SUGISAKA MASANORI

Journal of Advances in Artificial Life Robotics
Vol. 2(4); March (2022), pp. 184-188
ON LINE ISSN 2435-8061; ISSN-L 2435-8061
https://alife-robotics.org/jallr.html

Research Article

Competitive Positioning of R&D Strategies at Productive Frontier: The Case study on Cooperative Relationship between EV and Battery Makers

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ARTICLE INFO

Article History

Received 08 November 2021
Accepted 26 March 2022

Keywords

R&D strategies
EV makers
Battery makers
Patent analysis

ABSTRACT

This paper focuses on the R&D direction and the business strategy of EV firms and battery makers with reference to Porter's productive frontier. M. E. Porter (1996) claimed that the productivity frontier represents the maximum value that the organization can deliver at any a given cost, using technologies, skills and purchased inputs. He argued that strategic decisions are ones that are aimed at differentiating an organization from its competitors in a sustainable way in the future. We use the patent information of EV firms (Toyota, Tesla, Volkswagen) and battery makers (Panasonic, CATL, LG Chem) as the cases. We examine our propositions by social network analysis and text mining. The analysis in this paper includes: 1) trying to distinguish between differentiation and cost leadership strategy from R&D direction, and visualizing productivity frontier, 2) making discussing on the inter-organizational relation of EV firms and battery makers. In this paper, we clarify those patterns of cooperation EV firms and battery makers.

1. Introduction

EV (Electric Vehicle) is expected to spread as it has the potential to bring about major changes in global energy problems such as global warming countermeasures. The research and development of battery, which is the main component of EV, will be important for the diffusion of EV. For example, batteries keep going better. Average battery energy density is rising at 7% per year. And lithium-ion battery pack prices fell 89% from 2010 to 2020, with the volume weighted average hitting $137/kWh. Underlying material prices will play a larger role in the future, but the introduction of new chemicals, new manufacturing techniques and simplified pack designs keeps prices falling [1].

This paper will focus on the R&D direction and the business strategy of EV firms and battery makers. We use Porter's productivity frontier to discuss these issues. The analysis in this paper includes: 1) visualizing the productivity frontier of battery industry and distinguishing between differentiation and cost leadership strategy from R&D direction 2) discussing on the inter-organizational relationships of EV firms and battery makers. In this paper, we clarify the patterns of strategic alliance between EV and battery makers.

2. Backgroun

2.1. Productivity frontier

M. E. Porter defines the productivity frontier as: the sum of all existing best practices at a given time. And he explains the difference between operational effectiveness and strategic positioning with productivity frontier map [2]. Operational effectiveness means performing

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similar activities better than rivals performing them. In contrast, strategic positioning means performing different activities from rivals' doing or performing similar activities in different ways. (Fig. 1) He points out that constant improvement in operational effectiveness is necessary to achieve superior profitability. However, it is not usually sufficient. Competitive strategy is about being different. It means deliberately choosing a different set of activities such as non-price buyer value delivered or relative cost position to deliver a unique mix of value.

In the case of EV's battery, we focus on the R&D strategies of battery makers that choosing from LFP (LiFePo4), NCM (Nickel, Cobalt, Manganese) and Solid-state batteries. The characteristics of LFP are lower energy density than NMC, quite robust rather than

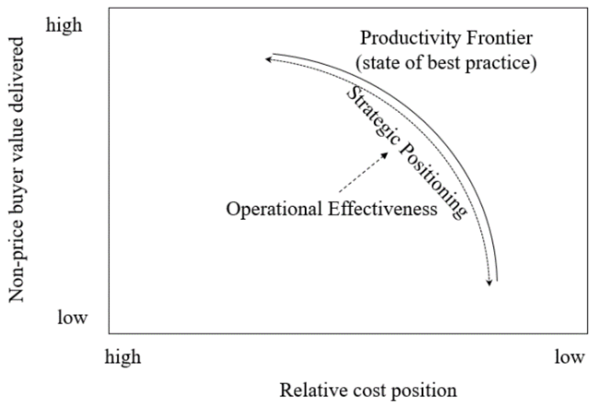

Fig. 1. Operational Effectiveness Versus Strategic Positioning modified by the authors

Table 1. Battery Types for EVs

	Iron Based (LFP)	Manganese + Nickel (NCM)	High Nickel
Cost	80% of High Nickel	90% of High Nickel	Highest Cost
Energy (Cell Level)	50% of High Nickel	92% of High Nickel	Highest Energy
Range	75% of High Nickel	85-90% of High Nickel	Highest Energy
Cycle Life	4000-12000	2000-3000	2000-3000
Power	Excellent	Good	Good
Safety	High	Moderate	Low
Recycle Value	Low	Moderate	High
Toxicity	Low	High	High
Material Abundance	Iron is Vastly Abundant	Mn = 1/10th Iron	Mn = 1/10th Iron

