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Identifying a Combination of Key Resources to Overcome the Entry Barriers in the Electric Vehicle Market

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ABSTRACT Our study clarifies a combination of key resources to overcome entry barriers in the electric vehicle market, and further their minimum level required to enter it. Analyzing 14 firms over 2005-2017, we find that firms securing a combination of low cost-high capacity battery, low vehicle price, long driving range and high safety rating successfully enter the market. A lack of any single resource results in market entry failures. Also, the relative importance of resources varies by market segments, emphasizing importance of a segment-optimized resources management. Theoretically, our study connects entry barriers to resource-based view. Managerially, firms can improve strategic resource management for a successful market entry. Government can introduce a package of policies supporting resources development or acquisition of such companies, thereby boosting market entry, innovation, and growth of companies.

INDEX TERMS Entry barrier, resource-based view, key resource, electric vehicle, fuzzy-set/qualitative comparative analysis.

I. INTRODUCTION

Entry barriers have been effective ways of preventing newcomers into the market, thereby limiting competition [1], [2]. Particularly, incumbents in the automotive industry had successfully used these, and therefore had maintained competitive advantages over more than several decades [3], [4]. Researchers argue that a mix of economies of scale, cumulative learning curve effect, product complexity, vast amount of initial investment, sophisticated supply chain and others is crucial to such success [4]. However, it should be noted that such strong entry barriers in the automotive industry have notably weaken over last decade. Many start-ups have entered the automotive market, and some company such as Tesla establishes itself as a leading company.

A number of studies tried to identifying key factors affecting such phenomenon, and hold a common view that it should be driven mainly by simpler architecture of electric vehicles (EVs) in comparison to complex architecture of conventional internal combustion engine vehicles (ICEVs) [5]–[7]. Simpler EV architecture lowers technological, manufacturing and supply chain barriers, and further enables newcomers to enter the automotive industry. Also, some studies suggest that incumbents' passive attitude toward new mobility business as well as technology should make entry barriers weakened [8], [9]. Other notable factors include eco-friendly government policies [10], [11] and growth of megacities and regions with high-income groups [12]–[14]. These favourable factors often concentrate on a certain region such as California, thereby facilitating rapid growth of new entrants.

Despite valuable, these factors are not enough to explain the success of new entrants in the automotive industry because of a lopsided focus on external factors. Entry barriers increase the cost of a new entrant more than existing players. In that regard, its internal capabilities and resources are critical to overcome the cost disadvantage due to entry barriers [1], [15]. In other words, we must identify key resources and capabilities, and trace their changes over time in order to gain competitive advantages under changing external technological, market and policy environment. One thing to note is failed entrants. Some entrants grow, but others fail. It implies that core internal capabilities and

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resources might be different between successful and failed entrant [16].

Considering this, we aim at clarifying combinations of key factors of new companies to enter the EV market, focusing on internal capabilities and resources. As a theoretical framework, we adopt a resource-based view because it can identify rare and valuable, in other words, differentiated capabilities and resources. Methodologically, we use a fuzzy-set qualitative comparative analysis (fs/QCA) because it can deal with small number of cases better than others. The number of entrants in the EV market is fourteen, meaning that we have difficulty in getting statistically significant results by using other quantitative techniques. The fs/QCA is appropriate to identify combinations of independent variables which support the causal relationship between those and dependent variable even with small and middle number of cases. Using these, we identify combinations of core capabilities and resources of new entrants to weaken strong entry barriers, and thereby to successfully enter the EV market in the automotive industry. Further, we make attempts to find the minimum thresholds of core capabilities and resources to avoid market entry failures. Our study can improve competitive strategies both of existing incumbents and new entrants, and further design policies to stimulate new EV entrants by well-focused resources subsidies and core capability improvement program.

The remainder is organized as follows: In the section 2, we review literature on the resource-based view and entry barriers. Our analytic methodology including research framework is introduced in the section 3. Then, we provide our analytics results in the section 4. Discussion and conclusion follow, including technological, strategic and policies implications.

II. LITERATURE REVIEW

A. ENTRY BARRIERS

Entry barriers are defined as obstacles preventing new entrants from being an established entity in a particular market [1], [17]. Barriers increase cost of production by a firm which seeks to enter a market, inhibits their entries, and therefore enables established firms to set prices above marginal cost [1], [15]. These permit established firms to earn monopoly profits while making entrants unprofitable. In other words, entry barriers affect competition as well as industry structure. Subsequently, previous literature mainly deals with two themes comprising strategic management and industrial organization [18].

At the outset, industry organization researchers focused on the effect of entry barriers on performances of new entrants, and tried to examining the causal relationship between cost disadvantage and financial performance of new entrants [15], [19], [20]. Also, at the industry level, they studied the effects of concentration upon industry performance [21], [22]. In these studies, economies of scale constitute a main source of barriers and profitability of established firms.

However, as industries evolve, various entry barriers have emerged and been used, affecting competition and market structure. Subsequently, following studies categorized barriers according to several criteria, and analysed the effects of specific entry barriers on corporate behaviour and performance [23], [24]. At first, entry barriers are classified as either exogenous or endogenous, and further technological, production, marketing and other barriers along the value chain [25], [26]. Exogenous barriers are embedded in the market conditions, and cannot be controlled by firms, including product differentiation, cost advantage, brand image, customer switching cost and government policy. Contrastingly, incumbents can create endogenous barriers including sales promotion and price competition.

Differently, the main theme of strategic management studies were about what resources and capabilities new entrants need to overcome entry barriers, and further to gain competitive advantages [16], [19]. Early studies focused on age of assets, economies of scale and market concentration to achieve cost advantages, but following studies weighed more on intangible barriers including technology and product differentiation, customer switching cost and technology (Bohnsack *et al.*, 2014; Harrigan, 1981; Karakaya, 2002; Rangone, 1999; Yip, 1982).

