Alliance formation in the electric vehicle industry during an era of ferment

William Sierzchula[a], Sjoerd Bakker[b], Kees Maat[b]

[a] Department of Transport and Logistics, Delft University of Technology

[b] OTB Research Institute for the Built Environment, Delft University of Technology

Abstract

When developing radical innovations, firms often form collaborative relationships with external organizations to have access to additional knowledge. For this reason, alliance formation is influential in innovation and thus plays a key role in industrial change. We used a case study of electric vehicles to analyze alliance formation as the automotive industry entered an era of ferment. We collected alliance data of 24 electric vehicle manufacturers from 2006 to 2011. This data was analyzed according to alliance type (explorative or exploitative), key knowledge areas, and firm type (incumbent or startup). The results show that firms displayed distinct alliance formation patterns in different key knowledge areas. Heterogeneity of alliance formation in key knowledge areas indicates that developing a radical innovation is not as simple as acquiring new expertise. Rather it is a complex process where in some instances firms seek to develop their knowledge base and in other instances they use the expertise of other companies. Analyzing alliance formation according to key knowledge area provides a much richer account of how firms approach knowledge acquisition during an era of ferment.

1. Introduction

The development and adoption of radical innovations represent crucial elements in industrial change (Dosi, 1982). Developing such innovations requires a large amount of resources and a knowledge base different from that used in the conventional technology (Teece, 1986; Tushman and Anderson, 1986; Powell et al., 2005). Firms can acquire new knowledge through in-house research and development (R&D) efforts and by partnering with external organizations that already possess this expertise (Koza and Lewin, 1998; Cassiman and Veugelers, 2006). Firms have increasingly used an alliance approach in order to have access to the resources and knowledge necessary to develop radical innovations (Powell et al., 1996; Rothaermel and Deeds, 2004). During turbulent periods in an industry known as eras of ferment, many firms develop radical innovations in order to remain competitive. Based on industrial dynamics, such as increases in technological diversity and firm entry, the electric vehicle (EV) sector entered into such an era of ferment in the late 2000s (Sierzchula et al., 2012). Eras of ferment often mark the shift from one dominant technology to another e.g., cassette tapes to compact discs. However, it is important to note that the outcome of the current EV era of ferment is far from certain. Our research analyzes the alliances formed by EV manufacturers during an era of ferment.

Previous studies analyzing alliance formation during the rise of a radical innovation found that during eras of ferment firms created partnerships geared towards technical exploration and establishing standards (Rosenkopf and Tushman, 1998; Van den Ven and Garud, 1994; Nesta and Mangematin, 2002). Once a dominant design emerged, businesses decreased their number of alliances and focused

on internal methods of organizational learning. This pattern suggests a connection between alliance formation and the standard industrial life cycle theory. Firms formed alliances during eras of ferment and focused on internal knowledge development during eras of incremental technological improvements. However, this connection has only been identified using certain types of collaborations e.g., associations geared towards establishing standards or partnerships regarding patents. Our research contributes to the literature by analyzing a broader range of alliances including joint ventures, mergers, associations, supplier relationships, equity investments, and R&D partnerships, formed by EV manufacturers during an era of ferment. Additionally, much of the research analyzing alliance formation has focused on the biotechnology sector (Nesta and Mangematin, 2002; Rothaermel and Deeds, 2004; Hagedoorn, 1993; Powell et al., 1996; Ahuja, 2000). This somewhat narrow focus represents a weakness in the literature. Our research adds to the literature regarding inter-firm collaboration during technological change by analyzing alliances formed in the automobile sector by EV manufacturers.

The remainder of this article is set up as follows. The following section provides a review of the background theory and literature dealing with industrial cycles and alliance formation with specific attention given to radical innovations as well as explorative and exploitative alliances. Section 3 outlines the methods that were used for firm selection, collecting the data, and analyzing the data. Section 4 provides results from analyses according to alliance type (explorative or exploitative), key knowledge area, and firm type (incumbent or startup). Section 5 offers concluding remarks.

2. Literature review and hypotheses formulation

Our research builds on two important threads of literature. The first being the influence of alliance formation on innovation and the second being industrial cycles. It is necessary to combine those two fields of research to provide the theoretical building blocks for why firms form alliances during different phases of industrial cycles. This section of the article identifies foundational elements within both areas of literature. Hypotheses are proposed where our research seeks to fill specific gaps in the literature.

2.1. Industrial life cycle

The industrial life cycle is robust and well-defined in the literature with technological development in the form of dominant designs and radical innovations demarcating eras of ferment and eras of incremental improvement (Utterback and Abernathy, 1975; Tushman and Anderson, 1986). The emergence of a radical innovation creates new market opportunities that require new areas of expertise (Anderson and Tushman, 1990). This situation, known as an era of ferment, disrupts incumbent control of the market and results in a flurry of activity as a host of new and existing firms seek to develop the innovation that will be most successful in the marketplace. As such, eras of ferment are characterized by increases in firm entry rate, industrial performance, technological variety, and high levels of uncertainty (Foster, 1986; Clark, 1985). These periods end when a dominant design emerges from the competing innovations to capture a majority of the market share (Abernathy, 1978). Eras of incremental change are characterized by low levels of uncertainty, a small number of principal incumbents, and competence enhancing improvements to the dominant design (Klepper, 1996; Tushman and Anderson, 1986).

It is important to note that although many technological changes have involved the industrial life cycle progression (radical innovation → era of ferment → dominant design → era of incremental

improvement → radical innovation), this cycle is not universally applicable. An era of ferment does not always lead to the rise of a new dominant design. For example, in the 1990s, EVs were developed by automobile manufacturers and introduced to the market, but they eventually faded away and the internal combustion engine (ICE) remained the dominant design. Additionally, an era of ferment may lead to several technologies being successful in different market niches (Windrum and Birchenhall, 1998). This situation arises due to high levels of demand heterogeneity in different markets. Although not all elements of the industrial life cycle are found in every radical change in technology, it still offers a useful perspective for viewing industrial dynamics and thus will be an important theoretical principle in our research.

