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Strategic flexibility in shifting to electrification: A real options reasoning perspective on Toyota and Nissan

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Abstract: This paper addresses commitment versus flexibility in the face of uncertainties about the electrification of vehicle powertrain technologies. A real options reasoning perspective is employed to analyse the potential option structures and underlying logic behind the strategies of Toyota and Nissan. The case analyses indicate that the Japanese carmakers have (compound) options to expand their electrified powertrain portfolios and switch battery sources. The findings also suggest that the stability of powertrain design rules serves as a foundation of real options and that carmakers' approaches to balancing the commitment to, and flexibility for, particular strategic actions are influenced by the nature of the uncertainties. Further, firms' perceptional and behavioural biases over uncertainties will affect the execution or abandonment of the options.

Keywords: powertrain electrification; battery electric vehicles; hybrid electric vehicles; real options reasoning; commitment; flexibility; uncertainties; Toyota; Nissan

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1 Introduction

The growing need for greener mobility has accelerated innovation in vehicle powertrains. Hybrid electric vehicles (HEVs), plug-in HEVs (PHEVs), battery electric vehicles (BEVs), and fuel cell electric vehicles (FCEVs), have increasingly gained popularity both in advanced markets (Chanaron and Teske, 2007; Haugneland and Kvisle, 2015) and emerging economies (Chen and Midler, 2016; Wang and Kimble, 2011; Li, 2015). Several extant studies (e.g., Amsterdam Roundtables Foundation and McKinsey & Company, 2014; International Energy Agency, 2012) suggest that electrified powertrains are likely to become the prevalent technologies in the long term.

However, in the short- and mid-term, internal combustion engine vehicles (ICEVs) will remain dominant because electrified powertrain vehicles, especially BEVs and FCEVs, still have technological and economic disadvantages (e.g., short driving distance, long charging time, high costs in battery and fuel cells, etc.). Although the long-term trends are clear, there remains a significant degree of uncertainty about the types, timing, and market value of future powertrains. Consequently, automotive manufacturers have to address ongoing choices among alternative powertrain technologies (Aggeri et al., 2009; Berggren et al., 2009; Clarke and Piterou, 2019; Dijk and Kemp, 2010). Under such uncertainties, some carmakers (e.g., Nissan, Tesla, and BYD) have committed to BEVs earlier than others (e.g., Toyota and Volkswagen).

Earlier commitment allows firms to establish technological leadership, pre-empt strategic assets, raise the switching costs of buyers (Lieberman and Montgomery, 1988), and gain increasing returns via network externalities (Katz and Shapiro, 1985). This commitment, however, often requires irreversible investments in specific markets, technologies, or usages that limit the flexibility to change the course of strategic actions (Dalziel, 2009; Gersch et al., 2013; Ghemawat and del Sol, 1998; Li and Li, 2010). The disadvantages of irreversibility will become prominent when uncertainties about the future are high, raising the question of how carmakers can move ahead of their competitors in the face of electrification of powertrain technologies while sustaining strategic flexibility under uncertainty.

This paper addresses commitment versus flexibility in the electrification of vehicle powertrain technologies. Based on publicly available data, this paper applies a real options reasoning perspective to reveal potential option structures and present hypothetical explanations about the underlying logic and constraints behind the carmakers' powertrain strategies. The remainder of this paper is structured as follows. Section 2 reviews the theoretical background on formulation and execution of real options. Section 3, after briefly explaining research settings and methods, illustrates the transitions of the powertrain electrification of Toyota and Nissan. Section 4 analyses the potential real options structures of the powertrain strategies based on real options reasoning perspective. Section 5 discusses the technological and managerial implications of retaining flexibility in powertrain strategies and properly executing (or abandoning) the options in the face of uncertainties. Section 6 concludes the paper.

2 Theoretical background

2.1 Real options reasoning

A real option is defined as a right, but not an obligation, to take specified actions (e.g., deferring, expanding, switching, or abandoning) at a specified cost for a specific period of time (Copeland and Antikarov, 2001; Trigeorgis and Reuer, 2017). Real options allow firms to wait until uncertainties are resolved before further committing to a particular course of action. As the payoff diagram in Figure 1 illustrates, the option holder can benefit from maintaining access to upside opportunities while limiting losses by not exercising the option. This asymmetric distribution of potential profits and losses suggests that the value of the option will increase when there are higher uncertainties.

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Figure 1 about here

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A real option consists of the following six variables: (1) the present value of an underlying asset; (2) the cost of holding the option (called an option premium); (3) the exercise price of the option (strike price); (4) the time until the option's maturity; (5) the volatility of the underlying asset; and (6) the risk-free rate for the duration of the option. In real options, the present value of the underlying asset is typically the sum of the expected cash flows generated by the asset or the project in question. While the holder of financial options cannot directly influence the value of the options, the holder of real options is able to affect the option values. The volatility is represented by the uncertainty of the value of the underlying asset. When there is no volatility, there is no reason to hold an option because flexibility has little value.

Much of the extant real options literature valuates options by using mathematical or simulation models based on financial option theories (Driouchi and Bennett, 2012; Trigeorgis and Reuer, 2017). However, in contrast to financial options, the availability of the empirical data (e.g., market prices and volatility of the underlying assets) that is needed to calculate the real option values is limited due to the absence of market transactions of the assets (Lander and Pinches, 1998).

Although an accurate calculation of an option's value is difficult, the logic of real options thinking is helpful in creating strategic flexibility (Bowman and Hurry, 1993; Kogut and Kulatilaka, 1994; Luehrman, 1998; McGrath, 1999). Real options reasoning is a heuristic for recognising hidden options in an investment and logically structuring possible decision-making courses (Barnett, 2008; Driouchi and Bennett, 2012; Kogut and Kulatilaka, 1994; McGrath, 1999; McGrath and Nerkar, 2004; Trigeorgis and Reuer, 2017). Real options reasoning provides firms with a cognitive framework to undertake more uncertain projects, stage investments to ensure the upside potential remains achievable while limiting losses, encourage flexible decision choices depending on contingent circumstances, and allow the management of a portfolio of multiple options opportunities (Trigeorgis and Reuer, 2017). In other words, real options reasoning can be used as a strategy formulation framework or decision-making metaphor in the presence of uncertainties (Bowman and Hurry, 1993; McGrath and Nerkar, 2004; McGrath et al., 2004).