The automotive industry had long been regarded as a good example of strong entry barriers [4]. It is no wonder that many studies have been devoted to entry barriers and their effects. Focusing on economies of scale, early studies investigated effects of manufacturing infrastructure, resources, and capabilities on cost advantages [30]. Driven by globalization and market segments diversification, new entry barriers became more important than traditional ones. As noted previously, product differentiation, consumer switching cost, and accessibility to distribution channels have become more important that as they were (Pehrsson, 2009; Stringham *et al.*, 2015). Growth of incumbents depended heavily on effective use of such entry barriers. However, over last decade, advances in vehicle electrification and digitalization have strengthened technological entry barriers more than others [8], [9]. Particularly, recent studies made efforts to investigate key entry barriers in the electric and autonomous vehicle markets, focusing more on technological barriers. Table 1 lists important entry barriers in the automotive industry with authors and publication years. It briefly shows an increasing attention to technological and market barriers.

Previous studies identify many exogenous and endogenous entry barriers, and examined their effects on corporate performance, behaviour and industry structure. However, even if Gable *et al.* (1995) points out mutually reinforcing relationships among entry barriers, effective combinations of entry barriers have rarely been investigated. Also, it should be noted that a new entrant could overcome such strong combinations of entry barriers by clarifying those and their mutual interactions [32]. Considering this, we can argue the necessity of a research which can identify a set of key entry

TABLE 1. Entry barriers in the automotive industry.

Entry barriers	Classification	Examples of studies
Economies of scale	Production	Bain, 1956; Baumers et al., 2016; Karakaya, 2002; Modigliani & Miller, 1958; Pine, 1993; Porter, 1980; Stigler, 1968
Learning curves	Production	Chi & Roehl, 1997; Devinney, 1987; Gaynor & Haas-Wilson, 1999; Karakaya, 2002; Levin, 2000; Marvin B Lieberman, 1987; Lutz et al., 2010; Madhok, 1996; Spence, 1981; Van den Hoed, 2007; Yao et al., 2013
Capital requirements	Production	Bain, 1956; Eaton & Lipsey, 1980; Harrigan, 1981; Karakaya, 2002; Karakaya & Stahl, 1989; R. S. Kumar & Subrahmanya, 2010; Matthyssens & Vandenbempt, 1998; Porter, 1980; Stringham et al., 2015; Thun, 2004
Access to distribution channels	Market	Karakaya, 2002; Ozman, 2011; Porter, 1980, 2007; Porter & Millar, 1985; Robertson & Gatignon, 1991; Stringham et al., 2015
Switching cost	Market	Buiga, 2012; McFarlane, 1984; Monteverde & Teece, 1982; Porter, 1980; Rugraff, 2012; Stringham et al., 2015; Wei & Chen, 2008
Product differentiation	Market & R&D	Bain, 1956; Bass et al., 1978; Guajardo et al., 2016; Nguyen et al., 2014; Porter, 1980; Reinhardt, 1998; Sorenson, 2000; Thomas & Weigelt, 2000
Technology	R&D	Adner & Kapoor, 2010; Bohnsack et al., 2014; Harrigan, 1981; Karakaya, 2002; Lee, 2005; Oltra & Saint Jean, 2009; Rycroft, 2006

barriers. Further, it is useful if we can evaluate the relative importance of each barrier and clarify their positive as well as negative interaction.

B. RESOURCE-BASED VIEW

The resource-based view provides a theoretical framework about why firms differ in performances based on differences in internal resources and capabilities [67]. Its primary proposition is that a firm must acquire and utilize rare, valuable, inimitable and non-substitutable resources and capabilities in order to achieve sustainable competitive advantage as well as higher performance (Barney, 1991). As a bundle of resources, a firm therefore should absorb, create, use and accumulate such resources in an effective way [69]–[71]. In other words, a firm must embrace continuous organizational learning to estimate future value of resources and apply them better than competitors [16]. The market entry success as well as growth of a new entrant also depends on identifying, acquiring and using such resources through organizational learning [72].

Empirical studies followed, and identified key resources across various industries including bearing, trucking and others [73], [74]. Some studies focused on key factors to acquire such resources. Teece *et al.*(1997) emphasized importance of capabilities of strategic resources assessment and development beyond simple acquisition of important resources. Further, some researchers suggested the key role of a valuable and unique resource base to maximize the synergy among resources [76]. These studies hold a common view that an efficient combination of core resources and complementary factors should improve firm performances, regarding it as a core competency to gain competitive advantages (Prahalad & Hamel, 1994; Makadok, 1998).

In that regard, many researchers have examined the causal relationship between resource-based view and competitive advantage in a wide variety of phenomena such as information system and organizational network [70], [78]–[80]. These studies show that firms focusing on intangible resources should outperform firms strategically oriented to tangible resources. Such results are consistent with expectations in Barney (1991), stressing increasing importance of heterogeneous intangible resources as sources of competitive advantages. However, as Teece *et al.* (1997) pointed out, changes in external environment could reduce usefulness of any resource. Recent studies therefore have studied the process from environmental change, to organizational learning, and to development and accumulation of heterogeneous resources, and further examined relationships between those [16], [81].

Along such development, in the automotive industry, researchers identified key conventional resources including manufacturing infrastructure, cumulative manufacturing know-how, experienced workers, brand image and accessibility to distribution channels [82]–[84]. Those result in low-cost advantage, strong brand loyalty and wide market penetration. However, external forces including stronger environmental regulation, fluctuating oil price, vehicle electrification and digitalization have driven changes in core resources and capabilities of automotive firms. Some researchers argue that core resources should be electrification, environment and digital technologies [81], [85]. However, there is few researches about what core resources are for market entry and growth, and also about their minimum quantity required. It is why automotive firms have difficulty in determining resources that their strategies build on.

III. METHODOLOGY

A. RESEARCH FRAMEWORK

Our research aims at identifying a set of key resources to overcome entry barriers in the EV market, and further estimating their minimum threshold. As shown Fig.1, we collect data on EV firms over 2005-2017. Data about firms not trying market entry or having missing/unreliable resources data are removed. Then, we select candidates of core resources and entry barriers based on literature review, and define causal as well as outcome variables. Literature on entry barriers and resource-based view provides a theoretical framework with reference to studies on EV adoption factors.