2.2. Alliance formation and innovation

The relationships of firms, alliances, knowledge, and innovation have evolved throughout the literature. The past fifty years has seen innovation move from large corporate laboratories to multi-firm networks. After World War II, large corporations such as DuPont, Xerox, AT&T, and GE developed innovations in company research centers (Schumpeter, 1942; Etzkowitz, 2003). Inventions to come out of such corporate research laboratories included cell phones, transistors, Kevlar, and the personal computer. There were examples of more progressive inter-firm relationships such as the Manhattan Project and the American Synthetic Research Program (Freeman, 1991), but businesses generally partnered with outside entities only for simple functions or to acquire news regarding external research and development (Nelson, 1990). However starting in the 1970s and 1980s, firms gradually increased collaboration efforts in order to reduce uncertainty and have access to each other's resources (Pfeffer and Salancik, 1978; Freeman, 1991). This was largely because radical innovation required a large amount of resources and a new base of knowledge. Few firms had the necessary expertise for radical innovation, leading to a rise in alliance formation between firms with complementary knowledge areas (Grant, 1996). Taking advantage of complementarities in key knowledge areas through collaboration has been specifically important for innovation in sectors with high levels of complexity e.g., biotechnology and new materials (Hagedoorn, 1993; Blomqvist and Levy, 2006). Indeed, Powell et al. (1996) and Nesta and Mangematin (2002) argue that in complex industries the locus of innovation now occurs not at the individual firm level but within networks of firms. Both Shan et al. (1994) and Ahuja (2000) support this notion by positively correlating the number of alliances with innovation output in the number of patents granted. In general, the literature has identified a positive relationship between a firm's tendency to form collaborative alliances and its ability to innovate.

2.3. Exploration and exploitation alliances

Alliances are used by firms in order to gain access to and make use of partners' resources and capabilities (Freeman, 1991). They are categorized as *explorative* if they create new knowledge or *exploitative* if they build on and refine existing knowledge (March, 1991; Koza and Lewin, 1998). Explorative alliances are used in innovation and gaining new expertise e.g., R&D and joint ventures to develop new products (Cohen and Levinthal, 1990). Exploitative alliances are used for commercialization activities e.g., supplier and marketing relationships. Explorative and exploitative alliances represent fundamentally different ways that firms interact with each other regarding knowledge. These sorts of relationships are specifically relevant during an era of ferment where firms are attempting to acquire

new expertise. The literature generally shows that the formation of explorative and exploitative alliances is associated with resource availability. In mature industries i.e., those that require lower levels of resources for incremental innovation, firms are more likely to develop market access (exploitation) alliances (Hagedoorn, 1993). On the other hand, firms have formed explorative alliances when they do not possess the resources necessary to develop an innovation in-house (Carlsson and Stankiewicz, 1991; Tushman and Rosenkopf, 1992; Hagedoorn, 1993; Oliver, 2001; Nesta and Mangematin, 2002).

Based off of those studies, firms seeking to develop radical innovations during eras of ferment would form explorative alliances due to lack of resources. During eras of ferment, firms develop radical innovations. This requires a large amount of resources and new expertise. In instances where firms do not have the resources to develop a radical innovation, they would seek to form alliances to make use of other companies' resources and capabilities. Additionally, eras of ferment would seem to discourage exploitative alliances because they are associated with commercialization instead of development of innovations.

> *Hypothesis 1: During an era of ferment, manufacturers seeking to develop electric vehicles (a radical innovation) will engage in a higher proportion of explorative as opposed to exploitative alliances.*

Rothaermel and Deeds (2004) identified a correlation between product development and alliance formation as it relates to notions of uncertainty and firm expertise. They noted that in the product development stage (associated with high uncertainty and new expertise), biotechnology firms were more likely to forge explorative alliances. As those products were commercialized (associated with less uncertainty and existing expertise) firms were more likely to forge exploitative alliances. Our study seeks to identify whether a similar alliance formation pattern exists during the product development stage for electric vehicles.

2.4. Startup and incumbent firms

Startup and incumbent firms occupy prominent positions in both the industrial life cycle and alliance formation literature. Some studies analyzing industrial change have noted that startups are more likely than incumbents to develop radical innovations (Foster, 1986; Christensen, 1997). Other research has shown the opposite to be true (Chandy and Tellis, 2000; Jiang et al. 2010). According to the industrial life cycle, In an era of ferment there is a large influx of startup firms which consolidates down to a couple of large incumbents during an era of incremental improvements. However, it is the alliance literature which provides better guidance regarding how incumbents and startups will form alliances during an era of ferment. A resource-based explanation has been used to identify why startups are more likely than incumbents to form alliances (Colombo et al., 2006). Firms form alliances to have access to additional knowledge, resources, and experience (Freeman, 1991). Incumbents almost always have more resources than startup firms. This encourages startups (as opposed to incumbents) to form alliances in order to gain access to greater resources (Barabasi et al., 1999). If firms have the resources necessary to develop and commercialize a product, then they will avoid forming alliances (Rothaermel, 2001). For this reason, as firms grow larger and accumulate a greater amount of resources, their tendency to form alliances decreases (Colombo et. al., 2006). Incumbents (due to their abundance of resources) can be more selective in forging alliances while startups (driven to form alliance for legitimacy, resources, and

experience) cannot be as discriminating in choosing their partners (Baum et al., 2000; Rothaermel, 2001).

