What Drives Innovation Choices in The Small Satellite Industry? The Role of Technological Resources and Managerial Experience

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ABSTRACT

The rapid growth of the small satellite industry has led to many new firm entries and an increased number of innovations. While some companies have focus their innovation efforts on improving the satellite systems, others have devoted their efforts on finding novel applications of small satellites. In this paper, we examine what factors drive companies' innovation choices, and how technological resources and top management team experience influence companies' pursuit of innovation. We categorize innovation choices in terms of products and application innovation. Using data from 196 companies seeking profit in the small satellite industry, we show that while having related technology is positively related to product innovation, having a CEO with more diverse experience is positively related to application innovation. We also find that firms may not be able to pursue product innovation if they don't have the necessary technological ingredients. Innovation choices are important antecedents of companies' innovation performance. By identifying the drivers of firm's innovation choices, results of this paper provide implications for explaining innovation performance.

INTRODUCTION

With the development of the small satellite industry, an increasing number of companies have focused their effort on finding novel applications of small satellites. Data gathered from the space systems have been applied in areas such as agriculture, pharmaceutical, financial trading, navigation etc. Despite the wide use of small satellite technologies, we know little about why these companies focus on satellite applications such as data processing, but not improving the satellite systems themselves. In this paper, we examine what factors drive their innovation choices, and how technological resources and top management team experience influence companies' pursuit of innovation.

When facing new technologcial changes, such as the new trend of big data processing, not all companeis are equiped with the neccesary technological capaiblity and managieral mindset to be successful. This study digs into firms' technological profiles and CEO's prior experience and examines how these factors impact the firm's innovation choices. We collected and analyzed data from 196 companies in the small satellite industry. We categorized innovation choices in terms of products (such as introduction of new launch systems, improved satellite components, and novel ground equipment) or application innovation (finding novel applications of existing satellite products by using big data processing technologies to analyze data transmitted from satellite systems and provide novel implications). In the next sections, we first provide explanations from strategic management theories. We next explain our data sources, empirical measures, and the analytical methods we used to test these theoretical explanations. Lastly, we summarize results and provide implications.

THEORETICAL EXPLANATIONS

The Role of Technological Resources

A company's technological resource is one of the most commonly used predictors of innovation-related outcomes. In this paper, we focus on two aspects of a company's technological resources – technological relatedness and technological diversity. Technological relatedness, defined here as the extent to which a company's knowledge base and the small satellite industry knowledge base cover similar technology domains[1], reflects the degree to which their technological problem solving focuses on the same narrowly defined areas of knowledge[2]. Technological diversity refers to the range or breadth of technologies possessed by a company[3]. It describes whether a company focuses on developing a narrow or a broad range of technologies[4].

We argue that in the small satellite industry, technologically related firms are more likely to pursue product innovation than application innovation for the following reasons: technologically related firms can understand and learn the small satellite technologies faster, and they have more opportunities to use their existing expertise to introduce new products in related

domains. Therefore, technologically related firms are more likely to pursue product innovation. In addition, technological relatedness is less relevant for application based innovations. When firms choose application based innovations, technological relatedness offers less distinct knowledge elements that can facilitate new combinations and novel purposes of applications. The learning advantages surrounding deep industry expertise that are important for product innovations are less valuable. Firms do not need to develop deep industry specific knowledge to find new areas of application.

On the other hand, we argue that technologically diversified firms are more likely to pursue application innovation than product innovation. When firms create innovations by introducing new products in an emerging industry, they need more industry specific knowledge[5]. The benefits provided by technological diversity – superior capabilities to identify and accept new knowledge – are not enough to generate the expertise required for developing industry-specific products. These challenges are amplified where technologically diverse firms are less motivated to devote resources to developing such expertise. Therefore, we argue that technologically diversified firms are less likely to pursue new product innovations in an emerging industry. However, application based innovations require less industry-specific knowledge but more combinative capabilities. Technologically diverse firms have more distinct knowledge elements that can be used for combination. Deep understanding of underlying technologies is not required for application based innovations. This motivates technologically diverse firms to explore application based opportunities from emerging industries.