2.2 Formulation of real options

Identified option opportunities have to be structured in real assets or projects. Although some strategic initiatives (e.g. technology acquisition through venture capital investments, joint ventures, strategic alliances, etc.) have inherent option-like structures (Alvarez and Barney, 2001; Burgers et al., 1993; Folta, 1998; Hurry et al., 1992; Kogut, 1991), firms have to deliberately embed flexibility into the product architecture to create options in product systems (Baldwin and Clark, 2000; Garud and Kumaraswamy, 1995; Sanchez and Mahoney, 1996; Ulrich, 1995).

The essence of the product architecture resides in the definition of fixed and variable elements of the design rules of the product system. The fixed elements of the design include the mapping from functional elements to physical components, interface rules, and specifications of components or subsystems that are commonly used across multiple products (Baldwin and Clark, 2000; Ulrich, 1995). The variable elements are components, subsystems, or industrial designs specific to each of the individual product variations. The fixed elements serve as platforms where the variable elements can be added, substituted, or removed to tailor product features to meet specific market needs (Baldwin and Woodard, 2009). The modularisation of product architecture increases option opportunities by allowing the product system to be flexibly reconfigured through mixing and matching of modules (Baldwin and Clark, 2000).

2.3 Implementation of real options

In a normative sense, a firm will execute an option when uncertainties are resolved and circumstances are favourable. Conversely, when situations are unfavourable, the option will not be executed if it is still active or will be abandoned when it expires. The flexibility inherent in real options comes from abandonment of the options (Adner and Levinthal, 2004; Barnett and Dunbar, 2008). However, terminating options in real organisational settings can be difficult.

One cause of this difficulty is the ambiguity of the option's value (Posen et al., 2018). Unlike financial options, there are no explicit market values for real options. The success or failure of the project may depend on managers' subjective judgements. When managers over- or under-evaluate the option value, there is a risk that the 'out-of-the money' option will be exercised or vice versa. Adner and Levinthal (2004) pointed out that the life of options might be extended when *ex post* discovery gained from initial investments opens new directions for the original options. In such circumstances, the firm will face greater difficulty in deciding when to abandon the options.

Another challenge comes from the fact that most options on strategic initiatives do not have an explicit and exogenous expiration period (Adner and Levinthal, 2004). If there is no explicit termination deadline, the duration of the option depends on the discretion of, or negotiation among, managers on the option opportunity. In theory, since option values become higher as the option duration increases, the ambiguity of the expiry date leads to a risk of overvaluation.

3 Powertrain electrification of Toyota and Nissan

3.1 Research setting and methods

To develop a better understanding of the conditions and logic behind the flexibility embedded in technological and organisational contexts, a comparative case study is conducted. Trigeorgis and Reuer (2017) encouraged case-focused research to reveal the logic, conditions, and contexts of individual real option cases. While much of the empirical work in the real option literature has been conducted at the aggregated cross-section level, research is needed at the project level to understand the rich details of technological and organisational contexts that enable or disable effective formulation and execution of real options (Adner and Levinthal, 2004).

The research setting is the powertrain electrifications by Japan's large and established carmakers: Toyota Motor Corporation and Nissan Motor Corporation. Toyota and Nissan are particularly appropriate research objects because they employ contrasting powertrain electrification strategies. Both are headquartered in Japan, operate worldwide, and have similar organisational sizes and product portfolios. Since the introduction of the first HEV (the Prius) in 1997, Toyota has intensively developed hybrid technologies and expanded its product line-up of HEVs. As of 2018, Toyota and Lexus, its luxury vehicle division, had 29 and 10 HEV models, respectively, and combined annual sales of HEVs of 1,630,000 units[1]. Meanwhile, as of 2019, Toyota had only one PHEV model (the Prius PHV), one FCEV model (the Mirai), and no BEVs. In contrast, Nissan was one of the first carmakers to release a BEV, the Leaf, in the mass market. The Leaf is the most sold BEV model in the world and its cumulative sales reached 400,000 units in March 2019[2]. Nissan also has HEV models but opted for the series hybrid powertrain that uses an electric motor powered by electricity generated by an internal combustion engine (ICE).

Another difference between the two carmakers is the degree of vertical integration of components for electrified powertrains. Toyota favours internalisation of the core components and subsystems of the HEVs (e.g., electric motors, inverters, power-split units, and batteries). A joint venture (JV) was established in 1996 with Panasonic Corporation to manufacture nickel-metal hydride batteries for HEVs and commitment to the JV was reinforced in 2010 through an increase in Toyota's ownership to 80 per cent from 60 per cent. Nissan, under an alliance with Renault, has changed its supplier relations and shifted to a more open sourcing policy[3]. Regarding BEVs, Nissan established a JV with NEC Corporation in 2007 because the performance and costs of the battery are crucial. However, Nissan decided to sell the JV to a third party in 2018. These differences in organisational environments enable an analysis of the differences in flexibility in the powertrain strategies.

The intentions and logic behind the powertrain strategies are examined by using event trees to illustrate the trajectories of the divergences and mergences of the powertrain types released in the Japanese market by Toyota and Nissan[4]. The event tree analyses span nearly three decades from the 1990s to the 2010s. Prius defines the stages of Toyota's event tree because it is its flagship HEV model and the carmaker has introduced new technologies along with new generations of the Prius. While Nissan released the first BEV as early as 2010, its powertrain strategy has not been as consistent as Toyota's. The phases of Nissan's event tree are therefore determined by the introduction of new powertrain technologies. This paper also analyses the combination of the electrified powertrains and vehicle platforms. When the powertrain and platform are tightly coupled, the product architecture is deemed to be more integral; if the powertrain and platform are loosely coupled, the product architecture is more modular.

To draw the event trees and describe the background technological and organisational context, archival data from corporate official websites, business publications (e.g., newspapers, business magazines, and industry reports), and publicly available documents generated by the government and industrial associations are used.

3.2 Trajectory of Toyota's powertrain electrification

Figure 2 illustrates the evolution of Toyota's powertrain electrification in the form of an event tree.

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Figure 2 about here

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First, one can see the steady increase in the number of HEV models as stages proceed. It is noteworthy that the rapid expansion of the HEV portfolio in period three matches the introduction of taxation reforms and incentives for next generation and fuel-efficient vehicles in 2009[5]. As the tax reduction and exemptions were implemented, and purchase subsidies were determined according to the fuel efficiency and exhaust gases of the models, the HEVs as well as the PHEVs and BEVs were given the most preferential treatments. Toyota doubled the HEV models in period three from the previous period.