Source: Tesla's Battery Day

economical (abundant materials, no need of Nickel and particularly Cobalt). The characteristics of NMC are higher energy density, shorter lifetime, lower safety margins, and higher price. The characteristics of high nickel and solid-state batteries where liquid electrolyte and separator are replaced by a solid material, have to solve many issues and the R&D are still on progress and mass production have not started yet. (Table 1)

Therefore, we can say that LFP is in the lower right, NCM is in the middle, and high nickel and solid material is in the upper left on the productivity frontier.

2.2. *The overview of EV and battery industry*

After a decade of rapid growth, in 2020 the global electric car stock hit the 10 million mark a 43% increase over 2019 and representing a 1% stock share. Battery electric vehicles accounted for two-thirds of new electric car registrations and two-thirds of the stock in 2020 [3]. Demand for EV battery by region is highest in China, the EU and the US are the other regions. Recently, the EU has seen a noticeable increase. (Fig. 2)

In the case of EV makers, Tesla is No. 1 in global EV sales and its increase is significant. On the other hand, existing automaker such as Toyota and Volkswagen, has been lagging behind in battery EV production. In the case of EV battery makers, CATL in China ranks first in the world's EV sales, and its increase is large. LG chem. in Korea and Panasonic in Japan rank second and third (Table 2). As they are key players in this market, this paper will focus on the EV firms such as Tesla, Volkswagen and Toyota, and battery makers such as Panasonic, CATL and LG Chem.

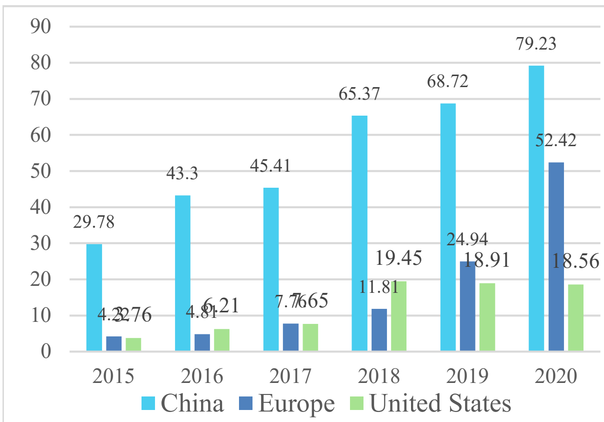

Fig. 2. EV battery demand by region (2020)

Table 2. World Plugin Vehicle Sales (2020)

Model	Brands	Battery Maker	2020H1Sales	2021H1Sales	Y-O-Y
Tesla Model 3	Tesla	CATL, LG, Panasonic	142,346	243,753	71.20%
Wuling HongGuang Mini EV	SAIC	CATL, Gotion High-tech	- - -	181,810	- - -
Tesla Model Y	Tesla	LG, Panasonic	13,415	138,401	######
BYD Han EV	BYD	BYD	- - -	38,667	- - -
Volkswagen ID.4	Volkswagen	CATL, LG, Samsung SDI, Gotion High-tech	- - -	38,499	- - -
GW ORA Black Cat	GWM	SVOLT,CATL	- - -	32,013	- - -
Renault Zoe	Renault	LG,AESC	37,154	31,426	######
Hyundai Kona EV	Hyundai	SK Innovation	19,286	31,233	61.90%
Volkswagen ID.3	Volkswagen	CATL, LG, Samsung SDI, Gotion High-tech	- - -	31,079	- - -
GAC Aion S	GAC	CALB, CATL	14,516	30,456	######
Li Xiang One EREV	Li Auto	CATL	- - -	30,154	- - -
Nissan Leaf	Nissan	AESC	23,867	29,372	23.10%
Changan Benni EV		Gotion High-tech, CATL, CALB, BYD	- - -	29,178	- - -
Kia Niro EV	Kia	SK Innovation	12,157	27,395	######
Chery eQ	Chery Auto	CATL, Gotion High-tech, Farasis Energy	- - -	27,136	- - -
Volvo XC40 PHEV	Volvo Cars	CATL, LG	- - -	26,839	- - -
Audi e-tron	Audi	LG, BYD	17,592	25,758	46.40%
Toyota RAV4 PHEV	Toyota	Panasonic, CATL, BYD	- - -	25,279	- - -
BMW 530e/Le	BMW	CATL, Samsung SDI	20,586	24,985	21.40%
Ford Escape/Kuga PHEV	Ford	Samsung SDI,BYD,SK Innovation	- - -	24,763	- - -

Source: Inside of EVs Website

3. Methodology and data

In this section, we analyze the R&D and business strategies of each EV firms and battery makers through social network analysis, which can visualize the characteristics of R&D patterns using archived patent information.