The Role of CEO Background

Despite the role of technological resources, managers also play important roles in influencing a company's innovation choices. Innovation decisions could be viewed as reflections of the values and cognitive bases of powerful actors in the company. Managerial background such as age, tenure, education, and functional background are shown to predict the firm's innovation decisions and outcomes[6]. In this paper, we focus on the role of CEOs. More specifically, we examine how CEOs' work experiences influence their innovation decision.

We argue that, if CEOs have more related industry work experience (if they have worked in the space industry for a significant period of time, they are more likely to pursue product innovation. CEOs with years of experience in the space industry have accumulate industry-specific knowledge concerning key products on the market, their technological features and potential shortcomings. When they scan information from the external environment – the new emerging industry, they are more likely to pay attention to information that is related to the firm's existing line of products. They may be aware of technologies that advance, add to, or challenge their existing products. As noted by one of satellite industry CEOs: "I have been an aerospace engineer for more than 30 years, and we see there are still a lot of areas that we could improve to build a better satellite".

CEO industry experience diversity, the range or breadth of industries that the CEO has worked in before joining the firm, on the other hand, may decrease the likelihood of pursuing product innovations and increase the likelihood of pursuing application innovation. By serving as CEOs in different industries, they have more knowledge on different industry structures and how to manage firms in different parts of the industry value chain. With this diverse knowledge, they periphery areas to gather industry information. They are more likely to see how the entire industry works, but the technological advancements of specific products may be filtered out. Their perceptions of technological advancement in the emerging industry are more likely to position technologies as tools, but not the end product. As one CEO we interviewed highlighted, "what is so fascinating about this industry are not only the technologies themselves, but also how you can use these satellites in so many different areas. The data they provide is much better in value".

Joint Effect of Technological Capability and CEO Experience

In this section, we develop arguments concerning how CEO experience interacts with technological capability in influencing firm's innovation choices. As argued in the previous sections, if both technological capabilities and CEO's experience are highly related to the emerging industry, then the firm is more likely to pursue product innovation. On the opposite side, if both resource and CEO experience are diverse, then application innovation may be preferred. However, when firm level technological capabilities are not aligned with the CEO's experience, the interactions become more interesting. We proceed to examine how firms make innovation choices if they have related technological resources but the CEO has a diverse background, or if firms have diverse technological resources but the CEO has related industry work experience.

We argue that even though technologically related firms are more likely to pursue product innovation, this likelihood will be reduced if the firm has a CEO with

more diverse experience. On the other hand, even though technologically diverse firms are more likely to pursue application innovation, this likelihood will be reduced if the firm has a CEO with more related experience.

EMPIRICAL METHOD

Data Source

We next test theoretical explanations provided below using data from the small satellite industry. To obtain a list of firms operating in the small satellite industry, we used a database developed by NewSpace Global that provides information on both public and private firms operating in the small satellite industry. The database provides basic information including company founding year, location, industry segments, firm size, their estimated revenue, and NewSpace Global's rating of each firm based on its management team, market assessment, financial situation and technology development. We confirmed with multiple executives in the small satellite industry that this database is widely used, and that they believe the information it provides is accurate, and the ratings are fair. We used NewSpace Global's news database and other space industry focused news websites such as Spacenews.com, Aviationweek.com, and Satnews.com to collect information on firm's new product/service introduction and product/service descriptions.

Since the small satellite industry is a global industry with many firms operating outside the United States, we collected patent information of each firm from the World Intellectual Property Organization's PatentScope base. This database provides more complete information of patent for international firms. To gather data on CEO's background characteristics, we searched LinkedIn.com, company websites, and Bloomberg.com to gather information on the CEO's background and work experience. After removing firms with missing data, our final sample incorporated full information for 196.

Measurement

We measured the dependent variable product innovation versus application innovation using dummy variables indicating that the firm has either introduced a new product that focuses on small satellite components, system integration, ground equipment or control system, launch systems, or applied small satellite technologies to other areas.