One of the gaps in the literature is that it does not look at incumbent and startup alliance formation within the context of industrial change. An era of ferment is characterized by higher uncertainty, firm entry rate, and technological diversity (Foster, 1986; Clark, 1985). During such periods of high uncertainty, both incumbent and startup firms are attempting to develop radical innovations (Rothaermel, 2001; Colombo et al., 2006). Since radical innovations require new expertise, firms are likely to seek out partners that can provide this new knowledge. The greater resources controlled by incumbent firms make them appealing as a partner and suggest that they will be able to successfully form alliances if that is their goal. The obvious counterexample is if a startup has expertise that other firms find desirable. Startups during an era of ferment usually possess the expertise necessary to develop radical innovations. In those situations startups will likely have partnership offers from firms seeking access to new expertise. Therefore the question becomes whether startups (likely with desirable expertise) will form more alliances than incumbents with a high level of resources.

> *Hypothesis 2: During an era of ferment, incumbent electric vehicle firms will form a larger number of alliances than will startup electric vehicle firms.*

3. Methods

We collected first level alliance data for 24 electric vehicle manufacturers during the 2006 to 2011 timeframe. Figure 1 helps to visualize this data collection approach using a portion of the BMW alliance network. In Figure 1, BMW has alliances with Siemens, SB LiMotive, and AC Propulsion for a total of three alliances. Mitsubishi and Autoport are outside the immediate inter-firm network of BMW and thus would not be included among its alliances. Inter-firm networks were analyzed by looking at their development according explorative vs. exploitative alliances, key knowledge area, and firm type. The remainder of this methods section identifies how the firms were selected, and how data was collected and analyzed.

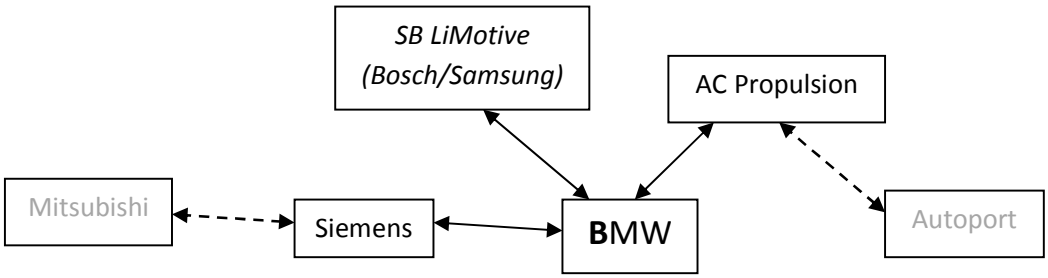

Figure 1: Sample of alliances for BMW

3.1. Firm selection

EV manufacturer firms were distinguished into startup and incumbent categories based on whether they had sold vehicles before 2000. A total of 17 incumbent firms were selected based on their high 2010 vehicle production statistics (OICA, 2011) and geographical diversity. These companies included: BMW, Chana, Daimler, FAW, Fiat, Ford, GM, Honda, Hyundai, Mahindra, Nissan, PSA, Renault, SAIC, Tata,

Toyota, and Volkswagen. Seven startups were selected based on geographic diversity. These companies included: Coda Automotive, Leo Motors, Mia Electric, Tesla Motors, Think, Venturi, and Zap.

We chose a time frame of 2006-2011 because it represents a transitional period when firms brought electric vehicles to market and the innovation entered the early adopter phase (Sierzchula et al., 2012). This fit with our research goal of identifying alliance formation during an era of ferment.

3.2 Data collection and analysis

Alliances were identified by analyzing company press releases and searching the news websites. www.green.autoblog.com and www.greencarcongress.com are websites that collect and display news about sustainable mobility. The sources for those news stories are provided allowing for confirmation of information veracity. Only alliances identified by trusted news sources such as Reuters, Bloomberg, and company press releases were used in our analysis. Internet search queries included three elements (1) the name of the EV auto manufacturer, (2) "electric car OR vehicle OR drive OR automobile", and (3) one of the following terms: “venture”, “supplier”, “merger”, “equity”, and “partner”. All company subsidiaries were also included in this search method e.g., Audi, Skoda, Bentley, SEAT, and MAN are subsidiaries of Volkswagen. Using that approach, we explored the first 200 hits on news websites (per search query) and all hits on EV manufacturer websites. During preliminary research, alliances suitable for our database were identified in the first 125 hits on news website. We chose to look at the first 200 hits to help ensure that we were able to capture all appropriate alliances. Partnerships dealing with pilot projects and municipalities were not included in our study.

Alliances were grouped according to their focus: charging and infrastructure, electric drivetrain, batteries, new body materials, promotion of EV adoption, standardization, and R&D. Based on the data, EV manufacturers formed alliances in four key knowledge areas: batteries, electric drivetrains, charging and infrastructure, and new materials. The IEA (2011) noted that expertise in those areas is important in the development of electric vehicles. Alliances involving new materials focused on carbon fiber as a way to decrease a vehicle’s weight and increase its driving radius. Using March’s (1991) terminology, alliances were categorized according to whether they sought to develop new knowledge (explorative) or built on and refined existing knowledge (exploitative). An example of an explorative alliance was Tesla and Daimler jointly developing electric drive components. An example of an exploitative alliance was Ford using Magna as a supplier for electric drive components. In the first example, Daimler created new knowledge regarding the development of electric drive components. While in the second example, Ford used Magna’s electric drive knowledge. The difference in the two alliances is that Ford was not developing its own electric drive expertise.

We used three different analyses on both the firm and industrial level to test for the hypotheses that were raised in the previous section of this article. We analyzed (1) the propensity of firms to form explorative or exploitative alliances (2) whether firms pursued explorative or exploitative alliances in key knowledge areas necessary to develop EVs, and (3) whether incumbent or startup firms were more likely to develop explorative or exploitative alliances.

At this point in the research article, it is worthwhile to note that alliances provide insight into the ways that firms use external approaches for knowledge accumulation. However, it does not give any notion as

to how firms are attempting to gain additional expertise through internal mechanisms such as hiring new staff, patenting, and experimentation. Thus, the results provided in our research need to viewed with the understanding that in addition to alliance formation, firms are also likely employing internal means to acquire knowledge necessary to develop and commercialize electric vehicles. With that caveat, the results are presented below.