Table 3. IPC code on battery

H01M50/00	Constructional details or processes of manufacture of the non-active parts of electrochemical cells other than fuel cells, e.g. hybrid cells
H01M6/00	Primary cells; Manufacture thereof; In this group, primary cells are electrochemical generators in which the cell energy is present in chemical form and is not regenerated.
H01M8/00	Fuel cells; Manufacture thereof; In this group, the following expression is used with the meaning indicated: "Fuel cell" means an electrochemical generator wherein the reactants are supplied from outside.
H01M10/00	Secondary cells; Manufacture thereof; In this group, secondary cells are accumulators receiving and supplying electrical energy by means of reversible electrochemical reactions.
H01M12/00	Hybrid cells; Manufacture there of (hybrid capacitors H01G11/00); Note. This group does not cover hybrid cells comprising capacitor electrodes and battery electrodes, which are covered by group H01G11/00. In this group, hybrid cells are electrochemical generators having two different types of half-cells, the half-cell being an electrode-electrolyte combination of either a primary, a secondary or a fuel cell.
H02J7/00	Circuit arrangements for charging or depolarising batteries or for supplying loads from batteries

Source: Japan Patent Office

We selected patent documents archived in patent database service by Patent Integration Co. All patents are classified according to the worldwide standard classification codes that is called IPC (International Patent Classification). This paper utilizes all patents of EV firms and battery makers since 2000, including USA and WIPO (World Intellectual Property Organization). We extract related patents such as “Battery (H1), Charging (H2)”, and then collect patents which are applied by each company. (Table 3)

3.1. *An approach based on the number of patent publications*

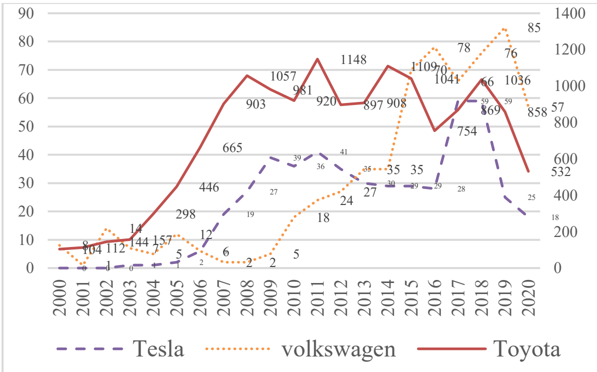

Fig. 3. Status of battery patents (by EV firms)

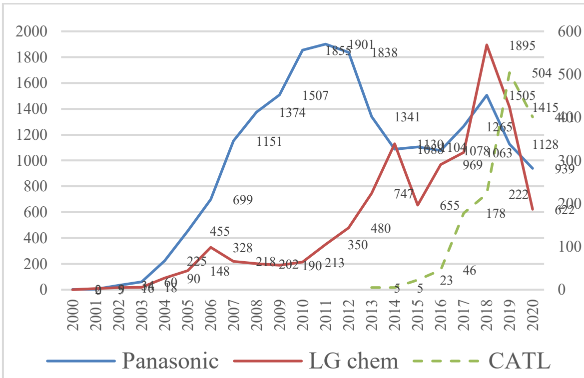

Fig. 4. Status of battery patents (by Battery Makers)

An approach based on the number of patents, in the case of EV firms, Toyota leading in patents has a strong dominance over its rivals such as Tesla and Volkswagen but falling short of Tesla in sales. In the case of Battery makers, Panasonic and LG Chem leading in patents have more dominant than CATL, but CATL's sale is the highest in this industry. (Fig. 3 and Fig. 4)

As a result, in the EV industry, the technological superiority with firm's patent has not resulted in business success. So why did this result happen? We consider the following hypothesis. Toyota has a strong patent in the field of future solid-state batteries shown in Table 4 and 5 , while CATL is concentrating on LFPs, which are low-cost and easy to mass-produce. As a result of the different R&D and business strategies of these firms, Tesla and CATL have gained a competitive advantage in the EV market.