Second, Toyota has not only released HEV-dedicated models (e.g., the Prius, Prius C, and SAI) but also added an HEV version of existing models such as the Corolla HV, Camry HV, Harrier HV, and others. The market segments of the HEVs range from small cars (e.g., the Yaris HV and Prius C) to large vehicles (e.g., the Alphard HV). The body types are also various: sedans (the Prius and Camry HV), hatchbacks (the Corolla Fielder HV), minivans (the Alphard HV and Estima HV), and SUVs (the Harrier HV and C-HR HV).

Third, Toyota has continually improved the performance of the hybrid system and increased its variation. The carmaker has employed the series-parallel hybrid system that combines an ICE and two electric motors with a power-split unit. The series-parallel hybrid system propels the vehicle through the ICE, the electric motors, or both, depending on the driving conditions. The hybrid system installed in the first-generation Prius was called the Toyota Hybrid System (THS). Other hybrid systems existed in this first period in addition to the THS. The Estima HV was equipped with the THS-C, which consisted of an ICE, two electric motors, and one continuously variable transmission (CVT). The Crown Mild Hybrid model had a simplified hybrid system with an electric motor/generator with a higher voltage system (THS-M). From period two onwards, a more downsized and lightweight hybrid system (THS-II) with higher efficiency was introduced to the second-generation Prius and then installed in subsequent models. In period three, Toyota developed the THS-II with a motor speed reduction mechanism to downsize the electric motors. The carmaker also introduced the THS-II with a two-stage motor speed reduction mechanism that could fit with rear-wheel drive models. Various ICEs can be combined with the THS-II: inline-four cylinder (1.5L and 2.0L), V6 (3.5L), and V8 (5.0L) engines.

Fourth, Toyota's hybrid systems were combined with various vehicle platforms. The list of HEV model platforms includes the B platform for small cars with front-engine and front-wheel drive (FF) cars, the MC and new MC platforms for subcompact FF vehicles, the K platform for mid/large size FF vehicles, and the N platform for mid/large size front-engine and rear-wheel drive (FR) cars. This implies that the product architecture of Toyota's HEVs is relatively modular because the combination of the hybrid system (THS-II) and vehicle platforms is loosely coupled, which allows the THS-II to be installed across various models.

Finally, Toyota has not favoured PHEVs and BEVs. It had only two generations of one PHEV model: the first PHEV (the Prius PHV) was introduced in period three (January 2012) and the second was released in period four (February 2017). Except for the BEV versions of the RAV4 that were sold on a limited scale in the 1990s and 2000s[6], Toyota has had no BEV models in its product line-up. Instead, the carmaker introduced the first FCEV, the Mirai, in December 2014 and had sold 7,900 units by March 2019.

3.3 Trajectory of Nissan's powertrain electrification

As shown in Figure 3, the event tree of Nissan's powertrain electrification has four stages: period zero (little electrification); period one (the first HEV licenced from Toyota); period two (the release of its first BEV); and period three (the introduction of the new modular platforms: Common Module Family).

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Figure 3 about here

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First, Nissan positioned BEVs as the primary powertrain for next generation green cars. It released the fully electric model, the Leaf, in the subcompact car segment in December 2010. The commercial production of the Leaf began earlier than the Tesla Model S. The Leaf was the most sold BEV in the world as of March 2019. However, the number of BEV models has been limited to only two: the Leaf and e-NV200[7]. The body structure of the Leaf is different from those of the ICEV models. It was specially designed to store a large quantity of rechargeable batteries in its underbody (Gersch et al., 2013). This suggests that the product architecture of the Leaf is integral because the electric powertrain is tightly coupled with the vehicle platform. This technological trait might have hindered the transplant of the electric powertrain to other models with ICEV-based platforms (Muniz and Belzowski, 2017).

Second, Nissan released HEV models in mid- and large-sized car segments. It opted for parallel hybrid systems that combine an ICE, an electric motor, and two clutches. The hybrid system was applied to the large FR models (e.g., the second generation Fuga, the fifth Cima, and the 13th Skyline), as well as the D segment FF models (e.g., the fourth Pathfinder and the second X-Trail/Qashqai). It is likely that the carmaker intended to improve driving performances as well as reduce carbon dioxide emissions by raising the bottom end of the fuel economy of heavier models through a hybrid of the powertrains.

Meanwhile, in the small and subcompact car segments, Nissan chose more conventional technologies, including engine downsizing, a stop-and-start system, and an energy recuperation system.

Third, weak technological linkages of powertrains existed within and between stages until period three. While the hybrid system was borrowed from Toyota and modified to fit with the existing ICEVs in period one, the BEV powertrains were developed in parallel with the hybrid systems in period two. The resulting technological configurations are quite different: whereas the Leaf has a unique platform dedicated to the electric drive and is run entirely by an electric motor (Gersch et al., 2013), the HEV models were based on existing body platforms and propelled by ICE with torque assists from the electric motors. Concerning the cross-stage linkages, the parallel hybrid systems developed by Nissan in period two had different technological configurations from the previous Toyota-licenced system.

The technological linkages in the electrified powertrains were established in the transition from period two to three. Nissan developed the series hybrid powertrain technology based on the electric drive systems used in the Leaf. The new hybrid system (called ‘e-Power’) was applied to its compact car (the Note e-Power) and minivan (the Serena e-Power). As the series hybrid powertrain uses an electric motor to propel the wheels, its driving feel is quite similar to that of BEVs. While mitigating the disadvantages of the BEVs (e.g., the short driving mileage, long recharging time, limited availability of recharging facilities, and higher battery costs), the hybrid powertrain attracts potential customers by offering BEV-like driving experiences within a reasonable price range.

4 Real options reasoning of Toyota and Nissan

4.1 Toyota's options to expand the HEV portfolio

Toyota will have the flexibility to decide whether to launch HEV versions in addition to the ICEV models. When the first Prius was released, it was the only HEV model and the hybrid system was dedicated to the model. From period two, the hybrid system was packaged as the THS-II and became installable in various ICEV models.