4. Results

The results section uses alliance data from the EV industry and analyses identified in the methods section to address the hypotheses raised earlier in this article. Not all of the startup companies existed for each year of the study period. The analyses were corrected to reflect this.

4.1. EV network growth

Table 1 shows the yearly number of alliances, firms, and firms per alliance in the EV inter-firm network. During the study period, the number of alliances increased from 17 to 173, the total number of firms in the network increased from 25 to 155, and the average number of firms per alliance decreased from 1.47 to .90. There were also 17 alliances that ended during this period. Alliances that ended were not included in future year data.

Industry level network growth (cumulative)			
Year	Number of alliances	Number of firms	Avg. no. of firms per alliance
2006	17	25	1.47
2007	27	34	1.26
2008	49	66	1.35
2009	88	91	1.03
2010	128	123	0.96
2011	173	155	0.90

Table 1: EV inter-firm network by number of firms and alliances

The general trend shown in Table 1 was an increase in the inter-firm network for the 24 EV manufacturers in our study. The decrease in the average number of firms per alliance indicates that firms became part of more than one alliance and that the network became 'denser' over the study period. Dense networks are characterized by increased connectivity and innovation among actors (Powell et al., 1996).

4.2. Exploration vs. exploitation alliances

We categorized alliances as being either explorative (creating new knowledge) or exploitative (building on and refining existing knowledge). The literature has found that firms generally forged explorative alliances during periods of uncertainty or as they move into new technological areas (Hagedoorn, 1993). Our research seeks to determine whether firms forged a larger percentage of explorative as opposed to exploitative alliances during an era of ferment (in which there is a high level of uncertainty and in which

firms attempting to enter new technological fields). Figure 2 provides a breakdown of the number of explorative and exploitative alliances for each year of the study from an industry-level perspective.

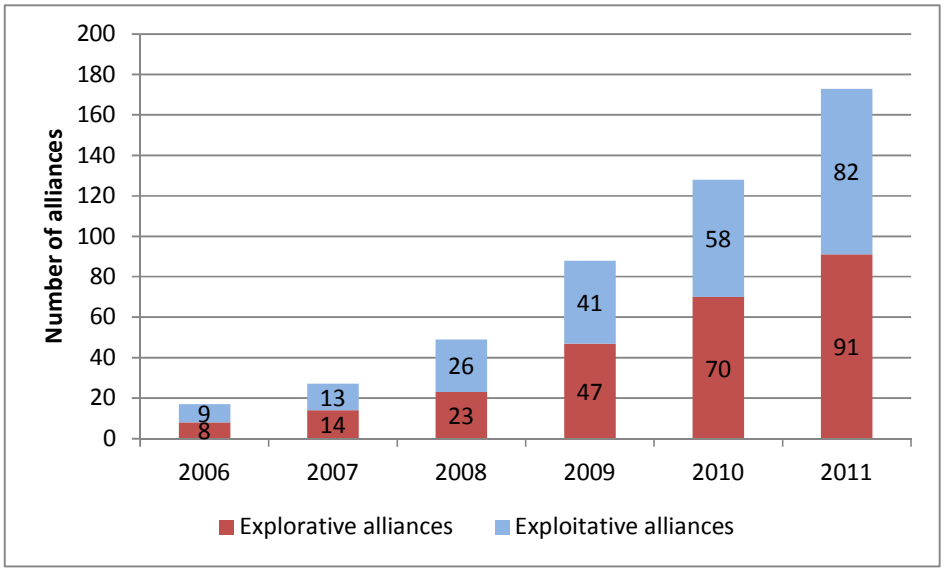

Figure 2: Distribution of explorative and exploitative alliances by year

Figure 2 shows that there were more explorative alliances in 2007, 2009, 2010, and 2011. Additionally, the number of explorative alliances grew at a faster rate than did the number of exploitative alliances (208% vs. 162%). However, the proportion of explorative and exploitative alliances moved within a tight range throughout the study period. Neither alliance type represented less than 45% or more than 55% of all alliances in a given year. This indicates that EV manufacturers were forming alliances to simultaneously pursue both commercialization and knowledge acquisition. Some of the exploitative alliances at the beginning of the study period can be explained by the level of EV commercialization at the time. In 2006, alliances from Mahindra (Reva) and Zap represented almost half of the alliances in our EV inter-firm network. Mahindra and Zap were selling electric vehicles at the time and their alliances were primarily geared toward exploitative relationships. However as the EV inter-firm network expanded, the Mahindra and Zap exploitation alliances represented an increasingly smaller proportion of all alliances in the study. Over the study period there were very few other electric vehicles brought to the market, so the notion that a large number of exploitative alliances in figure 2 were related to commercialized EVs does not hold. *On base, figure 2 does not support hypothesis 1 that during an era of ferment firms will engage in a higher proportion of explorative as opposed to exploitative alliances.* In fact, explorative and exploitative alliances were formed in almost equal proportions during the EV era of ferment. This indicates that both alliance types were desirable for automobile manufacturers during study period and runs counter the literature which expects a higher proportion of explorative alliances during a period such as an era of ferment.

4.3. Key knowledge areas

Because radical innovations represent new approaches to technology, firms need to acquire new knowledge in order to commercialize those products. One of the ways that EV manufacturers have sought to acquire new expertise is through alliances with external organizations. Alliances from our data

collection largely fell into four key knowledge areas: batteries, electric drive, charging and infrastructure, and materials. These knowledge areas have been identified as being very important for the development of electric vehicles (IEA, 2011). Table 2 provides a yearly breakdown of the number of alliances that were geared toward those important knowledge areas.[1] The alliances that were not associated with key knowledge areas are identified in the category of 'other'. For instance Coda builds the electric propulsion system of their vehicles and then sends them to China where the company Great Wall completes construction of the automobiles. In that situation the Coda is not interacting with Great Wall in any of the key knowledge areas.

