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Abstract

How do advanced materials ventures overcome the daunting commercialization challenges of the sector: high technology and market uncertainty over long time frames, and the need for significant complementary assets and substantial financing? Does uncertainty enhance or obstruct value creation? To address these questions, this paper draws on research on value creation, technology commercialization, and, more specifically, advanced materials commercialization, and presents new evidence from a sample of 43 advanced materials ventures. The sample ventures are compared and analyzed to elucidate risk reduction and value creation strategies. The sample is subdivided into nanomaterials, performance materials, and fuel cell ventures through a hierarchical cluster analysis, and subgroup commercialization metrics are described and compared.

We argue that embracing uncertainty enhances value creation for nanomaterials and performance materials ventures but diminishes value creation for fuel cell ventures. High value creators in our sample lend further support to this argument through their commercialization strategies: reduction of uncertainty by fuel cell ventures, and embracing uncertainty by nanomaterials ventures. All of the successful advanced materials ventures commercialize radical technologies, emphasize strategic alliances, and begin demonstrating value with near-term, substitution applications.

Keywords: Value Creation, Generic Technology, Radical Innovation, Technology Entrepreneurship, Advanced Materials, Technology Commercialization, Value Chain Positioning, Market for Technology, Uncertainty, Nanomaterials

1. Introduction

Like information technology and biotechnology, advanced materials technologies are viewed as a stimulus to economic growth and as an enabler of further technological innovation (Oliver, 1999; OECD, 1998). Radical innovation in advanced materials has the potential to make a significant impact on an extensive range of markets, industries and applications, including those within the biomedical, environmental, consumer electronics, energy, aerospace, and automotive sectors. However, large firms are often reticent to initiate radical innovation, preferring to acquire successful start-up ventures. Thus, there is a need to understand the strategies of new ventures in developing, commercializing and exploiting radical advanced materials technologies.

Despite the potential for growth, new ventures commercializing advanced material technologies face daunting challenges, including high technology and market uncertainty for extended time frames, and the need for substantial financing and complementary assets in order to develop technology to a point where it can create, and ultimately capture, value (Maine and Garnsey, 2006). This paper aims to demonstrate how, despite these challenges, value has been created by such ventures. We start with a literature review. Next, we present evidence from a sample of 43 advanced materials ventures and replicate the value creation model of Maine and Garnsey (2006). Following arguments about the heterogeneity of advanced materials ventures, we use hierarchical cluster analysis to divide the sample ventures into the three subgroups of nanomaterials, performance materials, and fuel cells, and compare characteristic features of each of these categories. High value creating ventures from the sample are analysed to identify alternative strategies for value creation in this sector. These value creation strategies are then discussed in the context of technology commercialization literature.

2. Literature review

In the following sections, we review the literature most relevant to our study. First, the value creation literature is reviewed, with a focus on value creation by new technology based firms. Second, the technology commercialization literature is reviewed. Third, the sparse literature on value creation by advanced material ventures is reviewed.

2.1 Value Creation

Proponents of resource based theory argue that firms' value creation and capture is explained by internal resources and capabilities (Penrose, 1959; Barney, 1991; Leonard, 1998) and the ability to alter existing capabilities rapidly to suit changing market conditions (Penrose, 1959; Teece et al., 1997; Eisenhardt and Martin, 2000), but these theories are more relevant for established firms, with established resources and capabilities. For a new technology venture, value creation can be better explained by aspects of a venture's commercialization strategy, such as its business model (Amit and Zott, 2001; Chesbrough and Rosenbloom, 2002), the applications it targets (Shane and Venkataraman, 2000), its access to complementary assets (Teece, 1986) and its location (Maine, Shapiro and Vining, 2010).

Value has been defined in a wide variety of ways, often linked to resource utilization (Amit and Schoemaker, 1993; Bowman and Ambrosini, 2000) or the satisfaction of needs (Peteraf and Bergen, 2003; Prahalad and Ramaswamy, 2004). We propose that value creation by technology ventures involves the development of useful artefacts, such as patents, prototypes, commercialized products, or tradable (scientific, design, or production) expertise, and that the latter two artefacts are stronger indicators of value creation for technology ventures than the former two.