This can be considered as an option to expand HEV models in the product portfolios (Avadikyan and Llerena, 2010) because the THS-II allows Toyota to gauge actual demands for hybrid models in each market segment and add adequate models adaptively. The underlying asset will be the sum of expected cash flows from the introduction of an HEV model to a specific market segment. The premium to hold the options is the research and development (R&D) expenses incurred to develop and improve the hybrid systems. The additional costs needed to develop an HEV version by applying the hybrid system to a base ICEV model is be the strike value to exercise the option. When the demand for a particular HEV model in an unfamiliar market segment is uncertain, in other words when there is a higher degree of volatility, the value of an option to wait until the uncertainties are resolved increases. In addition, as more models carry THS-II, the R&D expenses for the hybrid system will be allocated across a wide range of models, thereby lowering the strike prices of the options. This is one example of how the option holder can affect the value of the real options (in contrast to financial options) through his or her own efforts.

4.2 Toyota's compound options to expand the powertrain portfolio

The main elements of the THS-II include an ICE, a transmission, electric motors, a power-split unit, rechargeable batteries, and a power management unit. In theory, by adding or withdrawing relevant elements of the hybrid system, Toyota can efficiently develop PHEVs, BEVs, or FCEVs. As shown in Figure 2, by regarding these powertrains as technological systems that can be branched off from the hybrid system, the carmaker can retain the flexibility to progressively select appropriate technologies depending on changes in technological advancements, environmental regulations, and customer preferences. As these options derive from the fact that the hybrid system has already been developed, they are deemed to be compound options (Avadikyan and Llerena, 2010; Copeland and Antikarov, 2001).

The costs to gain compound options are the cumulative R&D expenses needed to develop the THS-II. As the R&D costs of THS-II have already been spread across a variety of the existing HEV models, Toyota is able to maintain the compound options at the lowest cost. In other words, Toyota has the flexibility to wait until promising powertrain technologies emerge while retaining HEVs as its main product lines.

Toyota used to regard HEVs as one of the alternative powertrains that existed alongside conventional ICEVs, compressed natural gas engine vehicles, and electric vehicles (see panel A in Figure 4). Around the time of the introduction of the second Prius, Toyota repositioned the hybrid system as the overarching technology of the various powertrains as shown in panel B of Figure 4. This modification of the powertrain strategy implies that Toyota recognised the flexibility of the hybrid system from the real options reasoning perspective, even though it does not use the term 'real options'.

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Figure 4 about here

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4.3 Nissan's compound options to expand the electrified powertrain portfolio

The option-like structure emerged in period three when Nissan derived the series hybrid system from the BEV powertrain technologies. The system is simple and sufficiently small to fit in existing ICEV powertrain systems. This technology can be seen as an option to expand the HEV portfolio depending on market demand. The underlying asset is the sum of expected cash flows from the HEV while the option premium is the R&D expenses invested to develop the hybrid powertrain from the BEV technologies. The strike price is the additional cost needed to develop the HEV version from the base ICEV models. Since the options to expand the HEV portfolio depend on the precedent option to develop the BEVs, they can be considered as compound options to expand electrified powertrains.

Although Nissan committed to the BEV as early as 2010, it was not able to increase sales as expected. Even though there have been eco-car taxation and purchasing subsidies that were very generous for BEVs, the carmaker seemed hesitant to commit to releasing additional BEV models. However, the series hybrid technologies allowed Nissan to create an option structure in electrified powertrains; it gained the flexibility to progressively release HEV models considering market and technological uncertainties. In addition, as many of the components and subsystems are common to both the BEV and the new hybrid powertrains, an increase in HEV model sales lowers the system costs for the BEV models that, in turn, lowers the strike price to execute the options to develop new BEV models.

4.4 Nissan's options to switch battery sources

Regardless of the purchasing strategy of the Renault-Nissan Alliance to source parts openly from non-*keiretsu* suppliers, Nissan vertically integrated battery technologies by establishing a JV in 2007 with NEC Corporation to develop and produce lithium-ion batteries. It purchased the lithium-ion batteries for the Leaf solely from the JV. However, Nissan interestingly announced in August 2018 that it would sell the JV to a Chinese firm[8].

Under circumstances in which global carmakers, automotive battery suppliers, and chemical firms have been fiercely competing for an advancement in battery performance, it is uncertain which agents will break through to become leaders. The vertical disintegration of the battery business provides options to switch suppliers. The underlying asset of the options is the sum of expected savings of the purchasing costs or cash flows gained from the potential access to better battery technologies. The premium to hold the options is the expense to establish the JV to, in turn, absorb the resulting knowledge of battery technologies. The more uncertain the pace of technological advancement, the more valuable the flexibility to switch sources.

5 Discussion

Although extant literature on real options reasoning provides conceptual frameworks (Adner and Levinthal, 2004; Barnett, 2008; Barnett and Dunbar, 2008; Luehrman, 1998; McGrath, 1999), simulation analyses (Miller and Arikan, 2004; Posen et al., 2018), and empirical evidence at the aggregate level (Dalziel, 2009; Kogut, 1991; McGrath and Nerkar, 2004), empirical studies at firm- or project-level are limited (Trigeorgis and Reuer, 2017). This is especially true for real options studies on the selection of technologies in the automotive industry. Avadikyan and Llerena (2010) presented one of the works but their analysis was conceptual. To fill this gap, this paper conducted a comparative analysis of the powertrain strategies of Toyota and Nissan. The previous sections have illustrated the trajectories of powertrain electrifications and the heterogeneity in the options structure. The comparative analysis has technological and organisational implications for formulating and exercising the potential options as follows.

5.1 Stability of design rules as a foundation of real options

This case study offers technological insights for the formulation of the options structure in product architecture. The cases of both Toyota and Nissan indicate that the stabilisation of the electrified powertrain design was an enabler of options to expand their HEV portfolios. For Toyota, there were multiple formats for the hybrid systems (e.g., the series-parallel hybrid, mild-hybrid, and hybrid with CVT) in period one. After convergence to the series-parallel format (the THS-II) in period two, Toyota expanded the HEV models progressively. Toyota defines the hybrid system as the fixed and thus common design element across different stages of powertrain evolutions while the mounting layouts (i.e., body types and platforms) are kept changeable.

In contrast, Nissan did not have stable design rules for the powertrain until period three. Its hybrid formats changed through period one (the series-parallel licenced from Toyota), period two (the parallel system), and period three (the series hybrid derived from the BEVs). The series hybrid technologies provided the common and fixed design elements between the BEVs and HEVs and allowed Nissan to have compound options to expand its HEV portfolio. This finding is consistent with the concept of a dominant design (Utterback, 1994). After the fluid period (period one at Toyota; from period one to two at Nissan), the intra-firm dominant designs of the hybrid systems were established and served as the technological platforms to create product variations (Baldwin and Woodard, 2009).

