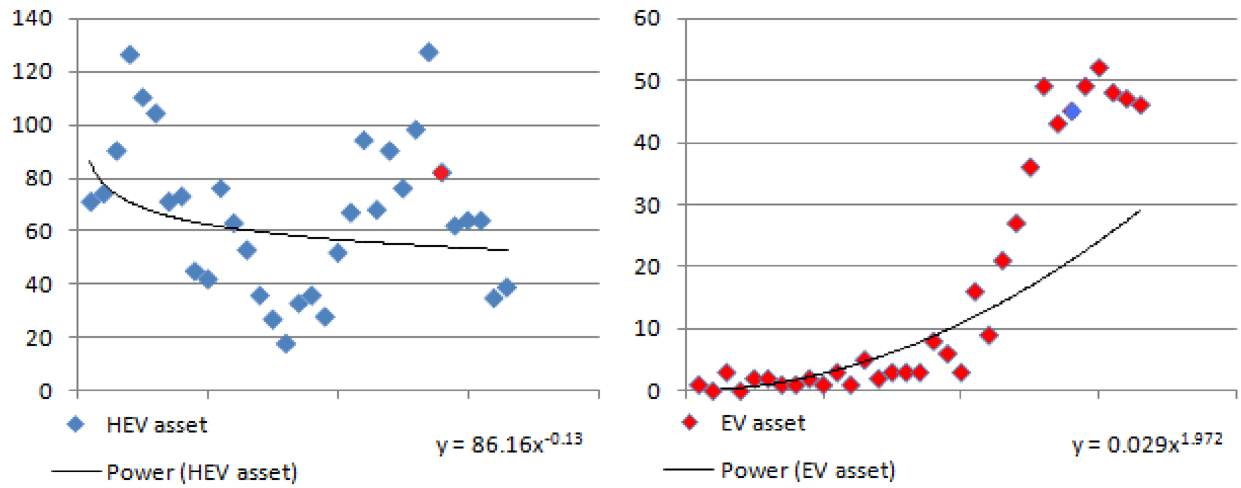


Figure 54., Result of ECE for Nissan's EV and HEV technological asset

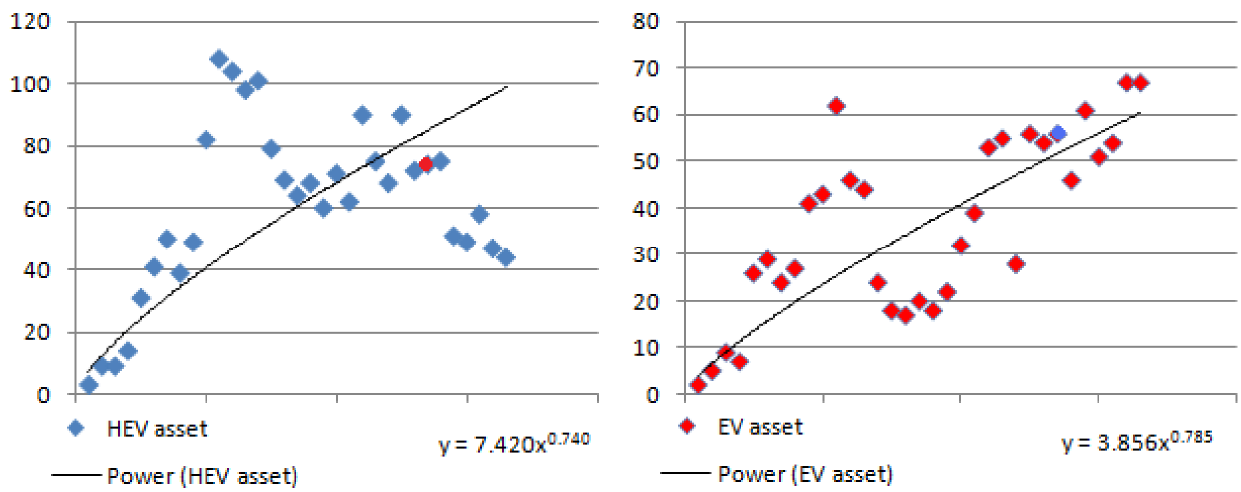


Figure 55., Result of ECE for Mitsubishi's EV and HEV technological asset

Appendix II

Semi-structured Focused Interview questions:

These following questions were asked during the focused interview with project managers:

1- Up until now, for commercializing your technology, what kind of risks have you taken and problems have you faced? Any problem that made your project slow, or cause it to halt…
2- Based on your current state of the project, what are the main barriers that your project will face in the future? What are your expectations?
3- Why do you think your idea, product is better than others? Why do you think it is good for the society?
4- How could you raise the social acceptance toward your technology? (namely eco-friendly vehicle)
5- What kind of strategies has your management team used so far to penetrate your technology in the society?
6- What kind of strategies has your management team used so far to beat other similar technologies? Like other eco-friendly products with the same characteristics?
7- What is the shortcoming of research body toward eco-friendly vehicles? What kind of knowledge do you seek the most from academic body?