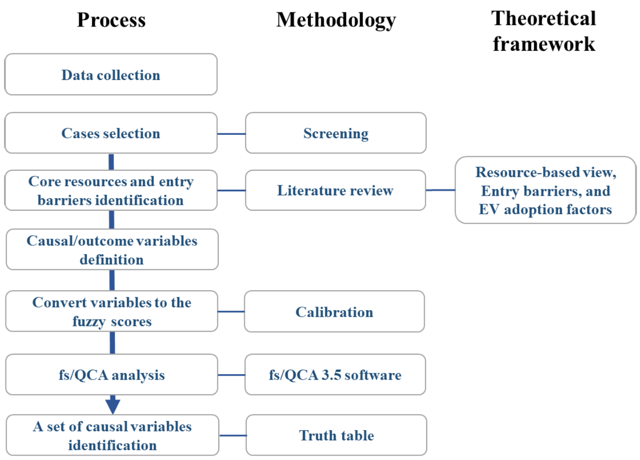

FIGURE 1. Research framework.

Our analytic model has two requirements: 1) reduction of biases due to small sample size limitation, and 2) identification of combination of multiple causal variables. We select the fs/QCA because it meets both requirements [86], [87]. Then, we convert causal and outcome variables to the fuzzy scores through the calibration stage, and conduct the fs/QCA analysis by using fs/QCA 3.5 software. It results in the truth table which provides a set of causal variables representing core resources in order to enter the EV market.

B. DATA COLLECTION

Considering the overall EV market growth, we set the period of data collection as 2005-2017. Over 2005-2007, most EV was not for commercial use, but for technology validation. High-speed EV appeared in 2008. EV companies increasingly entered the market since 2011, and produced one million vehicles in 2017.

Then, we collect EV data mainly from the U.S. Department of Energy, international energy agency, European Union, A2Mac1, and http://ev-database.org. There are 53 companies launching EV over 2005-2017. We select companies trying to enter the EV market because we focus on either success or failure of the market entry. All Chinese EV companies are excluded because data are not available enough. One thing to note is that these companies only enter the domestic market. Chinese EV companies are therefore separately analysed from North American and European companies targeting the global market. Then, we collect and integrate data of remaining 14 companies.

C. FUZZY-SET QUALITATIVE COMPARATIVE ANALYSIS(FS/QCA)

The fs/QCA is a set-theoretic approach to causality between condition and outcome (Ragin, 2008). It can explore how membership of cases in causal variables(conditions) relate to their membership in the outcome [88]. It also has an advantage of identifying the conjectural causation, where combinations of conditions cause the outcome [89]. Further, fs/QCA can find equifinality, where more than one combination of causal variables could lead to the same outcome [88]. Last but not least, it can be applied to a set of small-N data such as 14 cases in our study. It has been widely used in a variety of fields including sociology, politics, business, economics and others due to above-mentioned advantages [87], [90].

For application, after listing all cases, it begins with transforming causal and outcome variables to fuzzy-membership scores over the zero (non-membership from a set) to one (membership) through the calibration. Note that the origin is in descending order, and the median value is used as the crossover point [91]. Then, we have all possible inferences between causal and outcome variable. In the truth table analysis, Boolean algebra is used to reduce the number of inferences supported by the data. For example, if the number of causal variables is k, the number of combinations of possible causal variables is 2^k. The Boolean algebra selects combinations, where consistency and frequency value are above certain thresholds. It results in solutions which is a combination of causal and outcome variables supported by multiple cases, and is classified into complex, parsimonious and intermediate solutions.

IV. EMPIRICAL ANALYSIS

A. INDUSTRY BACKGROUND

Over last decade, driven by advances in electrification technologies and environment-friendly government policies, EV has been at the heart of attention. Subsequently, a number of countries provides supports to vitalize the EV market by using various policies [92]. The EV sales will rise to between 1.25-2.2 billion units by 2030 on the assumption of continuous active investment by major companies and market entry of innovative start-ups [93]. A typical cannibalization effect occurred for automotive manufacturers. The market share of conventional ICEVs has been reducing because of increasing market share of EVs. It leads to the weakening of existing entry barriers, and changes in key corporate resources and capabilities. In responsive to these, companies try to pre-empting key resources of EVs, and using entry barriers.

Some companies such as Tesla successfully entered the market, but others failed because the entry barriers in the EV market were not weak, but rather strong. Several companies once promised have failed to enter the market. Even after successful market entry, some companies had to withdraw from the market. It should be noted that some failed companies should lead the market in technology, manufacturing and others, in other words, had key resources. Put in another way, we can argue that any single cause is not enough to explain the success as well as failure of the market entry, meaning the necessity of identifying a combination of multiple causes.

B. DATA

For data collection of EV companies, we need criteria to classify those into similar groups for comparison. European

TABLE 2. EV companies.

Vehicle segments	Incumbents	New entrants
Micro	N/A	Reva Electric
A (mini car)	FCA, Smart	Think Global, Wheego Whip
B (small car)	BMW, Mitsubishi, Chevrolet, Renault	N/A
C (medium car)	Ford, Nissan	Coda Automotive
E (executive car)	N/A	Tesla
J (sport utility vehicle)	Hyundai-Kia	N/A

Union (EU) provides criteria which classify EV companies into existing incumbents and new entrants, and also EVs into target market segments based on vehicle size, purpose, engine and others [94]. New entrants are defined as companies launching commercial EVs for sale. Existing incumbents are defined as OEM (original equipment manufacturer) selling both ICEV and EV. As shown in Table 2, in six market segments, we can find 14 companies comprising nine incumbents and five new entrants. From a regional perspective, there are five US, five European companies, and four Asian companies. The market segment is used to select the representative EV model of each company for a fair comparison between EVs, and also between causal variables.

Table 3 provides the key resources of the representative EV models of 14 companies. We define the representative model as the best-selling one because it overcomes the entry barrier better than others. We will explain the way how we select key resources in the next section.

Additionally, we collect data about another key resource, vehicle safety. One of the most reliable measure is the safety score by the new car assessment program (NCAP) in Europe, and another by the national highway traffic safety administration (NHTSA) in US. Table 4 provides safety scores of eight EVs by seven companies. NHTSA five-star safety rating program evaluates how vehicles perform in frontal, side barrier, side barrier crashes and rollover resistance, and rates vehicle safety from one (lowest) to five stars (highest). NCAP has a similar vehicle safety rating system by using a five-point grading scale by evaluating adult/children passenger safety, traffic weakness, safety assistance system and others. For other EVs without official safety scores, we assess their scores on the assumption that vehicles using similar safety technologies should have similar scores.