Interestingly, the rigor in the design rules of the dominant hybrid designs seems not to be high in both the cases of Toyota and Nissan. Prior literature on modularity-in-design suggests that rigorous design rules enable product systems to create variation through mixing and matching of components and modules (Baldwin and Clark, 2000; Garud and Kumaraswamy, 1995; Langlois and Robertson, 1992; Sanchez and Mahoney, 1996). From real options thinking, standardised design rules—which facilitate the compatibility of the modules—lower the strike price of the execution of options to develop new models because engineering resources to apply and adjust hybrid technologies will be reduced. However, the more rigorously defined the design rules are, the narrower the scope of product families that can be derived from the base technologies.

The same trade-off can be found in the duration of the expiry period of the options. Standardisation of design rules will restrict the changes in mapping from functional elements to physical components, the interfaces between interacting modules, and the specifications of components. When the preconditions behind the design rules are changed (via exogenous technological advancements or changes in regulations, for example), the underlying option structures are undermined, after which the effectiveness of the options expires. The optimal balance between the rigor of the design rules and the product variety as well as the duration of the option expiry remains an open question.

5.2 Uncertainties about transactions and future values

The differences in the timing of the commitment to electrified powertrains and governance approaches between the two carmakers can be explained by the differences in the uncertainties inherent in powertrain technologies and firm preferences. Barney (2002) suggested that when the threat of opportunism in transactions is high, a hierarchical form of governance would be chosen to minimise transaction costs; if uncertainty about the future value of the investment is high, real options logic should dominate and less hierarchical governance structures will be chosen.

Toyota made the commitment to the HEVs earlier than any other carmaker. The first HEV was characterised as an architectural innovation (Henderson and Clark, 1990; Magnusson et al., 2003). While its hybrid powertrain consisted of the existing technologies (e.g., an ICE, transmissions, electric motors, and nickel-metal hydride battery), the configuration of the components was novel. The development of the HEVs required a high level of coordination to address unexpected problems caused by the interactions between the component technologies. Thus, Toyota strengthened cross-firm collaborations with its *keiretsu* suppliers to fine-tune the functional and physical interactions of components of the HEVs (MacDuffie and Fujimoto, 2010; Magnusson et al., 2003).

Meanwhile, the uncertainties about HEV market values can be regarded as being comparatively low because HEVs enhance rather than replace existing powertrains. Since HEVs are propelled by ICEs, unlike BEVs, drivers can use existing gas station networks without concern about battery power. The remaining uncertainty is the timing of demand increases for new HEV models in different market segments. In fact, when the so-called eco-car tax was introduced in 2009, Toyota quickly expanded the HEV portfolio in period three. In other words, the option-like structure of Toyota's hybrid system enabled it to wait until the market uncertainty decreased and efficiently release the HEV models to seize the opportunities created by the taxation reforms. Overall, Toyota addresses the technological uncertainties about hybrid powertrains by reinforcing the hierarchical form of governance, that is, vertical integration and *keiretsu*, while absorbing the uncertainties about future market values of hybrid powertrains by embedding the option structure into the product architecture of the HEVs.

Although Nissan was one of the first carmakers to release a BEV model in a mass-market segment, it is questionable if it was fully engaged in BEVs. The BEV was categorised as a radical innovation (Henderson and Clark, 1990) because the product architecture and primary components of the vehicle were both changed. The uncertainty about BEV technologies was especially high in an early and fluid stage of product evolution. Since the electric powertrain was tightly coupled with the dedicated vehicle platform, Nissan was unable to build the option structure into product architecture until period three. With no option structure in the vehicle design, even after the market uncertainty for electrified powertrain cars had been reduced by the taxation reforms since 2009, Nissan made no further commitment to release additional BEV models.

A theoretical implication of Nissan's seemingly counter-intuitive decision on the divestiture of its battery JV can be drawn from the real options reasoning perspective. Since the performance and cost of batteries are crucially important to the electrified powertrains, the carmaker had vertically integrated its battery value chain through a JV with NEC (Huth et al., 2013). According to Gersch et al. (2013), Nissan's batteries were specifically designed for BEVs and required dedicated production assets and processes that meant low flexibility in converting the usage of the batteries for other purposes. Under circumstances where technological uncertainties remain high, the specificity of the batteries constrains its freedom of strategic choices. The divestiture of the battery JV will allow the carmaker to wait and select the best suppliers from the battery market.

The potential downside of this flexibility is an increase in costs to govern the relationship with external battery suppliers (Barney, 2002; Sanchez, 2003; Williamson, 1979). When the opportunity exists for suppliers to behave opportunistically, Nissan will face hold-up concerns. In addition, in non-hierarchical settings (i.e., market transactions), it will be difficult for Nissan to convince suppliers to make transaction-specific investments. The bigger and more powerful the battery suppliers become, the more difficult it will be for the carmaker to control the suppliers.

5.3 Option abandonment and expiry

A key issue is whether Toyota and Nissan will be able to exercise or abandon the options in a timely fashion. As prior studies (Adner and Levinthal, 2004; Barnett and Dunbar, 2008) suggest, the flexibility of real options derives from the possibility of abandonment in the presence of an unfavourable situation.

First, the option holder's perceptions of uncertainties will influence the exercising of options. The case study of Toyota's powertrain strategy indicates that it has compound options to expand the portfolios of electrified powertrains. The carmaker can wait until alternative powertrain uncertainties are resolved. The more Toyota considers the prospect of BEVs to be uncertain, the more likely it is that it will continue to hold the options. This is because the real option allows asymmetric decision-making and the potential gains will increase when the volatility of the uncertainty is higher. When perceived uncertainties are high, options will not be exercised; this reduces opportunities to learn from experiences in the marketplace and reinforces pessimistic perceptions about the uncertainties. Such differences in the perceptions of uncertainties will lead to differences in the ways in which firms structure and exercise options and thus progressively enhance heterogeneity in firm behaviour and capabilities (Driouchi and Bennett, 2012; McGrath et al., 2004; Trigeorgis and Reuer, 2017).