Appendix III

Results on Toyota's patent analysis

year	HEV asset	EV asset	Cumm	engine	gene rator	FE emit	H drive	E battery	E motor	E drive	FCell
1980	122	1	256	83	2	37	0	1	0	0	0
1981	86	2	241	67	1	18	0	1	1	0	0
1982	70	0	206	57	0	13	0	0	0	0	0
1983	102	0	246	81	0	21	0	0	0	0	0
1984	139	2	353	112	0	27	0	1	1	0	0
1985	109	1	331	87	0	22	0	0	1	0	0
1986	61	2	305	47	0	14	0	2	0	0	0
1987	97	5	511	67	0	30	0	4	1	0	0
1988	65	2	424	49	0	16	0	1	1	0	0
1989	66	0	373	45	0	21	0	0	0	0	0
1990	44	0	216	28	1	15	0	0	0	0	0
1991	45	1	223	25	0	20	0	0	1	0	0
1992	62	3	213	41	0	21	0	0	2	1	0
1993	52	4	202	34	0	17	1	1	2	1	0
1994	45	1	185	32	0	11	2	0	0	1	0
1995	52	5	216	24	0	26	2	0	0	5	0
1996	50	6	211	36	1	11	2	2	1	3	0
1997	54	14	265	34	0	18	2	2	5	4	3
1998	109	14	457	56	0	47	8	3	7	2	2
1999	130	23	495	78	1	38	13	7	7	6	3
2000	103	26	428	64	1	28	10	12	8	4	2
2001	109	22	404	72	0	31	6	14	2	0	6
2002	89	35	401	49	0	29	11	18	2	1	14
2003	97	52	461	67	0	22	8	35	2	5	10
2004	119	41	443	71	2	40	6	24	3	2	12
2005	110	38	377	70	0	33	7	19	4	3	12
2006	190	36	549	136	1	41	12	21	4	1	10
2007	175	43	580	122	1	39	13	16	10	4	13
2008	182	40	736	124	6	34	18	13	2	6	19
2009	129	69	1051	77	1	28	23	14	16	10	29
2010	210	105	1455	135	1	42	32	17	23	18	47
2011	231	132	1011	127	2	54	48	13	27	21	71
2012	184	230	1231	83	1	54	46	37	29	41	123

Appendix IV

Results on Honda's patent analysis

year	HEV assets	EV assets	cumm	engine	gene rator	FE emit	H drive	E battery	E motor	E drive	FCell
1980	31	0	83	27	1	3	0	0	0	0	0
1981	17	0	67	11	0	6	0	0	0	0	0
1982	34	0	97	23	1	10	0	0	0	0	0
1983	33	0	108	12	1	20	0	0	0	0	0
1984	88	1	200	58	1	29	0	1	0	0	0
1985	115	0	319	85	1	29	0	0	0	0	0
1986	70	3	292	54	1	15	0	2	1	0	0
1987	104	5	405	78	3	23	0	0	5	0	0
1988	134	5	376	99	3	32	0	2	3	0	0
1989	96	2	368	77	2	19	0	1	1	0	0
1990	92	2	397	75	4	13	0	2	0	0	0
1991	54	1	253	46	1	7	0	0	1	0	0
1992	42	3	209	32	2	8	0	2	0	1	0
1993	72	7	267	43	2	27	0	1	3	3	0
1994	62	11	242	44	0	18	0	1	1	9	0
1995	68	18	264	37	1	30	0	8	0	9	1
1996	87	25	324	59	0	28	0	11	2	11	1
1997	101	27	362	67	1	30	3	11	4	12	0
1998	101	32	419	49	2	49	1	11	4	13	4
1999	93	27	492	58	4	23	8	13	4	9	1
2000	81	19	506	41	9	19	12	8	4	3	4
2001	146	41	608	98	2	27	19	22	8	5	6
2002	172	40	701	100	2	39	31	18	11	5	6
2003	179	56	698	123	9	26	21	11	16	8	21
2004	167	82	624	116	8	28	15	11	22	12	37
2005	157	90	783	101	4	30	22	10	28	16	36
2006	147	96	867	109	4	18	16	12	21	14	49
2007	108	88	917	78	1	17	12	15	21	15	37
2008	127	79	839	100	2	20	5	10	17	16	36
2009	118	94	913	89	3	18	8	5	29	14	46
2010	116	128	866	92	3	18	3	16	22	17	73
2011	113	122	919	84	8	17	4	12	39	24	47
2012	124	122	918	89	13	20	2	11	30	11	70