TABLE 3. Key resources.

Company	EV model	Battery system price per unit capacity ($/kWh)	Battery price ratio to vehicle price	EV price ratio to ICEV price in same segment	Mileage (km)
BMW	i3	458	0.234	1.057	160
Chevrolet	Bolt	262	0.449	0.875	383
Coda	Coda	950	0.737	0.952	142
FCA	500e	667	0.493	0.956	140
Ford	Focus electric	571	0.436	0.952	185
Hyundai-Kia	Soul(~2014) IONIQ (2016~)	650	0.503	0.938	150
Mitsubishi	i-MiEV	494	0.175	1.128	100
Nissan	Leaf	448	0.448	0.707	172
Renault	ZOE	571	0.433	0.725	210
Reva Electric	REVAi	899	0.573	1.004	80
Smart	Smart ED	667	0.383	0.846	135
Tesla	Model S and X	400	0.384	0.645	539
Think Global	Think City	900	0.575	1.059	160
Wheego Whip	LiFe	833	0.757	0.97	160

TABLE 4. Safety scores of nine EVs.

Assessment Program	Model (Company)	Year	Ratings (1-5)
NCAP	Model S (Tesla)	2014	5
	Leaf (Nissan)	2012	5
	i3 (BMW)	2013	4
	ZOE (Renault)	2013	5
	i-MiEV (Mitsubishi)	2011	4
	Soul (Hyundai-Kia)	2014	4
NHTSA	Focus EV (Ford)	2014	5
	Leaf (Nissan)	2012	5
	Model S (Tesla)	2016	5
	Model X (Tesla)	2017	5
Our assessment	500e (FCA)	2014	3
	Bolt (Chevrolet)	2017	5
	Coda (Coda Automotive)	2012	3
	REVAi (Reva Electric)	2011	1
	Smart ED (Smart)	2014	4
	Think City (Think Global)	2011	2
	LiFe (Wheego Whip)	2013	2

C. DEFINITION OF VARIABLES

1) OUTCOME VARIABLE

We define the outcome as a binary variable of success or failure of the EV market entry. Several proxy variables are available, but the most widely used is the total sales volume in previous studies [95]–[97]. Without any exception, firms withdraw from the market if they failed to reach the threshold of the total units sold, including Reva Electric (4,600 units sold), Think Global (2,500 units), Coda (117 units), and Wheego Whip (400 units). According to the previous literature, the most frequently used threshold is a half of the maximum units sold [91], [98]. We therefore adopt its normalized value, 0.5, as our threshold. The number of total units sold is normalized between 0 and 1.

2) CAUSAL VARIABLE

As shown in Table 5, we review previous literature on the EV market entry over 2011-2018, and identify its key factors including all electric range(AER), vehicle price, battery cost and others. These factors can be classified into internal variables comprising driving range, EV price, battery price/technology and overall performance, and external ones comprising safety/regulation, charging station/infrastructure, tax benefits/incentives, maintenance costs and total cost of ownership. For comparative analysis, some variables are not appropriate. For example, tax benefits and incentives vary by countries, and could be affected by macroeconomic variables such as country's level of household net disposable income [11], [92]. Also, charging time and infrastructure depend on the level of embedded technologies in charging stations, national energy independence, national power grid and others [100], [110]. Without controlling those factors, the comparative analysis among firms over different countries is likely to be biased. Maintenance cost is not much different between EVs in same segment. It is useful for comparison not between EVs, but between EV and ICEV [109], [111]. Similarly, recent studies show that total cost of ownership is almost same between EVs, and also between EV and ICEV in same segment [120], [121].

Besides above-mentioned factors, others are key resources of the EV firms. Key technological resources for the EV market entry are the battery price per unit capacity and battery price ratio to vehicle price. Battery occupies a large proportion of the EV cost, and is therefore crucial to the EV cost competitiveness in comparison to other EVs and ICEVs [85]. The battery price per unit capacity (T1 in Table 6) is an indicator of battery efficiency as well as battery cost competitiveness. Lower T1 means higher EV cost competitiveness and advanced battery technology. The battery price ratio to vehicle price (T2) measures the overall EV performance besides a battery because lower T2 means a larger proportion of the EV cost of other parts including safety systems, convenience features and others. Around similar EV price, the lower T2 usually leads to better performances of some of those parts due to more investment in relevant technologies. Put these together, a combination of low T1 and T2 results in cost as well as performance competitiveness because of advanced battery and other technologies.

Previous studies identify EV price (M1) and driving range (M2) as key factors of consumer EV choices, in other words, core consumer-side resources [99], [101]. Even if both are barriers to market entry, M1 is a stronger barrier than M2 because consumers are sensitive to M1 more than M2 [81], [117]. However, core consumer-side factors slightly vary by vehicle segments. In micro, mini and small car segment, M1 is a single dominant factor of most consumer choices [99]. Differently, in the executive and sport utility vehicle segment, both M1 and M2 are important [99], [106]. Particularly, the maximum driving range is a strong barrier to market entry in these segments [100]. Considering the trade-off between M1 and M2, consumers choose their favourite EVs [99].

TABLE 5. Key factors of an EV market entry.