	Batteries	Electric Drive	Charging & Infrastructure	Materials	Other
2006	7	12	2	1	1
2007	14	12	2	1	4
2008	25	18	5	2	6
2009	48	29	8	5	8
2010	70	45	14	9	13
2011	83	54	33	13	15

Table 2: Cumulative number of alliances in knowledge area per year

During every year of the study period except 2006, the battery knowledge area had the largest number of alliances. After batteries, electric drivetrains had the largest number of alliances followed by charging and infrastructure and finally materials. The relatively large number of alliances that were formed regarding batteries coincides with its significance to the development of electric vehicles (IEA, 2011). The recent increase in the number of alliances in charging and infrastructure and materials indicates that those knowledge areas have become more important as EVs have moved toward broader commercialization.

Figure 3 provides a firm-level analysis of alliance formation in key knowledge areas. It shows the average number of alliances per EV manufacturer in batteries, electric drivetrains, charging and infrastructure, and materials. Thus, if there were seven EV manufacturers that formed a total of 14 battery alliances, then that would average out to two battery alliances per firm. Figure 3 complements Table 3 by showing alliance formation per firm. Not all firms had alliances in knowledge areas for a given year. Firms without alliances in key knowledge areas were not included in the average number of alliances per firm.

[1] In Table 2 and Figures 3, 4, and 5, one alliance could count as collaboration for multiple knowledge areas.

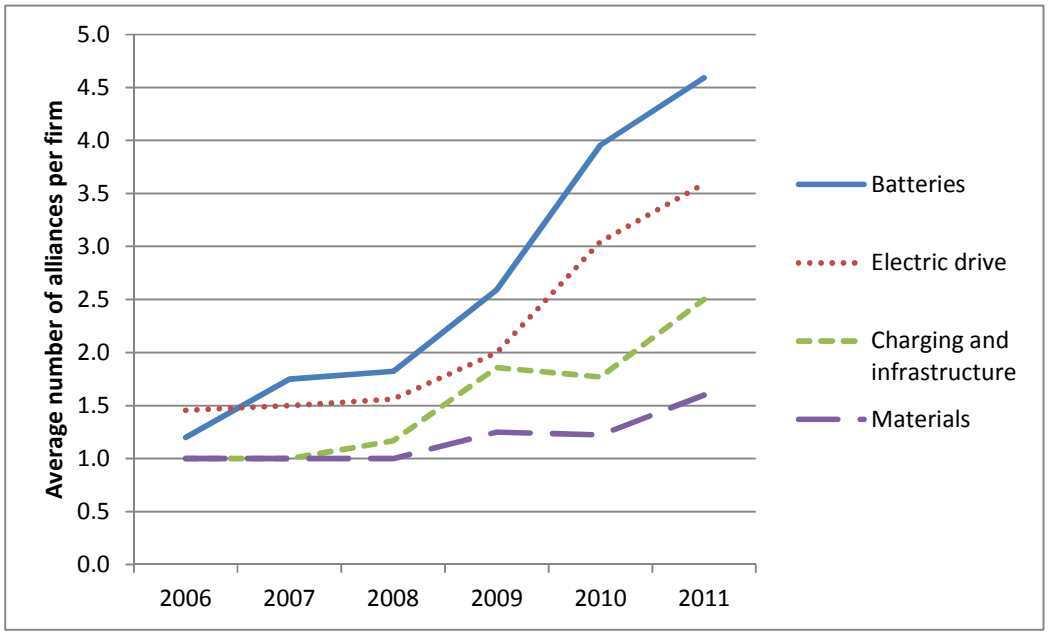

Figure 3: Average number of alliances per firm in key knowledge areas

Over the course of the study period, firms gradually increased their average number of alliances in all key knowledge areas. The number of batteries alliances increased from 1.2 per firm in 2006 to 4.6 in 2011. By 2011, there was only one manufacturer with one batteries alliance, and most manufacturers had four or more such alliances. A similar pattern of increasing the average number of alliances per firm was seen in the other knowledge areas of electric drive, charging and infrastructure, and materials. It is important to note that almost all of the alliances in Figure 3 were with new partners. There were some specific examples of EV manufacturers that forged additional alliances with existing partners e.g., Daimler and Evonik, Coda and Yardney, GM and LG chemicals, Nissan and NEC, and Think and EnerDel. However, instead of establishing alliances with a single firm, EV manufacturers generally displayed a strategy of developing a broad network of partners in key knowledge areas.

4.3.1. Exploration or exploitation alliances in key knowledge areas

Firms can acquire new expertise from external organizations through either explorative or exploitative alliances. The literature expects a higher proportion of explorative alliances as firms move into new technological fields (Cohen and Levinthal, 1990; Hagedoorn, 1993). Figure 4 is an industry-wide overview that identifies the total number of exploration and exploitation alliances formed in each of the four key knowledge areas: batteries, electric drivetrains, charging and infrastructure, and materials.[2]

[2] Figure 4 has more total alliances than Table 2 because it includes all alliances throughout the study period. Table 2 only included alliances which existed in a given year. Thus, a batteries alliance spanning 2007-2008 would not appear in the 2011 statistics for Table 2, but would appear under the batteries alliance category in Figure 4.