Value creation has also been measured in a number of ways, including the difference between inputs and outputs, the number and importance of patents, prototype development, product commercialization, employee growth, revenue generation, rate of growth of revenues and initial public offering (IPO) capitalization (Utterback et al., 1988; Cooper, 2003; Stuart and Sorenson, 2003; Katila and Shane, 2005; Hicks and Hedge, 2005). Revenues generated through market exchange are an objectively quantifiable measure of relative value creation and are stronger evidence of commercialization than alternative artefacts. For an investigation of successful R&D practices, highly cited patents are an excellent indicator; however, for an investigation of successful commercialization strategies, patents are not sufficient. As such, revenue generation and revenue growth are the preferred proxies for value creation by technology ventures (Utterback et al., 1988; Zahra, 1996; Almus and Nerlinger, 1999; Pries and Guild, 2007; Maine, Shapiro and Vining, 2010).

Firm patents and patent citations have also been proposed as a proxy for value creation by technology ventures (Hagedoorn and Cloodt, 2003). However, Giummo (2003) and Scherer et al. (2000) present evidence that only a small fraction of patents actually create value through either high citations or through successful commercialization of the invention. There are also several difficulties with using patent citations as a proxy for value creation. First, to capture highly cited patents in a comparative manner, one needs to leave a substantial time lag. Secondly, a patent can be highly cited and yet never commercialized in a manner that brings revenue to a technology venture. Some firms rely on SBIR awards to consistently develop patents (some of which are highly cited) without commercializing these technologies. Third, any relationship between patent citations and new product announcements differs largely by industry sector (Hagedoorn and Cloodt, 2003). Fourth, although patent citations are an appropriate metric for identifying firms with high quality R&D and high raw potential for commercialization, they have little or nothing to do with management or with commercialization strategies. When the research objective is to identify technology ventures with superior commercialization strategies, a success metric that reflects commercialization must be used.

2.2 Technology Commercialization

The key strategic choices firms make when commercializing technology regard the selection of target markets and applications, how broadly to attempt to commercialize technology, whether to participate in the product market or the market for technology, and whether to forward integrate along an industry value chain by acquiring or developing complementary assets. Market exploration or “matching” is a key capability of entrepreneurial companies (Penrose, 1959; Freeman, 1982). In particular, market selection is critical for ventures commercializing generic technology as different markets have different innovation ecosystems (i.e. all of the organizations who contribute to R&D, design, product commercialization and distribution for a new product and its complements) with differing levels of market uncertainty (Adner, 2006). Market uncertainty is decreased by choosing to target markets and applications where no complementary innovations are required before a technology can be commercialized (Adner, 2006). Market uncertainty is also reduced if the enabled product does not require new skill sets from customers, and if the enabled product attributes are easily observed and trialled by the consumer (Rogers, 1983). Near term substitution applications lower both technological and market uncertainty relative to emerging applications (Leonard, 1998).

Value creation and capture are also influenced by the breadth of markets in which a firm commercializes its technology. Neckar and Shane (2003) recommend attempting to commercialize technology in many distinct markets, arguing that this will improve value capture and reduce market uncertainty by giving more chances for success. Gambardella (2008) argues that a firm will maximize value capture by licensing broadly outside of its core market. In contrast, Davidow (1986) recommends a narrow focus, and that a firm should only enter markets where it is confident that it can capture at least 15% of the market. Financial constraints limit the number of markets most ventures can target, especially if the venture also needs to forward integrate and if customer needs and industry ecosystems vary widely between those markets (Maine and Garnsey, 2006).

The market for technology is the market for selling or licensing technology between firms (Gans and Stern, 1993; Arora et al., 2001; Pries and Guild, 2007). Participating in the market for technology generally captures less value than manufacturing products from the technology, but is an especially attractive option for new technology ventures without all of the required capabilities or complementary assets. Strong intellectual property rights are essential for this commercialization strategy (Teece, 1986; Gans and Stern, 1993; Arora et al., 2001). Gambardella (2008) recommends licensing a generic technology into any markets where it will not impinge on a firm's core market profitability, and argues that licensing becomes more attractive in fragmented markets. **Table 1** summarizes several scholars' rationale for choosing the market for technology over the product market.