Key factors	Publication range	Papers
Driving range	2011-2018	Adepetu & Keshav, 2017; Burgess et al., 2013; Carley et al., 2013; Egbue & Long, 2012; Lieven et al., 2011; Melliger et al., 2018; Mersky et al., 2016; Schuitema et al., 2013; S. Skippon & Garwood, 2011; S. M. Skippon et al., 2016; Travesset-Baro et al., 2015
EV price	2011-2018	Adepetu & Keshav, 2017; Barth et al., 2016; Burgess et al., 2013; Carley et al., 2013; Coffman et al., 2017; Graham-Rowe et al., 2012; Hu et al., 2013; Kester et al., 2018; Krupa et al., 2014; Lieven et al., 2011; Peters & Dütschke, 2014; Plötz et al., 2014; Rezvani et al., 2015; Schuitema et al., 2013; Yingjie Zhang et al., 2016; Yong Zhang et al., 2011
Maintenance cost	2011-2018	Bjerkan et al., 2016; Breetz & Salon, 2018; Falcão et al., 2017; Graham-Rowe et al., 2012; Hu et al., 2013; Jakobsson et al., 2016; Javid & Nejat, 2017; Krupa et al., 2014; Lévay et al., 2017; Palmer et al., 2018; Peters & Dütschke, 2014; S. Skippon & Garwood, 2011; Sørensen et al., 2015; Wee et al., 2018; Wu et al., 2015; Yong Zhang et al., 2011
Safety/regulation	2011-2018	Andwari et al., 2017; Arora et al., 2016; Egbue & Long, 2012; Graham-Rowe et al., 2012; Landucci et al., 2015; Rezvani et al., 2015; Steinhilber et al., 2013; X. Zhang et al., 2018; Yingjie Zhang et al., 2016
Battery price	2011-2018	Andwari et al., 2017; Curry, 2017; Egbue & Long, 2012; Hidrue et al., 2011; Jakobsson et al., 2016; Kim et al., 2017; Madlener & Kirmas, 2017; Neubauer et al., 2012; Nykvist & Nilsson, 2015; Palmer et al., 2018
Charging time/infrastructure	2011-2018	Berkeley et al., 2018; Carley et al., 2013; Coffman et al., 2017; Egbue & Long, 2012; Egnér & Trosvik, 2018; Graham-Rowe et al., 2012; Haddadian et al., 2015; Hu et al., 2013; Javid & Nejat, 2017; Lieven, 2015; Madina et al., 2016; Rong et al., 2017; Sierzchula et al., 2014; S. Skippon & Garwood, 2011; Steinhilber et al., 2013
Tax benefits/ incentives	2011-2018	Aasness & Odeck, 2015; Bjerkan et al., 2016; Brand et al., 2013; Kanamori et al., 2011; Kester et al., 2018; Langbroek et al., 2016; Sierzchula et al., 2014; Wang et al., 2017; Yan, 2018; Zheng et al., 2012
Overall performance	2012-2018	Bjerkan et al., 2016; Egbue & Long, 2012; Graham-Rowe et al., 2012; Javid & Nejat, 2017; Kester et al., 2018; Peters & Dütschke, 2014; Schuitema et al., 2013; Travesset-Baro et al., 2015; Wu et al., 2015
Battery technology	2015-2018	Berkeley et al., 2017; Gibson et al., 2017; Hannan et al., 2017; Letmathe & Suares, 2017; Liao et al., 2018; Nykvist & Nilsson, 2015; Pelletier et al., 2017; Quak et al., 2016; Wee et al., 2018
Total cost of ownership	2015-2018	Bjerkan et al., 2016; Breetz & Salon, 2018; Falcão et al., 2017; Jakobsson et al., 2016; Lévay et al., 2017; Palmer et al., 2018; Wee et al., 2018; Wu et al., 2015

TABLE 6. Definition of causal variables and fuzzy score.

Group	Causal variables	Measurement objective
Technology	Battery price per unit capacity(T1)	Battery cost competitiveness and product efficiency
	Battery cost to vehicle price ratio (T2)	Overall EV performances besides a battery
Consumer/ market	EV price(M1)	EV price competitiveness
	Driving range(M2)	Maximum driving range
Regulation	Collision safety(R1)	Protection from collision and crash

Among safety/regulation factors, the EV collision safety (R1) is a comprehensive entry barrier which is related technology, market and regulation factors. It depends on the battery technology resources and relevant R&D (research and development) capabilities which is a technological entry barrier. Also, higher collision risk is subject to legal sales regulation, and has a negative effect on consumer EV choices, implying the necessity of legal and market resources to overcome those. We adopt both NCAP and NHTSA safety indicator because there are the most widely ones. As shown in Table 6, we select five causal variables which is proven to be important in previous studies.

In the automotive industry, the competitive advantage came mainly from the low cost structure including robust supply chain and manufacturing efficiency [83], [84]. It was a key barrier to market entry. Quite differently, advanced technologies including battery are key resources and at the same time entry barriers in the EV market [154], [158]. However, at the initial stage of commercial EV introduction, cost competitiveness including battery cost, maintenance cost and tax benefit was crucial to EV market entry and growth. These resources are still important, but advanced technologies and overall performances have become increasingly important. It shows a shift of key resources from ICEV, to initial EV, and to recent EV. We therefore focus more on recent key EV resources as shown in Table 6.

As shown in Table 7, we convert the raw data of causal variables of EV models to fuzzy set scores by using calibration method by Ragin (2008). It enables us to identify a mix of causal variables which can explain either success or failure of market entry of those EVs.

D. RESULTS

As shown in the table 8, we identify three types of causal configurations of five variables to explain the outcome (success/failure of market entry) in the truth table [159]. Considering the small number of cases, we set the cut-off of the number of cases as two and the consistency threshold as 0.7 based on previous studies [160], [161]. Consistency refers to the percentage of causal configurations of similar composition which result in the same outcome value (Ragin, 2008). High consistency means that the causal relationship is supported well by cases. Our data are also characterized by medium complexity in terms of number of combinations

TABLE 7. Fuzzy scores of causal variables.

Company	EV model	T1	T2	M1	M2	R1
BMW	i3	0.79	0.91	0.14	0.51	0.82
Chevrolet	Bolt	0.95	0.51	0.68	0.85	0.95
Coda	Coda	0.05	0.06	0.51	0.34	0.51
FCA	500e	0.38	0.39	0.48	0.32	0.51
Ford	Focus electric	0.68	0.53	0.51	0.55	0.95
Kia	Soul(~2014) IONIQ (2016~)	0.41	0.37	0.53	0.41	0.82
Mitsubishi	i-MiEV	0.73	0.95	0.05	0.1	0.82
Nissan	Leaf	0.8	0.51	0.92	0.52	0.95
Renault	ZOE	0.58	0.54	0.9	0.6	0.95
Reva Electric	REVAi	0.07	0.23	0.29	0.05	0.05
Smart	Smart ED	0.38	0.67	0.74	0.28	0.82
Tesla	Model S and X	0.86	0.67	0.95	0.95	0.95
Think Global	Think City	0.07	0.23	0.14	0.51	0.18
Wheego Whip	LiFe	0.12	0.05	0.42	0.51	0.18

TABLE 8. Truth table.