Second, firms' efforts to combat technological uncertainties will affect real options decision-making. For example, one of deciding factors in shifting to BEVs from HEVs is the pace of improvements of rechargeable batteries. As Toyota and Nissan have compound options to expand the portfolios of electrified powertrains, they can wait until the technical issues have been solved and the costs of the batteries decline to a satisfactory level. If self-reliant efforts can resolve the uncertainties regarding batteries, firms will make R&D investments to increase the possibility of commercialising BEVs. Under such circumstances, the possibility of 'option traps' will increase (Adner and Levinthal, 2004).

The more a firm invests R&D resources into battery development, the more difficult it becomes to abandon the project because further development efforts may raise expectations of overcoming the technical challenges. This forces the firm to maintain its options almost indefinitely. As Toyota's R&D policy is to commit to all areas of next-generation technologies, the automotive manufacturer has a strong impetus to develop key technologies, such as BEV batteries and fuel cells, internally (Berggren et al., 2009). Such a tendency toward escalating the commitment (Staw, 1981) may undermine the options value of Toyota's hybrid systems in hedging downside risks. Meanwhile, Nissan's decision to divest its battery business will lower the risk of the escalation of commitment and increase the flexibility in its battery procurement.

6 Conclusions

This study explores commitment and flexibility issues in automotive powertrain electrification. An earlier commitment to hybrid or electric powertrains allowed Toyota and Nissan to pre-empt technological knowledge gained through learning-by-doing and raise market awareness of electrified vehicles. At the same time, they had to address the uncertain prospects of electrified powertrains. Real options reasoning enables the carmakers to develop strategic flexibility. The comparative case studies indicate that

Toyota has real options to expand its HEV portfolio and compound options to exploit alternative electric powertrains while Nissan potentially holds options to switch battery sources and compound options to expand its electrified powertrains portfolio.

The findings of this study provide several practical implications. First, to embed real options into the product systems, firms should establish stable design rules of the product architecture. The fixed elements of the design rules serve as the platform where variable elements can be added, removed, replaced, or updated. Properly defined design rules will lower the strike prices to develop new products and expand product portfolios. The stability of the design rules over generations of product evolution will positively affect the duration of the expiry period of the options.

Second, managers should be aware that perceptional biases against uncertainties could affect the execution or abandonment of the real options. Organisations with a higher uncertainty avoidance bias may under-execute the options and forego the upside opportunities and vice versa. The degree of vertical integration of core technologies will also affect the execution and abandonment of the options. When there is an expectation that extra R&D efforts will turn the situation into a favourable one, the firm may opt to hold the options longer rather than it should. This escalation of commitment will undermine the flexibility of the real options.

Like all works, this study has limitations that suggest opportunities for future research. Although the case analysis reveals that the stability of design rules plays an essential role in embedding option opportunities in the product architecture, this paper could not find the optimal balance between the degree of the stability of the design rules and the duration of the options expiry. When the fixed design elements of the product architecture are vulnerable to internal or external factors (e.g., changes in public policies on emission regulations or definitions of zero emission vehicles), the resulting real options may have shorter expiry durations. Collaboration between management, engineering, and financial studies would deepen the understanding of the architectural foundations of real option structures.

Finally, as the case study relies on archival data, the findings are based on the outsider's perspective. Although the case analyses reveal the real options opportunities and their underlying logic, it does not establish that the managers of Toyota and Nissan recognised the option values of their powertrain electrification strategies. Surveys and semi-structured interviews with managers and executives will improve our understanding of the psychological and behavioural aspects of the discovery, formulation, execution, and abandonment of real options in real organisational contexts.

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Figure 1 Payoff diagram (call option)