Firms also make a strategic choice as to how far downstream[1] to integrate into the industry[2] value chains[3] of each of their target markets[4]. Christensen et al. (2004) argue that there is an optimal degree of forward integration – the decoupling point – beyond which all the design

[1] In an industry value chain, upstream activities are further removed for the end consumer than downstream activities.
[2] We use Nightingale's (1978) definition of industry as: "...any grouping of firms which operate similar processes and could produce technically identical products within a given planning horizon."
[3] An industry value chain is a representation of all of the activities required to convert basic inputs into a solution for the end consumer (Porter, 1985).
[4] By market, we refer to potential buyers (and existing sellers) in a unique industry segment, such as automotive, consumer electronics, biotech/healthcare, sporting goods, energy, etc. We define market in this way as the potential alliance partners and desired product attributes vary significantly between these divisions, whereas they do not vary as significantly between applications within, for example, consumer electronics.

and manufacturing interdependencies in an industry value chain are predictable. Thus, downstream integration of activities (as far as the decoupling point) reduces uncertainty as well as increasing value capture. If the decoupling point happens to occur directly after a firm's intellectual property, licensing would be optimal.

Along with target market selection, revenue model choice, value chain position, and breadth of market focus also impact the uncertainty faced by a venture. Participating in the market for technology rather than the product market allows a venture to share uncertainty with its licensees (Teece, 1986). On the other hand, forward integration to the decoupling point in any chosen market is also recommended as a method of reducing the uncertainty faced by a firm (Christensen et al., 2004). Similarly conflicting messages are argued about the breadth of market focus (Shane, 2004; Gamberdella, 2008; Davidow, 1986; Maine and Garnsey, 2006), as summarized in **table 1**.

Value creation strategies can vary widely by industry or by technology sector (Amit and Zott, 2001; Nerkar and Shane, 2003; Chesbrough and Rosenbloom, 2002; Pisano, 2006). Earlier research by the authors showed that sector specific commercialization challenges are faced by advanced materials ventures, and that an advanced materials venture differentiates itself through its response to sustained technology and market uncertainty, through its strategies for reducing the risk of failure, and its ability to access financing and complementary assets (Maine and Garnsey, 2006). These arguments are briefly reviewed in **section 2.3**.

2.3 Value Creation by Advanced Materials Ventures

High levels of technology and market uncertainty have been found to have a negative influence on an advanced materials venture's ability to demonstrate value in a specific application, and thus on value creation (Maine and Garnsey, 2006). These uncertainties are highest at firm founding and gradually taper off until becoming significantly reduced after a firm has commercialized their first product, typically 10-15 years (Maine and Garnsey, 2007). At the firm level, high levels of technology uncertainty are influenced by the radical and generic nature of the technology, multiple market selection, and by the need for customer process innovation. High levels of market uncertainty are influenced by the value chain position of advanced materials ventures, the need for complementary innovation, and the continuity, observability and trialability of the advanced materials innovation. Each of these factors is depicted in **figure 1** and the effects on uncertainty are summarized in **table 2**.

The generic nature of advanced materials technology allows for applications in multiple markets. However, targeting multiple markets increases the technology uncertainty faced by a venture because the utility of product attributes varies widely for customers in different markets, as do regulatory hurdles and the need for customer process innovations (Maine and Ashby, 2002). Focus on a single target market, and thus on a relatively known combination of targeted product attributes, allows a venture to allocate resources and development efforts most efficiently. Beyond the innovation imbedded in the material or component created by the venture, technology uncertainty encompasses other process innovations required to enable the end product.