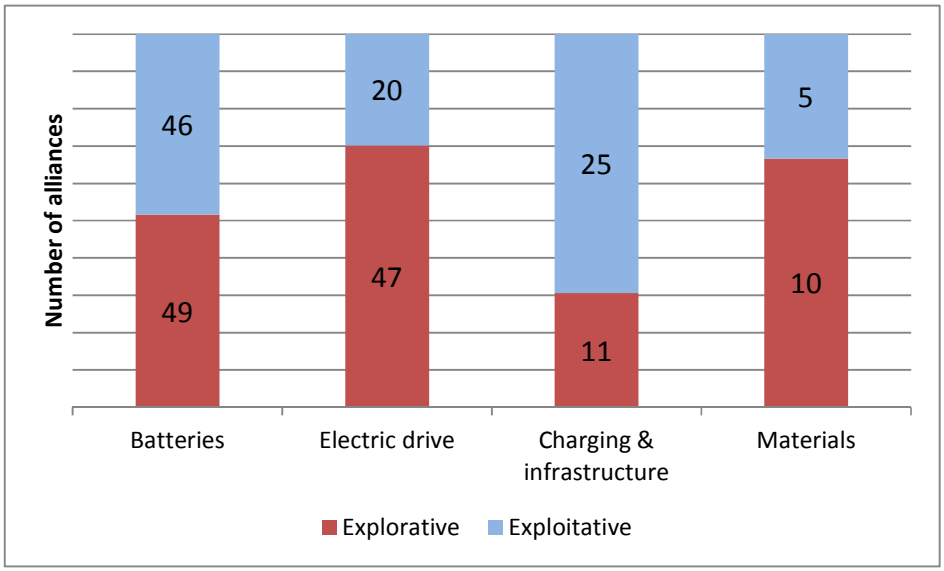

Figure 4: Explorative and exploitative alliances in key knowledge areas

Figure 4 suggests that firms were trying to gain expertise in electric drive and materials, commercialize charging and infrastructure, and simultaneously commercialize and gain technical knowledge about batteries. Over the study period, firms developed almost an even number of explorative and exploitative alliances regarding batteries. They developed more explorative alliances in electric drive and materials, suggesting a desire to eventually bring that knowledge in-house. Charging and infrastructure was the only knowledge area with a larger proportion of exploitative alliances. This is likely because charging and EV infrastructure are issues being addressed by other types of organizations e.g., government bodies and utilities. A significant chi-square ($p=0.01$) in the underlying data of Figure 4 shows that explorative and exploitative alliances are associated with the different knowledge areas. Ultimately, Figure 4 shows that firms had different approaches toward developing alliances in the four knowledge areas.

The industrial overview in Figure 4 does not identify how individual firms approached alliance formation in key knowledge areas. Thus we do not know whether a couple of firms made many explorative alliances in electric drive while other firms did not have any alliances in that knowledge area. Figure 5 attempts to address this shortcoming by showing whether individual firms formed explorative alliances, exploitative alliances, or both in the key knowledge areas of batteries, electric drivetrains, charging and infrastructure, and new materials. For example, Coda Automotive had a battery supplier alliance with Yardney Technical Products and a battery joint venture with Lishen Energy Systems. In that example, Coda Automotive pursued both exploitative and explorative alliances in the batteries knowledge area.

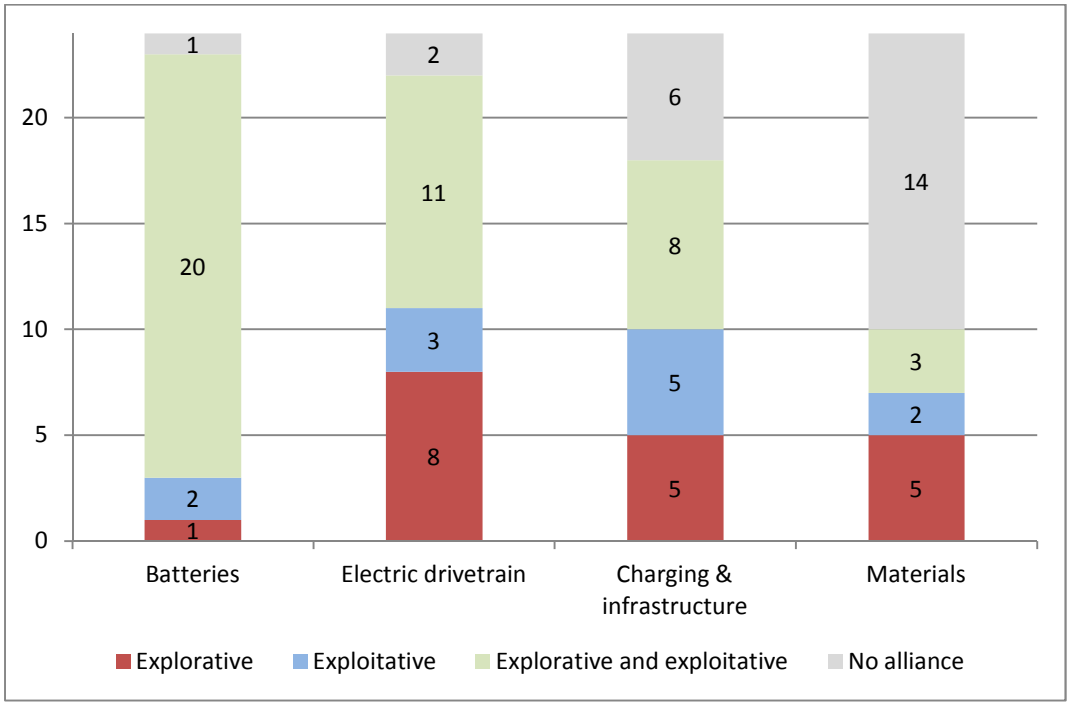

Figure 5: Explorative and exploitative alliances in key knowledge areas by firm

Similar to Figure 4, Figure 5 shows that firm approach toward developing explorative and exploitative alliances varied by knowledge area. Most firms (20 out of 24) developed both explorative and exploitative alliances in batteries. After batteries, the number of firms that developed both types of alliances steadily decreased across electric drivetrain, charging and infrastructure, and materials. Figure 5 largely reinforces Figure 4 except in charging and infrastructure alliances. Figure 4 shows more than twice as many exploitative alliances in charging and infrastructure while Figure 5 shows a more even distribution of alliance type. This difference is due to the large amount of exploitative alliances made by Nissan and Renault in charging and infrastructure. Another conclusion that can be drawn from Figure 5 is that few firms chose to just develop exploitative alliances in key knowledge areas. This suggests that firms were only likely to develop exploitative alliances in key knowledge areas where they already had an explorative alliance. Figures 4 and 5 provide additional insight for hypothesis 1 that *during an era of ferment firms will engage in a higher proportion of explorative as opposed to exploitative alliances.* Firms showed different alliance formation patterns for the key knowledge areas.