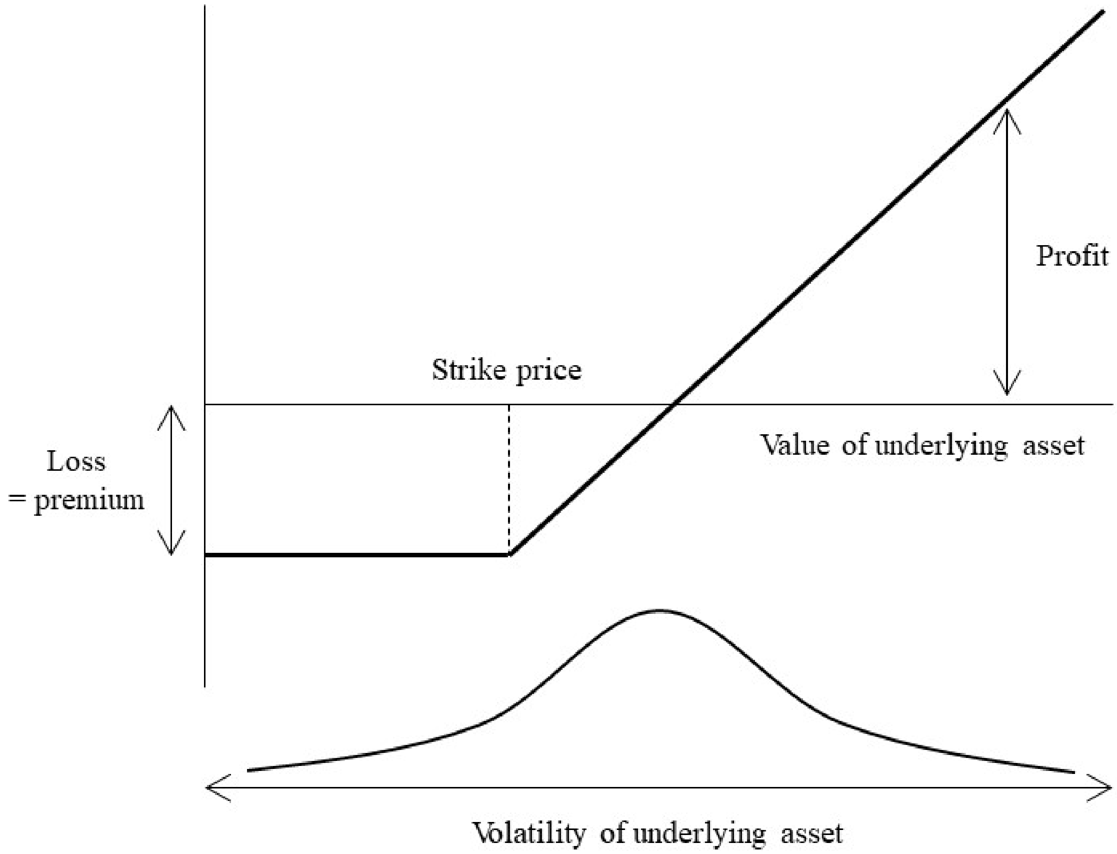
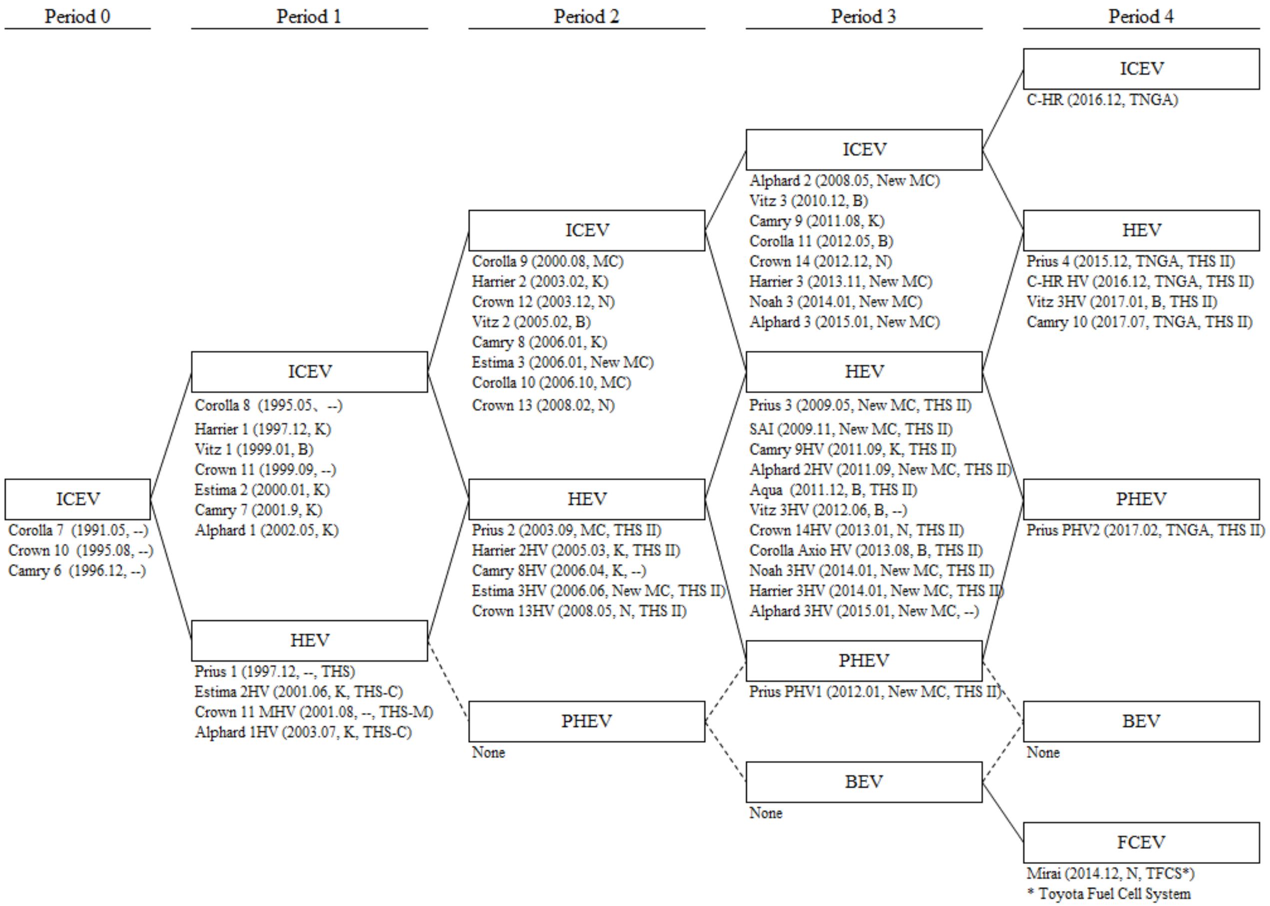
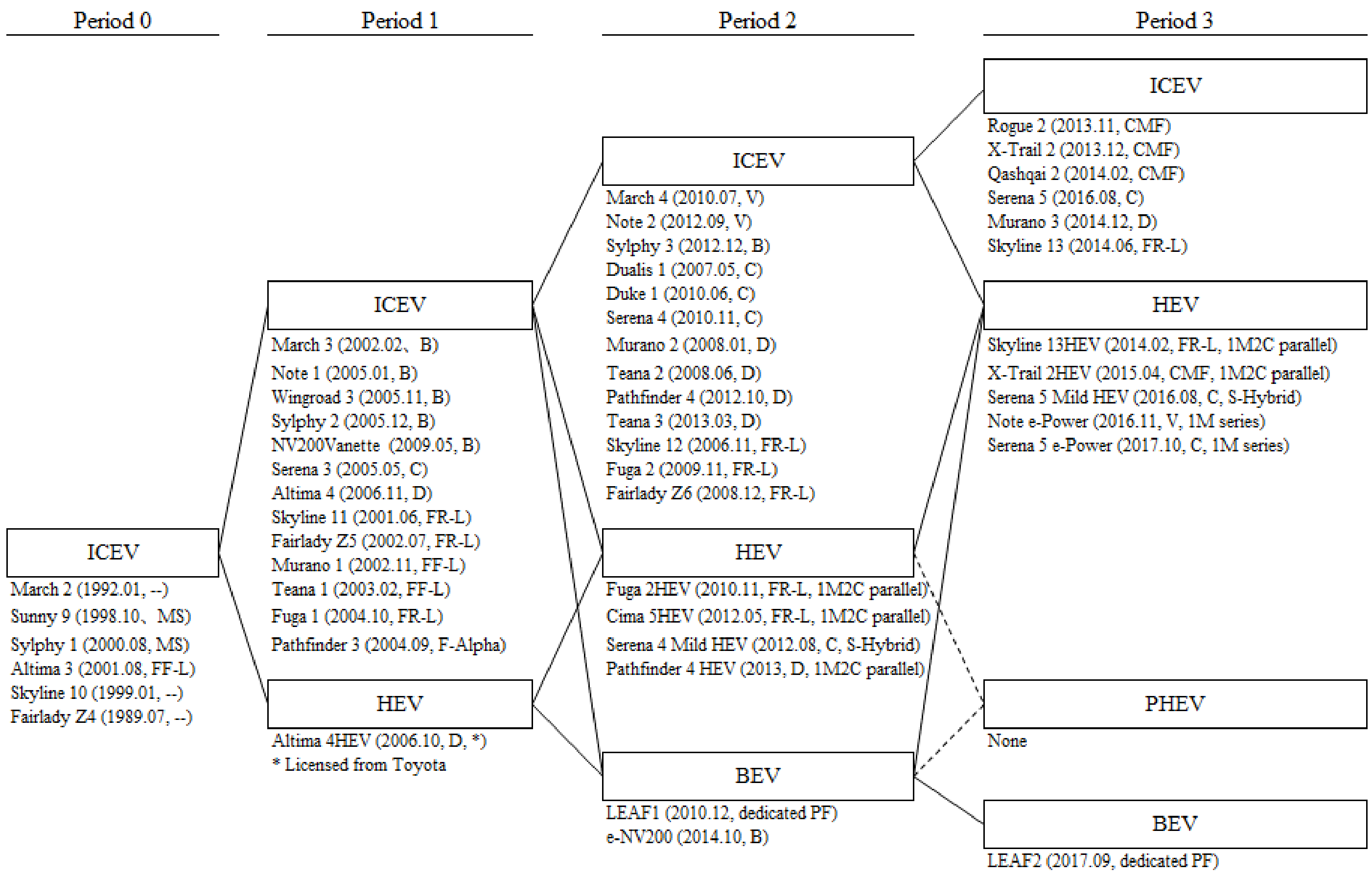