Market uncertainty is influenced by the need for complementary innovations within each industry ecosystem (Adner, 2006), the value chain position of a firm (Christensen et al., 2004), and lack of observability, trialability and continuity (Rogers, 1983). At the technology level, the vast number of potential target markets is another key source of market uncertainty in the commercialization of advanced materials technology (Maine and Ashby, 2002; Maine and Garnsey, 2006). Market choice and the decision of how many markets to target is a large bet, as development cycles are long and complex; moreover, alliance partners and customers seldom span market sectors. However, at the firm level, the additional value capture potential of each additional market is counterbalanced by the additional development costs, technological complexity, and diluted management and R&D focus of this strategy.   Thus, although a firm's decision to target a single market or multiple markets does not have a direct impact on increasing a firm's market uncertainty, finance plays a constraining role, and most small advanced materials ventures would run out of cash before simultaneously and rigourously exploring multiple markets. This leads to an indirect impact of multiple markets on market uncertainty at the firm level.

In order to overcome these technological and market uncertainties, advanced materials ventures need substantial financing and access to complementary assets. These financial resources can come from a range of sources including angel investors, government grants, corporate investors, venture capital and publicly held shares. Complementary assets (such as product design, volume production, distribution and market research capabilities) can be sought from incumbent chemical and materials firms and/or from component suppliers and OEM manufacturers. However, venture capitalists, corporate investors and strategic alliance partners are unlikely to commit any resources until value has been demonstrated to them in a specific application (**figure 1**).   Once sufficient financing and complementary assets have been secured, demonstration of value through viable prototype products is much easier to achieve. Thus, sufficient financing and access to complementary assets are mediating variables in value creation by advanced materials ventures.

3. Methodology

All of the relevant advanced materials firms that could be identified in five high-tech clusters in the US, UK and Canada were contacted for interviews. In the high-tech clusters surrounding

Boston, San Francisco, Cambridge, Vancouver, and Toronto, 64 advanced materials ventures[5] were contacted between 2002 and 2006, and 45 of those firms agreed to be interviewed. Interviews were conducted with founders, CEOs, COOs and/or chairmen in order to access information regarding both quantitative data and first hand experience at navigating sector specific challenges. The interview data was supplemented with publicly available quantitative data[6] including number of patents and estimates of revenue and employment numbers. Two firms were removed from the sample during the analysis stage, leaving 43 firms**.**[7]

A number of ratings and proxy measures were used to operationalize the model's variables: these are discussed below. To search for commonalities, patterns and replicability of Maine and Garnsey's (2006) value creation model, those variables were analyzed both with simple linear regression, and with statistical marketing software.[8] Because this data was not normally distributed and because it has been argued that the advanced materials sector is too heterogeneous to treat as a single entity, cluster analysis was employed to examine and compare the firms. The firms are grouped by shared characteristics rather than relying on linearity or set degrees of variance (Guild and Pries, 2007). Hierarchical cluster analysis was used to divide the sample ventures into clusters by measuring the distance between pairs of observations. This technique produces a dendrogram (**figure 2**) and an accompanying output which indicates which variables, or model attributes of the sample firms, had the most influence on the clustering of the sample firms.

[5] We contacted ventures if their primary focus was conducting advanced materials R&D and/or developing materials R&D intensive products and if they had more than 5 employees.
[6] through such secondary sources as Lexis Nexis, Dun and Bradstreet, and www.uspto.gov
[7] One firm was removed because it failed shortly after the beginning of the study, and thus growth metrics could not be established and further data could not be collected. The other firm was removed from the sample because it was actually an amalgamation of established players in the composites and advanced materials industry.
[8] The software used for this analysis was R Commander.

This hierarchical cluster analysis, [9] and a k-means elbow plot[10] used to cross-check the outcome, indicated that the sample firms could be best grouped into three clusters to balance meaningful differences between clusters and minimization of information loss at each successive grouping. By examining the ensuing clusters, we observed that the type of materials in each was fairly distinct. The first branching separates performance materials ventures[11] and nanomaterials ventures from fuel cell ventures. This indicates a significant difference between the overall mix of variables amongst the fuel cell companies and more similarities between performance and nanomaterials as groups. The most influential attributes of firms in this clustering were access to complementary assets, lack of continuity, observability and trialability of the product, number of markets targeted and need for complementary innovations. The differences in these attributes are described in **section 5.2**. Because our sample size is small, the subgroups are not statistically significant, but are valuable for observing patterns amongst the firms, and, as such, are used in our sample analysis.