Technological relatedness is measured as the overlap of a focal company's patents with those of emerging technologies in terms of patent classes

$$\text{Technological relatedness}=\frac{\sum_k \sqrt{C_{k,A} \cdot C_{k,B}}}{\sqrt{\text{Patents}_A \cdot \text{Patents}_B}}$$

We multiplied the number of patents in patent classes (k) for companies A and small satellite related classes B, summed up the results from every patent class, and then divided the result by the geometric mean of patent portfolio sizes. To identify satellite related patent classes, we followed previous studies and considered the four-digit classes that were assigned to all of the patents of key satellite firms in the sample. Then we ranked these classes based on the number of patents in each class and the number of firms that had patents assigned to them. We considered the top 50 classes to be the satellite classes and calculated the relatedness measure based on the top 50 classes. To illustrate what are the key capabilities in developing satellite technologies, we selectively listed of the top 10 patent classes in Table 1.

Table 1: Top Ten Patent Classes In the Satellite Industry

	Patent Class	Number of Patents	%	Description
1	B64G	253	14.16	Cosmonautics; vehicles or equipment therefor
2	H01Q	224	12.53	Aerials (radiators or aerials for microwave heating)
3	H04B	148	8.28	Transmission
4	G01S	86	4.81	Radio direction-finding; radio navigation; determining distance or velocity by use of radio waves;
5	F02K	59	3.3	Jet-propulsion plants
6	H01P	55	3.08	Waveguides; resonators, lines or other devices of the waveguide type
7	H01M	35	1.96	Processes or means, e.g. batteries, for the direct conversion of chemical energy into electrical energy
8	G05D	34	1.9	Systems for controlling or regulating non-electric variables
9	F01D	24	1.34	Non-positive-displacement machines or engines, e.g. steam turbines
10	H04L	24	1.34	Transmission of digital information, e.g. telegraphic communication

We measured technological diversity using the Herfindahl index, which is calculated as[7]:

$$1-\sum_{i=1}^{k} s_i^2$$

where s_i represents the share of patents in four-digit class i, and k represents the number of different patent classes the firm has filed patent for. The minimum value of 0 represents a firm that has all of its patents filed in the same patent class, and the maximum value of 1 represents a firm that has every patent filed in a distinct class.

CEO experience relatedness is measured as the number of years the CEO of the firm has worked in the space and aviation industry divided by the total number of years this CEO has ever worked. CEO experience diversity is measured as the number of different industries the CEO has worked in prior to joining the firm. For each firm the CEO has work experience with, LinkedIn has its industry classification. We use the industry classification from LinkedIn to identify the number of different industries.

We also include control variables including basic information such as firm age, firm size (average number of employees), and geographic location (headquarters in North America, Asia, or Europe). Performance variables, such as the average estimated revenue of the firm, are also included. NewSpace Global provides its own ranking of all the firms listed in the database based on their investment potential, which we also included as a control variable. NewSpace Global provides its own ratings (from 1-10) in four areas of each firm: market, capitalization, technology, and management team. As these may influence innovation choices, they were also included. Table 2 provides descriptive statistics and definitions for each variable.

Statistically Method

We examined the variance inflation factor and did not find evidence of possible multicollinearity. Since the dependent variable is binary, we use a logit regression model. We also run the analysis using a probit model and obtain similar results. Results of our logit regression analysis are shown in Table 3.

Table 2: Summary Statistics and Variable Definitions

Variable Name	Definition	Mean	Standard Deviation
Product Innovation	Equals 1 if the firm has introduced a new product or services that focuses on small satellite components, system integration, ground equip ment, control system, or launch system, 0 otherwise	0.54	0.5
Application Innovation	Equals 1 if the firm has introduced a new product or services that apply small satellite technology to other areas such as internet service, earth observation etc., 0 otherwise	0.47	0.5
Tech Relatedness	The overlap of a focal company's patent with those of emerging technologies in terms of patent classes	0.16	0.14
Tech Diversity	A Herfindahl index calculated using the share and number of patents in each patent class	0.6	0.31
CEO Experience Relatedness	The number of years the CEO of the firm has worked in space and aviation industry divided by the total number of years this CEO has ever worked	0.82	1.03
CEO Experience Diversity	The number of different industries the CEO has worked in prior to joining the firm	2.63	1.81
Firm Age	The age of the firm in years	22.07	20.55
NSG Rank	The ranking of the firm in the New Space Global Database	273.19	188.87
Avg Emp	Estimated average number of firm employees from the New Space Global Database	474.55	1421.8
NorthAmer	Equals 1 if the firm is headquartered in North America	0.71	0.45
Asia	Equals 1 if the firm is headquartered in Asia	0.06	0.23
NSG MGT	New Space Global's rating of the firm's management team	4.28	1.25
NSG MKT	New Space Global's rating of the firm's marketing capability	4.38	1.2
NSG Capital	New Space Global's rating of the firm's financial capability	4.1	1.41
NSG Tech	New Space Global's rating of the firm's technological capability	4.69	1.5
Avg Rev	Estimated average revenue from the New Space Global Database (in millions of dollars)	24.79	35.58