Figure 2 Event tree of Toyota's product portfolio



[Notes] The numbers after model names refer to model generations. ICEVs (year of market launch, type of platform); HEVs/PHEVs (year of market launch, type of platform, type of hybrid technology). HEVs and PHEVs in each period are those launched following the introduction of each generation of Prius into the market. ICEVs in each period are those that were sold when each generation of Prius was introduced into the market.

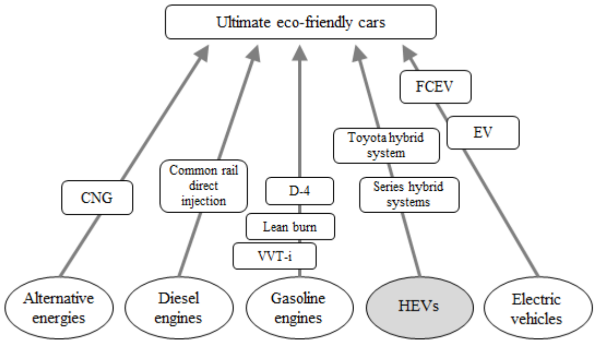
Figure 3 Event tree of Nissan's product portfolio



[Notes] The numbers after model names refer to model generations. ICEVs (year of market launch, type of platform); HEVs/PHEVs (year of market launch, type of platform, type of hybrid technology); and BEVs (year of market launch, type of platform). FF1M2C: Front-engine and front-wheel-drive, one motor and two clutches. FR1M2C: Front-engine and rear-wheel-drive, one motor and two clutches.

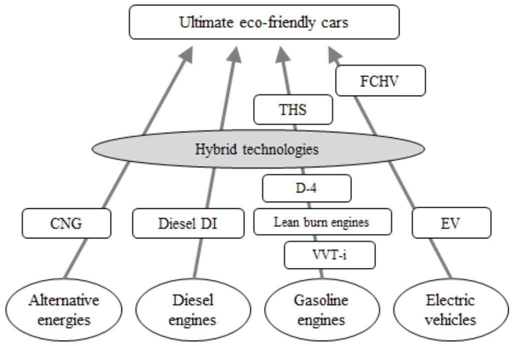
Figure 4 Repositioning of hybrid technologies at Toyota

Panel A
HEVs as one of the alternative powertrains around period one



Source: Toyota Sustainability Report 1998, p. 36.

Panel B
Hybrid systems—the overarching technology around period two



Source: Toyota Sustainability Report 2002, p. 18.

[1] Toyota Motor Corporation. [online] https://global.toyota/en/company/profile/production-sales-figures/ (Accessed 5 May 2019).

[2] Nissan Motor Co., Ltd. [online] https://newsroom.nissan-global.com/releases/nissan-leaf-first-electric-car-to-pass-400k-sales?lang=en-US&rss (Accessed 5 May 2019).

[3] One of the symbolic initiatives of the strategic alliance was the establishment of the Renault-Nissan Purchasing Organization (RNPO) in 2001. RNPO is responsible for purchasing all parts and the selection of suppliers for Renault and Nissan.

[4] This paper focuses on the Japanese market because Toyota and Nissan normally introduce new technologies, especially new powertrains, in their mother country first and roll them out in other markets.

[5] The taxation reform, so-called 'eco-car tax', included the reduction or exemption of vehicle weight tax and automobile acquisition tax (Ministry of Land, Infrastructure, Transport and Tourism, 2009). Subsidies to build the charging stations were also provided. Since the taxation reforms were introduced, in part, in response to the global financial crisis, the preferential treatments were temporal measures until 2012. However, the preferential measures have been extended after 2012 and onward.

[6] The Zero-Emission Vehicle (ZEV) regulation introduced by the California Air Resources Board required major car manufacturers to offer the specific percentage of the zero- or low-emission vehicles (e.g. HEVs, PHEVs, BEVs, and FCEVs) depending on the car sales volume. Toyota leased the BEV-version RAV4 in the U.S. to meet the requirement of the ZEV.

[7] Nissan's alliance partner, Renault, has marketed several BEV models in passenger car segments, namely the Fluence Z.E. in 2010, Twizy in 2012, and Zoe in 2012. Either the body constructions or battery sources of the Renault's BEV models are quite different from those of Nissan's. The Fluence Z.E. and Zoe were engineered based on the platforms of the ICE-version Fluence and Clio (Gersch et al., 2013). Both the Fluence Z.E. and the Leaf use the batteries from AESC. However, since the Fluence Z.E. employed the battery swapping system (QuickDrop), it is very likely that the vehicle construction is quite different from that of the Leaf. The Twizy and Zoe use the batteries from LG Chem.

[8] Nissan Motor Co., Ltd. [online] https://www.nissan-global.com/EN/DOCUMENT/PDF/FINANCIAL/TSE/2018/20180803TDnet_E.pdf (Accessed 9 May 2019).