Subsequent analysis tested whether relationships existed at the full sample level and at the sub-group level. Because of the complex and interdependent nature of the variables investigated (**figure 1)**, we would not expect to find simple, linear relationships. The patterns and trends we find are interpreted in light of existing literature and then further illuminated by the case studies.

Proxies were created for the variables depicted in **figure 1**. Proxy scores for these model variables were created from primary and secondary source data gathered on each venture. The

[9] Hierarchical cluster analysis uses an algorithm to sort each data point into successive clusters based on a selection of variables. This produces a dendrogram diagram, a tree-like structure that depicts the clustering and indicates the relative improvements given by each branching.
[10] For clustering, *k* generally indicates the optimal numbers of clusters to examine, ie, the number that best models the data without losing all details in one cluster or maximizing accuracy by giving each point its own cluster. An elbow plot visually models the percentage of variance explained by the clustering against the number of clusters. When the marginal gain for adding additional clusters drops, this indicates *k*.

variables which required coding from the authors were the radical nature of the technology, access to complementary assets, position in industry value chain(s), and lack of continuity, observability, and trialability. These were assessed through press release information and partnership information from publicly available sources, and through interview notes. For example, for access to complementary assets, the authors would identify alliance partners, assess complementary assets held by different partner firms, assess the depth of the partnership relationship indicated by press releases, and translate these assessments into a rating of no access, limited access or high access to required complementary assets. Two of the authors coded the data independently, according to the scoring system outlined in **table 3**, and arrived at levels of intercoder consistency of 91%, 88%, 84%, and 86% respectively, all of which meet the required level of intercoder reliability (Cohen, 1960; Pries and Guild, 2007). For those firm's variables where we differed, we agreed upon a mutually acceptable coding.

The factors chosen to estimate technology uncertainty and market uncertainty were those identified in **figure 1** and discussed in **section 2.3**. Technology uncertainty was proxied for each firm by the sum of their scores for radical technology, required process innovations and multiple markets, divided by the theoretical points possible: each firm was then ranked relative to the other firms in the sample from low uncertainty to high uncertainty. Market uncertainty was proxied by the sum of the scores for lack of continuity, observability and trialability, upstream position and need of complementary innovations, divided by the theoretical points possible: again, each firm was then ranked relative to the other firms in the sample from low uncertainty to high uncertainty.

A proxy score for access to finance was calculated by ranking and summing the various sources of financing each venture had achieved. Each venture was allocated one point for angel

[11] The term "performance materials" refers to polymer, ceramic, and metallic materials with electronic, lightweight

financing (and/or minor government grants), one point for SBIR grants, two points for public venture funding, two point for direct corporate venture investment, and four points for venture capital funds for a score out of ten. These weightings were chosen because of their relative difficulty of achievement and the typical amount of funds achieved through each. Using only one of these finance sources would have been simpler and more elegant, but would have excluded relevant sources of funding. A better metric would have been total funds raised by each of these ventures, but that data was unobtainable for the complete sample.[12]

Demonstrated value in a specific application is a variable that is very difficult to observe objectively. We gathered data on prototype development and use it in our descriptive analysis (**section 5.1**). However, as all but one venture in our sample had developed a prototype, it was not a good differentiator. A rating of the quality of prototypes prepared or a comparison of existing and newly provided performance attributes for substitution applications would be the most desirable proxies, but the former is extremely difficult to objectively determine and the latter omits emerging applications. Thus, patents provide the best available proxy for this model variable. We assume that the higher the number of patents a firm has produced, the greater the likelihood that it has demonstrated value in one or more specific applications. US patents were assessed for all firms in the sample, to have a single method of comparison. Although most firms patent in the lucrative US marketplace, it might be expected that this measure would be biased towards US firms. In fact, US companies are only slightly over represented in terms of the number of US patents issued to them: US ventures comprise 56% of the sample while holding 62% of the total patents in the sample. The UK is 19% of the sample, holding 16% of the patents while Canadian ventures are 25% of the sample and hold 22% of the patents.