RESULTS

Results of the logit regression analysis are shown in Table 3 and Table 4. Effect sizes are reported in the Tables. * denotes p<0.1, ** denotes p<0.05, and *** denotes p<0.01;

Table 3: Logit Regression Results

	Model 1	Model 2	Model 3
	Product	Product	App
Tech Relatedness		3.408**	-3.357**
Tech Diversity			0.105
CEO Related Exp			
CEO Diverse Exp			
*Tech Related * CEO Diverse*			
*Tech Diversity * CEO Related*			
Firm Age	0.005	0.007	-0.006
NSG Rank	0.004	0.004	-0.003
Average employees	0.000	0.000	0.000
NorthAmer	0.209	0.213	-0.197
Asia	1.638	1.767	-1.713
Managment NSG score	0.238	0.184	-0.193
Market NSG score	0.37	0.302	-0.285
Captilization NSG	-0.465*	-0.431	0.435
Technology NSG sore	0.473*	0.445*	-0.437
Average Revenue	-0.003	-0.002	0.001
Constant	-4.2	-4.199	4.008
N	196	196	196
chi square	25.49	34.58	33.53
Pseudo R square	0.0945	0.1282	0.1251

In Table 3, Model 1 contains all control variables; Models 2 and 3 tests for the explanatory power of technological capability; In Table 4, Models 4 and 5 add the effects of CEO experience; Models 6 and 7 additionally show the joint effects. With regard to the goodness-of-fit statistics, the chi-square estimates associated with all models are highly significant (p<0.05 for Model 1, and p<0.001 for Model 2-7). The pseudo R^2 also shows that each subsequent model is significantly better than the preceding model.

Model 1 shows the effect of control variables on firms' innovation choices. We found that a firm's capitalization rating is negatively related to its likelihood of pursuing product innovation (-0.465, p<0.1), and a firm's technological rating is positively related to its likelihood of pursuing product innovation (0.473, p<0.1). It is likely that firms with more financial resources could take more risk to experiment with application innovation, and firms with stronger technological resources have more technological ingredients for them to pursue product innovation.

Table 4: Logit Regression Results (Continued)

	Model 4	Model 5	Model 6	Model 7
	Product	App	Product	Applicati
Tech	2.105*	-2.762**	0.490	-0.369
Tech Diversity	-0.265	0.366	-0.222	1.534
CEO Related Exp	1.259***	-0.923***	0.937***	-0.288
CEO Diverse Exp		0.521***	-0.667***	0.639***
*Tech Related * CEO Diverse*			1.737	-1.711
*Tech Diversity * CEO Related*				-1.490**
Firm Age	0.018	-0.007	0.005	-0.011
NSG Rank	0.006	-0.006	0.005	-0.007
Average	0.000	0.000	0.000	0.000
NorthAmer	0.543	-0.464	0.501	-0.469
Asia	1.796	-1.579	1.355	-1.318
Managment	0.463	-0.304	0.288	-0.413
Market NSG	0.593*	-0.595*	0.585	-0.562
Captilization	-0.373	0.396	-0.404	0.328
Technology	0.486	-0.467*	0.469*	-0.557**
Average	0.000	-0.000	-0.000	0.000
Constant	-8.930	6.186	-5.582	6.622
N	196	196	196	196
chi square	59.46	76.57	78.26	81.90
Pseudo R square	0.2218	0.2944	0.3009	0.3149

Model 2 tests effect of technological relatedness. As hypothesized, technological relatedness is positively related to the likelihood of pursuing production innovation (3.408, p<0.05). Its effect is consistent across Model 2-5. Model 3 tests the relationship between technological diversity and a firm's likelihood of pursuing application innovation. We argued a positive relationship between technological diversity and application innovation. While the sign of the coefficient is positive, it is not statistically significant (0.105, p>0.10). Therefore, we did not find support for this argument.