Table 4. Frequency of Major Words in Patents (Toyota)

		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
NCM	Nickel	7	8	9	7	17	6	13	19	18	18
	Cobalt	1	4	1	3	13	7	13	19	14	11
	Manganese	3	1	0	2	9	4	7	5	12	13
LFP	Iron	3	4	7	9	13	12	25	30	22	13
	Phosphate	0	0	2	1	5	7	2	5	11	5
	Ferrum	0	0	0	0	0	0	0	0	0	0
Solid state	Solid	7	5	6	7	26	25	38	35	46	61
	state	30	25	32	52	81	108	142	152	154	121
		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
NCM	Nickel	18	23	15	21	36	20	12	32	37	18
	Cobalt	16	17	8	10	13	11	3	15	13	7
	Manganese	17	19	15	11	23	16	6	18	10	6
LFP	Iron	21	24	14	20	43	21	8	16	19	15
	Phosphate	3	10	11	11	33	18	7	14	14	14
	Ferrum	0	0	0	0	0	0	0	0	0	0
Solid state	Solid	75	56	45	49	63	98	79	106	117	59
	state	197	148	125	156	206	156	172	245	274	168

Table 5. Frequency of Major Words in Patents (Toyota)

		2014	2015	2016	2017	2018	2019	2020
NCM	Nickel	1	0	1	5	19	38	15
	Cobalt	0	0	1	3	12	32	9
	Manganese	0	0	0	4	9	34	3
LFP	Iron	0	1	0	4	8	25	7
	Phosphate	0	1	2	9	13	34	6
	Ferrum	0	0	0	0	0	0	0
Solid	Solid	0	0	1	2	5	4	1
	state	0	2	0	8	9	17	25

3.2. *An approach by social network analysis*

Fig. 5 shows the R&D and business strategy of each EV firms and battery makers with social network analysis with transaction and patent data. (Table 1 and Table 2) Tesla is at the network centrality of EVs ecosystem. By region, CATL is at the network centrality in China. LG Chem is the network centrality in EU and USA. Panasonic is the network centrality in Japan. As explained in the previous section, Toyota, Panasonic and LG Chem have more power than Volkswagen, Tesla and CATL in patent, but Tesla and CATL have better position than their rivals at the business level. This success is due in part to Tesla's central position in the EV ecosystem and its collaboration with Panasonic, LG Chem, and CATL. CATL has taken a central position in the Chinese region, where EVs were rapidly spreading.

Specifically, Tesla uses NCM batteries from Panasonic and LG Chem, which offer superior performance, in the U.S. and other developed countries, while CATL's LFP batteries are cheaper and safer in the Chinese market. In other words, Tesla ensures strategic flexibility by using different leading battery makers in each region (Panasonic, LG Chem and CATL). On the other hand, CATL, which has lagged behind in battery R&D, has been supplying low-cost LFP batteries to EV makers (GWM, GAC, SAIC) in its own country while moving into the development of NCM and solid-state batteries.

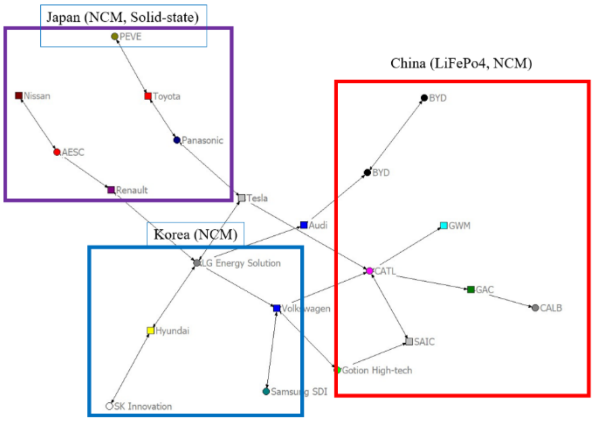

Fig. 5. The relation between EV firms and battery makers by social network analysis

4. Discussion and conclusions

We have discussed the patterns of cooperative relationship between EV firms and battery makers under the impact of radical technological changes [4]. In our analysis, Tesla has good position which can use both low cost (LFP) and high quality (NCM) in productive frontier. In Japanese firm's case, Panasonic and Toyota have continued to grow in importance. Because they have cooperative relationship with Tesla and Toyota. Toyota is an important player in the Japanese automotive industry, but the challenge is how to recover from its late start in the EV market.

Moreover, we find the similarities and differences in the R&D strategies from EV firms and battery makers. In the future study, we will discuss how these companies have taken different R&D strategies?

Acknowledgements

This work was supported by JSPS KAKENHI Grant Number JP 18K04629, 19K01913 and 20K01941.

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