Type	T1	T2	M1	M2	R1	Cases (n)	Outcome	Cases	Consistency
E1	1	1	1	1	1	5	1	Nissan, Tesla, Ford, Renault, Chevrolet	0.895631
E2	0	0	0	1	0	2	0	Wheego Whip, Think Global	0.689349
E3	0	0	1	0	1	2	0	Kia, Coda	0.516129

of causal variables. In that regard, we adopt the intermediate solution method which is appropriate to deal with it.

The causal configuration denoted by E1 can explain the successful market entry supported by four cases. Its consistency means that a firm with a similar causal configuration is likely to successfully enter the market with a probability of 89.5631%. The solution coverage of five causal variables is 0.643979, meaning that these variables can account for 64.3979% of success/failure of market entry. In other words, the causal configurations based on five variables can explain a successful market entry better than failures.

1) CAUSAL CONFIGURATION FOR EV MARKET ENTRY SUCCESS

As shown in the table 8, in order to successfully enter the EV market, a company has to satisfy the causal configuration E1. Cases of such successful market entry based on E1 are observed in the upper market segments including B, C and S in the table 2. The maximum ICEVs price was $40,000 in the C-segment, and $38,080 in the B-segment. Successful EV models by Nissan and Ford were priced under $40,000 in the C-segment, and Renault's EV under $38,080 in the

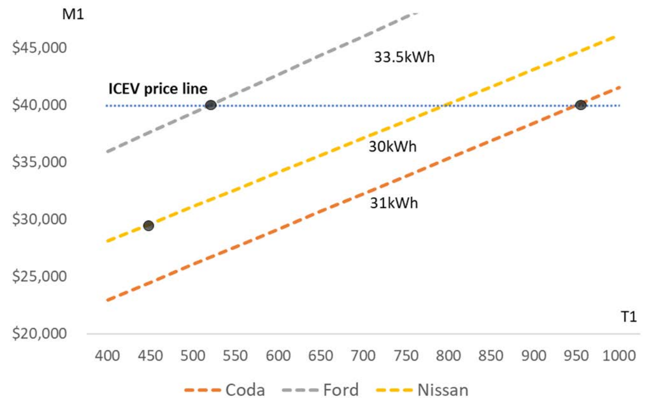

FIGURE 2. Linear relationship between T1 and M1 in the C-segment.

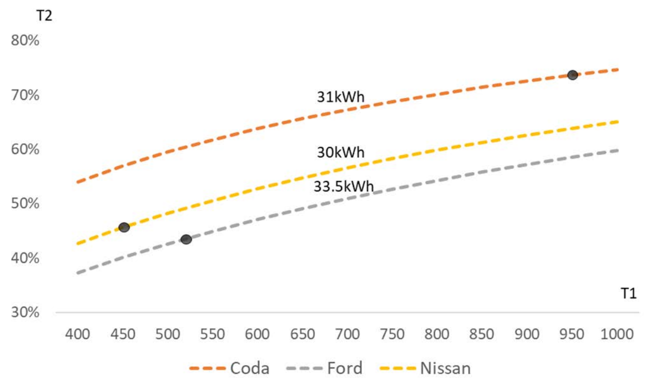

FIGURE 3. Linear relationship between T1 and T2 in the C-segment.

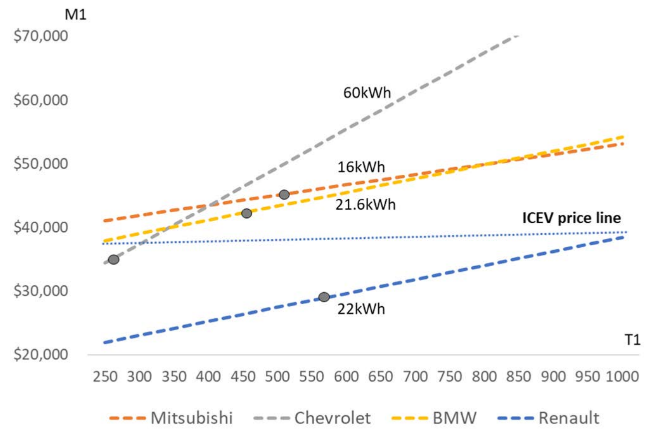

FIGURE 4. Linear relationship between T1 and M1 in B-segment.

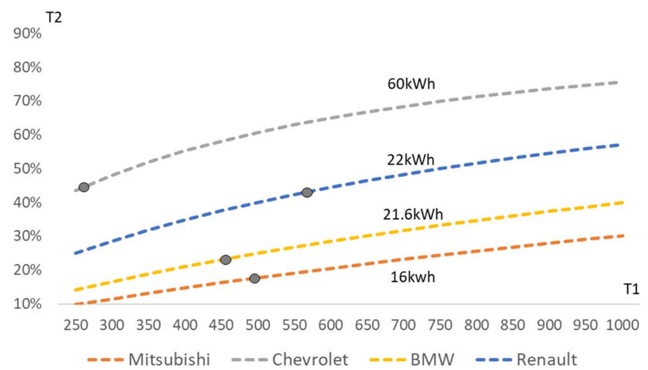

FIGURE 5. Linear relationship between T1 and T2 in B-segment.

B-segment, having price competitiveness. Tesla's EV was not expensive in comparison to ICEVs including Mercedes S-Class, Porsche Panamera, BMW 7, Audi A8, and Lexus LS in the E-segment. Such EV price (M1) competitiveness built on low battery price per unit capacity (T1) and battery price ratio to vehicle price (T2). These EVs had driving ranges (M2) not much shorter than ICEVs, and longer than other EVs. Their safety ratings (R1) were also above an industry average. These results are consistent with previous studies [99], [163].

Fig. 2 shows the linear relationships between battery price per unit capacity (T1) and EV price (M1) for Coda, Ford and Nissan in the C-segment. Using data about batter prices and capacities of suppliers and EV prices, we employ a simple linear regression, and get the lines in the Fig. 2. The upper horizontal line represents the maximum ICEV price ($42,000) based on prices of Honda Civic, Hyundai Elantra, Ford Focus, Volkswagen Golf and Toyota Corolla. These ICEVs occupy a large market share. Three black coordinates in the Fig. 2 represent T1 and M1 of EV models by Coda, Ford and Nissan. As expected, EV prices of three companies below the maximum ICEV price, but Nissan and Ford have an advantage of lower T1 than Coda. In the Fig. 3, battery price ratio to vehicle price (T2) of Nissan and Ford are also far lower than Coda. Therefore, Nissan and Ford could provide consumers with low price EV and relative advantages in other features including safety, and has a better combination of resources in order to overcome the entry barriers of cost as well as EV price competitiveness.