4.4. Incumbent and startup alliance formation

The literature has shown that startup firms are more likely to form alliances than larger incumbents. However, this relationship has not been analyzed during industrial life cycles, which leads to our analysis of alliance formation by startup and incumbent firms during an era of ferment. We calculated the average number of explorative and exploitative alliances formed by startup and incumbent firms throughout the study period.

Our review of the industrial life cycle and alliance literature revealed that both startups and incumbents develop radical innovations. While startup firms are more likely to form alliances, both firm types seek to form explorative alliances during periods of high uncertainty or when moving to a new technological

field (circumstances found during an era of ferment). Table 3 shows the average number of explorative and exploitative alliances formed by startup and incumbent firms each year of the study period. It is important to note that in Table 3, alliance averages were only calculated among firms that participated in the EV network (that had at least one alliance). Also, some alliances included more than one of the EV manufacturers in our study.

	2006	2007	2008	2009	2010	2011
Incumbent explorative alliances	1.1	1.3	1.3	2.7	4.3	5.7
Startup explorative alliances	0.5	1.2	1.5	2.1	3.4	4.0
Incumbent exploitative alliances	0.6	0.9	1.1	1.9	3.0	4.7
Startup exploitative alliances	1.5	1.2	1.7	2.0	2.7	3.0

Table 3: Average number of explorative and exploitative alliances per firm type by year

Table 3 shows that the average number of explorative and exploitative alliances increased throughout the study period for both startup and incumbent firms. Incumbents in general ended up with a higher average number of explorative and exploitative alliances than did startups. Table 3 supports hypothesis 2 that *during an era of ferment, incumbent firms will form a larger number of alliances than will startup firms.* This could be because the greater resources available to incumbents allowed them to form more alliances in a situation where alliances were beneficial (high market and technological uncertainty).

Table 3 also provides limited support for the notion that both startups and incumbents seek to develop explorative alliances during periods of high uncertainty or when moving to a new technological area. Incumbents were more likely to form explorative alliances while startups had a higher proportion of exploitative alliances in the first half of the study period. This situation was already explained earlier in that at the beginning of the study (2006) Zap and Venturi (both startups) were selling EVs and had a large proportion of exploitative alliances. The relatively low number of startup alliances could also have been due to their existing expertise regarding EV development. Firms might have been less motivated to develop explorative alliances because they already possessed technological knowledge specific to EVs e.g., electric drivetrains. In fact, many of the startup firms provided their own battery and electric drivetrain expertise to other auto manufacturers e.g., Coda and Great wall, Tesla and Daimler, Think and Valmet automotive, and Zap and Youngman Auto. This supports Dyerson and Pilkington's (2005) expectation that new entrants to the EV industry will likely seek to collaborate with established incumbent firms. It also supports the more general notion that startup firms seek to develop alliances with resource-rich incumbents (Barabasi et al., 1999; Baum et al., 2000).

5. Conclusions

This research used alliance formation patterns by EV manufacturers to provide insight into inter-firm collaboration during an era of ferment. We tested hypotheses, derived from the literature, that during an era of ferment firms would forge more explorative alliances than exploitative alliances and that incumbent firms would be more likely than startup firms to form partnerships. Below are conclusions based on those hypotheses as well as the theoretical implications from our findings.

Hypothesis 1 stated that during an era of ferment firms would forge a higher proportion of explorative as opposed to exploitative alliances. Additionally, our research sought to discover whether alliance formation patterns varied as they related to specific knowledge areas important for the development of electric vehicles. Results identified differences between the proportion of explorative and exploitative alliances formed by EV manufacturers on the industrial level and in key knowledge areas. The industrial level, which included yearly totals of all partnerships, showed that EV manufacturers formed a similar number of both explorative and exploitative alliances throughout the study period. This provided a different result than the more linear relationship between alliance formation and product development (explorative alliances → products in development → exploitative alliances → products to the market) found by Rothaermel and Deeds (2004). It also ran counter to the research from (Hagedoorn, 1993) where firms were more likely to forge explorative alliances when they moved into new technological areas. The large number of exploitative alliances indicates that as manufacturers were developing EVs, they sought to use expertise of other firms to a greater extent than was found in earlier research of inter-firm collaboration during an era of ferment.

Analysis of key knowledge areas showed that manufacturers displayed distinct alliance formation tendencies regarding batteries, electric drivetrains, charging and infrastructure, and new materials. Since companies are currently bringing EVs to market, it is likely that the speed in which expertise can be integrated into a commercial product played a part in firms' approaches to alliance formation. In our research, manufacturers formed both explorative and exploitative alliances regarding battery development. Due to the complexity of batteries, manufacturers likely formed exploitative relationships in order to quickly bring an EV to market. However, the desire to stay on top of the value chain and bring battery development in-house also encouraged EV manufacturers to form explorative alliances. This alliance formation behavior positioned auto manufacturers with the ability to bring an electric vehicle to the market in the short-term while being able to independently develop electric vehicles in the long-term. For electric drivetrains and new materials, firms displayed the typical behavior of forming explorative alliances in new technological fields. In those areas, EV manufacturers sought to use explorative alliances to develop their own knowledge base. This indicates that through explorative alliances, expertise in electric drivetrains and new materials can be obtained quickly enough to commercialize EVs in the short term. Regarding charging and infrastructure, firms generally developed exploitative alliances. The lack of explorative alliances identifies that EV manufacturers had a different approach toward charging and infrastructure than the other key knowledge areas. This approach to alliance formation could have occurred because charging and infrastructure standards are not yet established and will largely be decided by government agencies. Thus, EV manufacturers may not see it is an immediate or important commercial opportunity.