Model 4 tests the effect of CEO industry experience relatedness. We propose that CEOs with more related industry experience are more likely to pursue product innovation. Results in Model 4 supports this argument (1.259, p<0.01). We argued that CEOs with more diverse industry experience are more likely to pursue

application innovation. Results in Model 5 support this argument (0.521, $p<0.01$).

Models 6 and 7 examine the interactions between technological resources and CEO experience. We argued that CEO industry experience negatively moderates the relationship between technological relatedness and a firm's likelihood of pursuing product innovation. Yet, as shown in Model 6, the coefficient for the interaction term is not in the predicted sign (1.737, $p>0.1$). Lastly, Model 7 tests the moderating effect of CEO experience relatedness. As shown in the model, CEO experience relatedness negatively moderates the relationship between technological diversity and application innovation (-1.490, $p<0.05$).

Overall, the results show that technological relatedness has a strong positive effect on product innovation (Models 2-5). Yet, this positive relationship becomes non-significant when the interaction term of CEO experience is added (Model 6-7). We did not find a significant effect of technological diversity on application innovation. On the CEO experience side, results showed that CEOs with more related experience are indeed more likely to pursue product innovation (Model 4-6), but after adding the interaction term, the independent effect of CEO related experience becomes non-significant. CEO experience diversity showed a consistent positive effect on application innovation, even after adding the interaction term (Model 5-7). CEOs' related experience reduces technologically diverse firms' likelihood of pursuing application innovation.

CONCLUSIONS

Results show that while having related technology is more important for product innovation, having a CEO with more diverse experience is more important for application innovation. We also find that firms may not be able to pursue product innovation if they don't have the necessary technological ingredients. Moreover, pursuit of application innovation improves when CEO's experience which shapes the mindset and vision for the firm. More specifically, if the company has more satellite related patents, then they are more likely to focus on introducing new satellite products. However, this effect weakens when the company also has a CEO with diverse industry work experience. On the other hand, companies with more diverse patents pursue more application innovations, but this effect is reduced for firms that have CEOs with more satellite related industry experience.

Innovation choices are important antecedents of firm's innovation performance. We believe the distinction between product versus application innovation is a novel and meaningful distinction and show that different factors drive firms' innovation choices. The growth of small satellite industry is driven by the wide range of applications of the focal product – because the technology could be used and applied in many different areas, it generates growth potential and attracts more firms to enter into the industry. By identifying the drivers of firm's innovation choices, we explain why and how firms differ in their innovation success.

References

1. Frankort, H. T, "When does knowledge acquisition in R&D alliances increase new product development? The moderating roles of technological relatedness and product-market competition," Research Policy, vol. 45, No.1, 2016
2. Makri, M., Hitt, M. A., and Lane, P. J, "Complementary technologies, knowledge relatedness, and invention outcomes in high technology mergers and acquisitions", Strategic Management Journal, vol. 31, No. 6, 2010
3. Patel, P., and Pavitt, K, "The technological competencies of the world's largest firms: complex and path-dependent, but not much variety", Research Policy, vol. 26, No. 2, 1997
4. Argyres, N, "Evidence on the role of firm capabilities in vertical integration decisions", Strategic Management Journal, vol. 17, No. 2, 1996
5. Balasubramanian, N, "New plant venture performance differences among incumbent, diversifying, and entrepreneurial firms: the impact of industry learning intensity", Management Science, vol. 57, No. 3, 2011
6. Alexiev, A. S., Jansen, J. J., Van den Bosch, F. A., and Volberda, H. W, "Top management team advice seeking and exploratory innovation: The moderating role of TMT heterogeneity", Journal of Management Studies, vol. 47, No. 7, 2010
7. Lahiri, N, "Geographic distribution of R&D activity: how does it affect innovation quality", Academy of Management Journal, vol. 53, No. 5, 2010