In the B-segment, the ICEV maximum price line ($38,080) is set with reference to prices of Renault Clio, Volkswagen Polo, Ford Fiesta, Peugeot 208, and Opel Corsa. In the Fig.4, EV prices of Renault and Chevrolet are positioned below the ICEV maximum price line, showing their price competitiveness. In terms of the battery cost competitiveness by T1, Chevrolet has a clear advantage against others including Renault.

Tesla has no competitors in the E-segment, and we therefore have difficulty in comparing its EV with others. We therefore divide the EV price (M1) by the maximal ICEV price in each segment, and create a new variable of the relative EV price (M1'). We use it as an axis, sets up the T1-M1 plane in the Fig. 6, and fix the coordinate of Tesla's EV. Notably, Tesla has the lowest M1' and the second-lowest T1, showing its price as well as cost competitiveness stronger than smaller and cheaper EVs. Similarly, in the T1-T2 plane, Tesla has the third-lowest T2 which is also lower than most EVs. Clearly, Tesla has one of the best combination of resources in comparison to other EV companies, and it EV model has clear advantages of price, cost and performances in other

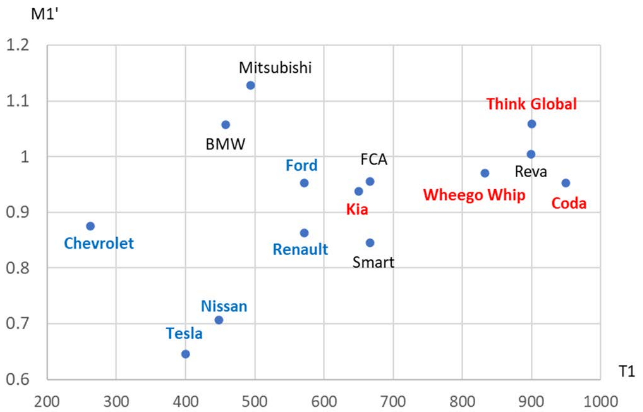

FIGURE 6. Positions of EV companies in the T1-M1′ plane.

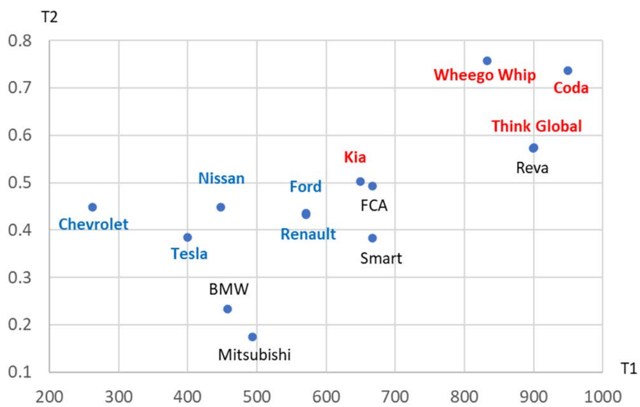

FIGURE 7. Positions of EV companies in the T1-T2 plane.

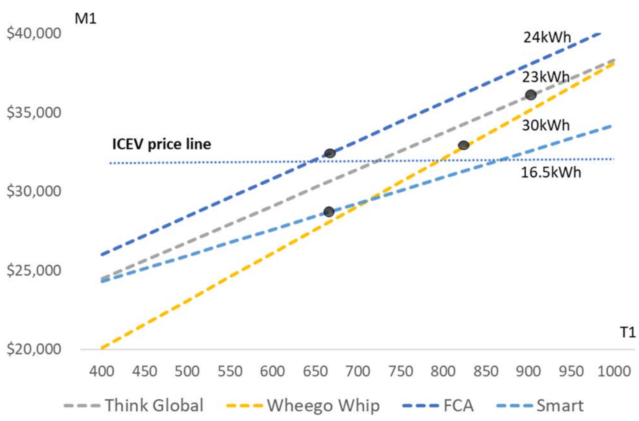

FIGURE 8. Linear relationship between T1 and M1 in the A-segment.

features. These results can clarify the reason why Tesla can successfully enter the EV market, and then gain competitive advantages against other EVs.

2) CAUSAL CONFIGURATION FOR EV MARKET ENTRY FAILURE

In the A-segment, the causal configuration of four variables below thresholds except for the driving range (M2) failed to enter the market. Also, similar configuration of four

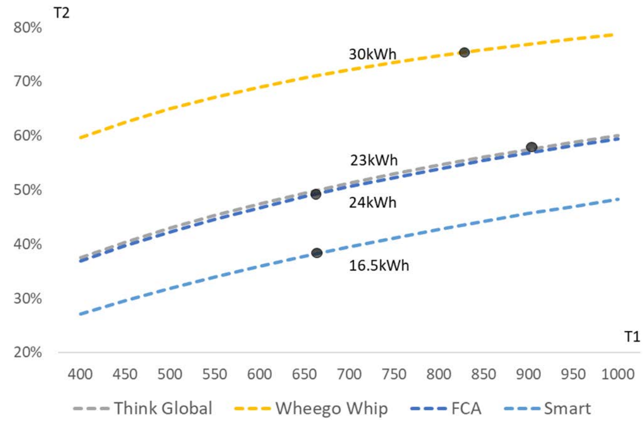

FIGURE 9. Linear relationship between T1 and T2 in the A-segment.

variables below thresholds except for the EV price (M1) failed the market entry. In the Fig. 8, the maximum ICEV price line is at the $32,368 with reference to ICEVs comprising Citroën C1, Renault Twingo, Kia Picanto, Peugeot 108 and Fiat 500). Wheego Whip and Think Global failed to enter the market. Their M1 is higher than $32,368 because of higher T1 than others, implying their difficulty to overcome the price/cost barriers. On the assumption that these companies could reduce T1 down to 650$/kwh which FCA achieved, Think Global could reduce its M1 to $30,250, and Wheego Whip to $27,505. These M1s are below $32, 368, implying cost as well as price competitiveness enough to enter the A-segment. In the Fig.9, their T2s are higher than others, meaning its expected negative effects on performances of other features. Overall, higher T1 might result in not only weak price/cost competitiveness, but to higher T2 and inferior performances of other features to competitors.