Hypothesis 2 stated that during an era of ferment, incumbent firms will form a larger number of alliances than will startup firms. Both startup and incumbent firms were expected to seek alliances to provide the expertise necessary to develop electric vehicles. Our results showed that incumbent firms formed a higher rate of both explorative and exploitative alliances. This indicates that during an era of ferment incumbents were able to use their greater level of resources to successfully form alliances providing them a competitive advantage over startup firms.

The main theoretical contribution of our research is that during an era of ferment, alliance formation behavior differs according to key knowledge areas. This adds an additional level of analysis to the standard categorization of alliances as being either explorative or exploitative. Within our research, this was born out through firms having distinct patterns of explorative and exploitative alliances in areas of expertise important for developing electric vehicles. Studying alliances as they relate to knowledge areas key to developing a radical innovation provides a much richer description of how firms acquire new expertise during an era of ferment.

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Bibliography

Abernathy, W., 1978. The Productivity Dilemma. Johns Hopkins University Press, Baltimore.

Ahuja, G., 2000. Collaboration Networks, Structural Holes, and Innovation: A Longitudinal Study. Administrative Science Quarterly 45(3), 425-455.

Anderson, P., and Tushman, M., 1990. Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change. Administrative Science Quarterly 35, 604-633.

Arthur, W., 1989. Competing technologies, increasing returns and lock-in by historical events. Economic Journal 99 (1), 116-131.

Beckman, C., Haunschild, P., and Phillips, D., 2004. Friends or Strangers? Firm-Specific Uncertainty, Market, Uncertainty, and Network Partner Selection. Organization Science 15(3), 259-275.

Blomqvist, K., and Levy, J., 2006. Collaboration capability – a focal concept in knowledge creation and collaborative innovation in networks. International Journal of Management Concepts and Philosophy 2(1), 31-48.

Carlsson, B., and Stankiewicz, R., 1991. On the nature, function and composition of technological systems. Journal of Evolutionary Economics 1, 93-118.

Cassiman, B., and Veugelers, R., 2006. In Search of Complimentarity in Innovation Strategy: Internal R&D and External Knowledge Acquisition. Management Science 52 (1), 69-82.

Chandy, R., and Tellis, G., 2000. The Incumbent's Curse? Incumbency, Size, and Radical Innovation. The Journal of Marketing 64 (3), 1-17.

Christensen, C., 1997. The Innovator's Dilemma. Harvard Business School Press, Boston, MA.

Clark, K., 1985. The interaction of design hierarchies and market concepts in technological evolution. Research Policy 14, 235-251.

Cohen, W., and Levinthal, D., 1990. Absorptive Capacity: A New Perspective on Learning and Innovation. Administrative Science Quarterly 35, 128-152.

Dijk, M., 2000. Technological Regimes and Industrial Dynamics: the Evidence from Dutch Manufacturing. Industrial and Corporate Change 9 (2), 173-194.

Dijk, M., and Yarime, M., 2010. The emergence of hybrid-electric cars: Innovation path creation through co-evolution of supply and demand. Technological Forecasting and Social Change 77, 1371-1390.

Dodgson, M., 1993. Learning, trust, and technological collaboration. Human Relations 46, 77-95.

Dosi, G., 1982. Technological paradigms and technological trajectories. Research Policy 11, 147-162.

Dyerson, R., and Pilkington, A., 2005. Gales of creative destruction and the opportunistic incumbent: The case of electric vehicles in California. Technology Analysis & Strategic Management 17 (4), 391-408.

Etzkowitz, H., 2003. Innovation in innovation: the Triple Helix of university-industry-government relations. Social Science Information 42 (3), 293-337.

Foster, R., 1986. Innovation: The Attacker's Advantage. Macmillan, London.

Freeman, C., 1991. Networks of innovations: A synthesis of research issues. Research Policy 20, 499-514.

Grant, R., 1996. Toward a knowledge-based theory of the firm. Strategic Management Journal 17, 109-122.

Hagedoorn, J., 1993. Understanding the rationale of strategic technology partnering: interorganizational modes of cooperation and sectoral differences. Strategic Management Journal 14, 371-385.

Hagedoorn, J., and Duysters, G., 2002. External sources of innovative capabilities: The preferences for strategic alliances or mergers and acquisitions. Journal of Management Studies 39 (2), 167–88.

Hamel, G., 1991. Competition for competence and inter-partner learning within international strategic alliances. Strategic Management Journal 12, 83-103.

Hill, C., and Rothaermel, F., 2003. The Performance of Incumbent Firms in the Face of Radical Technological Innovation. Academy of Management Review 28 (2), 257-274.

IEA, 2011. Technology Roadmap Electric and Plug-in Hybrid Electric Vehicles. OECD/IEA, Paris.

Jiang, L., Tan, J., and Thursby, M., 2010. Incumbent firm invention in emerging fields: evidence from the semiconductor industry. Strategic Management Journal 32, 55-75.

Klepper, S., 1996. Entry, Exit, Growth and Innovation over the Product Life Cycle. The American Economic Review 86 (3), 562-583.

Klepper, S., 2002. The capabilities of new firms and the evolution of the US automobile industry. Industrial and Corporate Change 11 (4), 645-666.

Koza, M., Lewin, A., 1998. The co-evolution of strategic alliances. Organization Science 9, 255–264.

March, J., 1991. Exploration and Exploitation in Organizational Learning. Organization Science 2 (1), 71-87.

Nesta, L., and Mangematin, V., 2002. Industry Life Cycle, Knowledge Generation and Technological Networks. Economics of Science, Technology and Innovation 28 (4), 199-220.