Appendix V

Results on Nissan's patent analysis

year	HEV asset	EV asset	cumm	engine	generator	FE emit	H drive	E battery	E motor	E drive	FCell
1980	71	1	182	42	4	25	0	0	0	1	0
1981	74	0	257	46	0	28	0	0	0	0	0
1982	90	3	334	64	0	26	0	3	0	0	0
1983	126	0	383	97	0	29	0	0	0	0	0
1984	110	2	391	88	0	22	0	1	0	1	0
1985	104	2	359	86	1	17	0	1	0	0	1
1986	71	1	307	57	0	14	0	0	0	1	0
1987	73	1	331	58	0	15	0	1	0	0	0
1988	45	2	257	38	0	7	0	1	1	0	0
1989	42	1	309	28	0	14	0	0	1	0	0
1990	76	3	415	58	0	18	0	0	3	0	0
1991	63	1	377	50	0	13	0	0	1	0	0
1992	53	5	396	45	0	8	0	1	2	2	0
1993	36	2	266	23	1	12	0	0	0	2	0
1994	27	3	191	18	0	9	0	0	1	2	0
1995	18	3	146	10	0	8	0	0	1	2	0
1996	33	3	133	24	1	7	1	1	0	2	0
1997	36	8	171	21	0	15	0	5	2	1	0
1998	28	6	221	19	0	9	0	3	2	1	0
1999	52	3	283	42	0	8	2	2	0	1	0
2000	67	16	308	42	0	17	8	6	4	6	0
2001	94	9	326	53	0	30	11	5	5	1	0
2002	68	21	283	43	1	20	4	3	10	4	4
2003	90	27	352	57	1	27	5	7	10	2	8
2004	76	36	395	44	0	22	10	6	19	3	7
2005	98	49	531	61	0	26	11	2	25	7	15
2006	127	43	382	80	2	28	17	11	12	6	14
2007	82	45	451	54	0	14	14	13	12	9	11
2008	62	49	401	37	1	13	11	13	13	6	17
2009	64	52	323	30	0	27	7	19	9	5	19
2010	64	48	244	28	0	23	13	21	7	5	15
2011	35	47	220	12	0	13	10	16	7	3	21
2012	39	46	260	21	0	14	4	10	4	6	26

Appendix VI

Results on MMC's patent analysis

year	HEV asset	EV asset	cumm	engine	gene rator	FE emit	H drive	E battery	E motor	E drive	FCell
1980	3	0	11	3	0	0	0	0	0	0	0
1981	4	0	9	3	0	1	0	0	0	0	0
1982	4	0	5	4	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	0	0	0
1984	4	0	10	4	0	0	0	0	0	0	0
1985	7	0	20	6	0	1	0	0	0	0	0
1986	8	0	27	8	0	0	0	0	0	0	0
1987	6	0	28	6	0	0	0	0	0	0	0
1988	4	0	28	4	0	0	0	0	0	0	0
1989	17	0	41	15	0	2	0	0	0	0	0
1990	13	0	48	10	0	3	0	0	0	0	0
1991	15	0	49	11	0	4	0	0	0	0	0
1992	22	0	41	14	0	8	0	0	0	0	0
1993	19	0	43	13	0	6	0	0	0	0	0
1994	20	0	50	12	0	7	1	0	0	0	0
1995	20	0	52	14	0	5	1	0	0	0	0
1996	15	1	51	9	0	4	2	1	0	0	0
1997	16	0	35	11	0	3	2	0	0	0	0
1998	38	2	71	29	0	7	2	0	0	2	0
1999	26	4	63	26	0	0	0	0	0	4	0
2000	16	1	35	12	0	4	0	0	0	1	0
2001	11	0	25	6	0	2	3	0	0	0	0
2002	13	2	33	9	0	2	2	1	0	1	0
2003	14	0	28	6	0	7	1	0	0	0	0
2004	21	0	45	10	0	11	0	0	0	0	0
2005	17	1	52	10	0	7	0	0	0	1	0
2006	16	2	39	12	0	4	0	2	0	0	0
2007	18	0	43	14	0	3	1	0	0	0	0
2008	13	0	28	11	0	2	0	0	0	0	0
2009	6	5	38	3	0	3	0	3	1	1	0
2010	18	5	54	17	0	1	0	2	1	2	0
2011	13	9	42	6	0	7	0	3	0	6	0
2012	9	10	28	5	0	4	0	4	1	5	0