Despite M1 below the maximum ICEV price, Coda Automotive failed to enter the C-segment because its T1 is far beyond a threshold. If it can reduce it T1 to 520$/kwh by Ford, its M1 could have dropped to $26,670 with 0.64 of T2. Although these conditions are met, Coda Automotive has a difficulty in entering the C-segment because it has disadvantages of M2 in comparison to competitors. Finally, Hyundai-Kia has no comparable EVs in the J-segment, but could not go beyond thresholds of three variables except for M1 and R1.

V. DISCUSSION

Under asymmetric information, new entrants have difficulties in identifying key resources and their minimum required level to successfully enter the EV market. These companies tend to focus on a couple of resource to overcome some barriers while ignoring other important resources and barriers. It is likely to result in market entry failures. A successfully EV market entry needs all key resources beyond the minimum required level.

Our analytic results provide evidences for such argument. Excellence in any single resource was not enough.

New EV entrants must secure a combination of low cost-high capacity battery, low EV price, long driving range and competitive performances in safety and other features. They also satisfy their minimum requirements. Satisfying all required conditions, Ford, Renault, Nissan and Chevrolet could successfully enter the EV market, and keep their market positions. However, Think Global and Wheego Whip focusing on longer electronic driving range overlooked battery cost as well as EV price competitiveness, struggled from a low safety rating, and consequently withdrew from the market. Somewhat differently, Kia and Coda gained EV price competitiveness, but lost competitiveness in others including driving range and battery cost. These companies could not hold their market positions.

It should be noted that relative importance of each resource varies by market segments. In the low-priced EV segments, consumers are sensitive to price more than others including driving range. New entrants have to reduce its EV price, at least, down to ICEV prices. It is therefore crucial to reduce the battery cost below a threshold, meaning that companies either develop its own low-cost battery or find a capable supplier. Contrastingly, in the high-priced segment, consumers focus on a longer driving range more than price, implying that a battery capacity is important more than a battery cost. Consequently, new EV entrants have to understand resources requirement of a target market segment, and either procure or develop a combination of key resources. Some researchers argue that Tesla's success should depend heavily on strategically entering a high-priced vehicle segment. However, our research shows that its success could not be explained by such single factor, but by comprehensive advantages of key resources over competitors. Tesla has a competitive advantage of low battery-cost-to-vehicle-price ratio even over EVs in the low-priced segment, implying its strong cost competitiveness. One more thing to note is that a competitive advantage of a resource could lead to another competitive advantage of another resource. Some companies including Nissan and Renault could improve its safety features because of more budget availability due to low battery cost.

From a policy perspective, our study shed a light on a problem about what an effective policy incentive structure is in the EV market. As noted in previous studies, EV diffusion will not accelerate if policy incentives are not sufficient to induce consumers to buy those. U.S.(United States of America) government therefore has increased EV tax credits from the base $7,500 up to $12,500 in 2021. Chinese government recently cuts its subsidy by 20%, but still reimburses about $2,200. Many countries have a similar incentive structure focusing on tax credit and subsidy. However, our study suggests that such price-focused incentives might be not enough to boost EV adoption. Companies need a combination of key resources to enter the EV market. It means that customers need not only low cost but others including longer driving range and advanced safety features. Well-focused government policies including R&D funding and safety assessment education can help EV companies secure key resources, increase overall EV competitiveness, and thereby accelerate mass adoption. In other words, governments should design and implement policies facilitating key resources development or outsourcing by EV companies. Further, new entrants boost innovation as well as competition in the EV market, facilitate cost reduction as well as differentiation of EVs, and thereby attract more customers.

VI. CONCLUSION

The automotive industry has long been characterized by oligopoly and incremental innovation. Existing incumbents did not have to explore disruptive innovation because strong entry barriers limited competition. They therefore focused on incremental innovation of ICEVs. As noted previously, a dramatic change around EV and autonomous vehicle has been unfolding. It attracts new entrants to the market, introduces new technologies and EVs, and attract more customers. Strong entry barriers have been weakened, damaged and partly broken, thereby creating opportunities for new entrants. Many firms entered the EV market. Some were successful, but others not. It is no wonder that academic as well as practical research try to identifying key factors of a successful market entry.

From an academic viewpoint, our study contributes to identifying not an individual key resource/factor but a combination of key resources with their thresholds required to enter the EV market. Also, previous studies focus on external factors including infrastructure and policy incentive. Differently, our study clarifies importance of internal resources and their synergies to overcome entry barriers, thereby building a bridge between market entry barrier and resource-based view. Resource-based view focuses on attributes of resources, but attributes including rarity and value are not enough in a market with various entry barriers. A variety of key resources required to overcome such barriers has to be combined in an effective way while maximizing their synergies. Our study provides some supporting evidences.

Practically, our study has managerial as well as policy implications. New entrants can recognize importance of securing a combination of key resources required to overcome entry barriers. Firms can improve strategic resources management, thereby successfully enter the market based on competitive advantages of key resources. Government can introduce a package of policies supporting resources development or acquisition of such companies, thereby boosting market entry, innovation and growth of companies in the EV market. Also, a policy optimized to needs of a specific market segment is likely to increase its effectiveness.

Despite such contribution, our study has several limitations. Above all, the small number of cases limit generalization of our analytic result and interpretation. Statistical analysis based on large number of cases is needed in following research. Also, we suggest some interpretation about causal relationships between resources, but cannot validate those in a strict way. Either qualitative or quantitative validation can increase its reliability, and might identify new synergies or conflicts between resources. Another problem is restricting analysis to representative EV models while excluding various EV models by same company. There might be some bias about measurement of EV performances and resources. Last but not least, we cannot consider important external factors including government policy, infrastructure and others, and therefore cannot suggest a more comprehensive view as well as interpretation. In a similar context, internal intangible resources including design, brand loyalty and others need to be considered. Following studies need to address these issues on the assumption that more data are available.

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