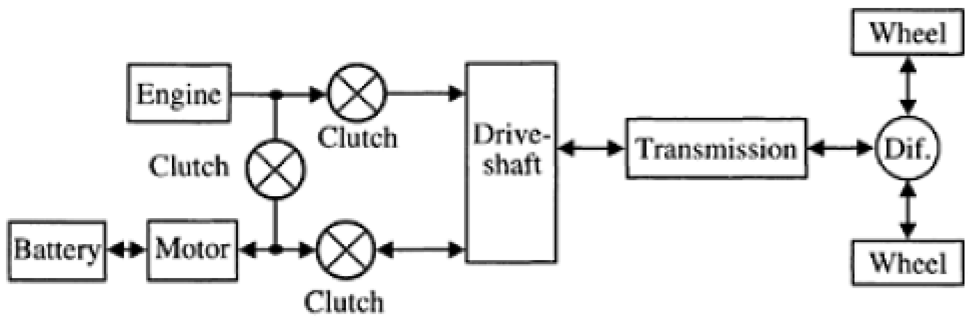
Appendix VII

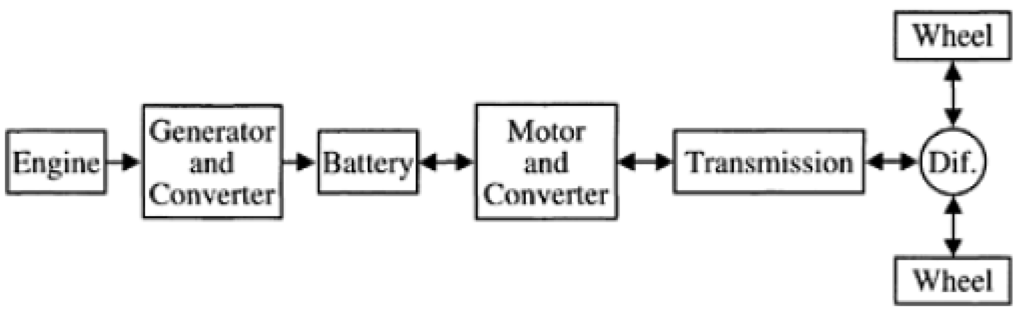
Results on Mitsubishi Group's patent analysis

year	HEV asset	EV asset	cumm	engine	gene rator	FE emit	H drive	E battery	E motor	E drive	FCell
1980	3	2	225	3	0	0	0	0	2	0	0
1981	9	5	266	7	1	1	0	3	2	0	0
1982	9	9	315	7	2	0	0	1	8	0	0
1983	14	7	307	8	5	1	0	0	7	0	0
1984	31	26	496	17	12	2	0	4	22	0	0
1985	41	29	595	26	11	4	0	1	26	0	2
1986	50	24	612	27	8	15	0	2	18	1	3
1987	39	27	880	20	13	6	0	2	15	3	7
1988	49	41	881	29	9	11	0	8	28	0	5
1989	82	43	1178	59	9	14	0	7	32	1	3
1990	108	62	1348	78	10	30	0	6	49	2	5
1991	104	46	1448	85	4	15	0	3	41	1	1
1992	98	44	1489	71	8	19	0	0	39	3	2
1993	101	24	1440	68	18	15	0	5	16	1	2
1994	79	18	1493	55	6	16	2	3	15	0	0
1995	69	17	1441	50	2	16	1	4	10	2	1
1996	64	20	1382	41	10	11	2	6	9	2	3
1997	68	18	1284	45	10	10	3	5	13	0	0
1998	60	22	1634	42	5	10	3	4	14	3	1
1999	71	32	1654	60	5	6	0	7	18	4	1
2000	62	39	1575	42	7	13	0	16	21	2	0
2001	90	53	1749	56	18	13	3	16	29	1	7
2002	75	55	1410	44	18	11	2	25	25	1	4
2003	68	28	1381	40	12	15	1	17	7	2	2
2004	90	56	869	62	6	21	1	15	41	0	0
2005	72	54	917	52	7	12	1	7	46	1	0
2006	74	56	879	48	16	10	0	11	41	2	2
2007	75	46	1005	57	9	9	2	10	26	5	5
2008	51	61	1001	39	7	4	1	8	49	2	2
2009	49	51	1239	26	9	10	4	9	31	4	7
2010	58	54	1411	44	7	5	2	4	37	6	7
2011	47	67	1397	25	6	14	2	17	32	9	9
2012	44	67	1517	23	7	12	2	16	40	8	3

Appendix VIII

A schematic view of HEV components for parallel (up) and series (down) Hybrids (from Husain, 2003)





Appendix IX

A schematic view of EV components (from Husain, 2003)