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structural, environmental and/or cost performance advantages.

[12] This data was gathered for a subset of the sample and was consistent with the results of our analysis.

Finally, the outcome variable, value creation, has been measured by scholars in many differing ways, including through the number and/ importance of patents, prototype development, products commercialized, and through metrics such as employee growth, revenue generation, rate of growth of revenues and time to IPO. Despite this diversity, the preferred proxies for value creation by technology ventures are revenue generation and revenue growth (Utterback et al., 1988; Zahra, 1996; Almus and Nerlinger, 1999). As the technology ventures in our sample are built around the advanced materials technologies we are observing, firm revenues reflect commercialization of this technology. Revenues are an indicator of value delivered to customers who would not otherwise purchase the product. Revenues are not an indicator of value captured, as revenues measure what customers pay for deliverables by the firm, and do not take into account costs the producer incurred. However, given the early stage of these advanced materials ventures – most of which are privately held – comparing profitability was not a viable option.

Because of the emergent nature of this sector and the varied ages of the firms in our sample, we use revenue growth as our primary proxy for value creation. Our measure of revenue growth evaluates the growth in revenue which has occurred since the firm was founded in its current form. Because revenues are frequently irregular for early stage technology ventures, we took an average revenue over 4 years and divided that by the age of the firm. Hence, our value creation measure becomes (avg.(2005- 2008 firm revenue)) / (firm age). This success metric is similar to one used by Utterback et al. (1988) to assess long term success in a sample of technology ventures.

We chose to use the age of the firm in its current form, as that date was closest to when these technologies began to be the focus of the efforts of the firm. For example, some of the technologies, in particular the performance materials technologies, were incubated within a larger organization, and then either a smaller venture was spun off to commercialize the radical technology or the focus of the entire firm was shifted to concentrate on commercializing the radical technology. This is analogous to a technology incubated within a government lab or a university lab before a new venture was formed to commercialize the radical technology.

4. Sample of Advanced Materials Ventures[13]

Although all advanced materials ventures, there is significant variation amongst the firms in our sample. The technologies and products these ventures are developing range from carbon nanotubes for consumer electronics, drug delivery, and energy storage application, to biological scaffolding for surgical procedures, and to magnetic nanoparticles for water purification. The sample also includes materials intensive fuel cell companies.

The advanced materials ventures in our sample are all relatively small in size. As shown in **figures 3a** and **3b**, 91% of the ventures interviewed had less than 100 employees, and all had less than $100 million in annual revenues. Notably, 40% of the firms had between 5-19 employees and 37% of the firms had between 20-49 employees. In terms of revenue generation, the majority of the sample of firms (58%) had less than $5 million in annual revenue, while 9% had $20-$50 million, and only 5% of the firms had $50-100 million in annual revenue.

The majority of our firms are also relatively new: the median firm age[14] of the sample was 7 years in 2006. At the time our interviews were completed, 67% of the 43 firms had been founded within the previous decade. However, the 26% of firms in the sample which were founded 20 or more years ago[15] provide evidence of the long timelines involved in advanced materials commercialization, as, by 2006, 82% these older sample companies were still earning

[13] This information was compiled from the authors' primary source interviews from 2002-2006, supplemented with information from company websites and other secondary source information.
[14] Age in current form. Median age from original founding is 10 years.
[15] Of these more established firms, only 45% have been in their current form for more than 20 years.

less than $15 million in annual revenue. The vast majority of the firms were independent start-ups.

5. Analysis

The ventures in our sample were mainly in the early stages of commercialization despite a quarter of them being founded over 20 years ago. Although most of the ventures in our sample had yet to capture value or profit from their business activities, all of the ventures had begun to create value. The model we employ describes a series of relationships between the variables that affect value creation (**figure 1**). **Section 3** and **table 3** describe the proxies we use for these variables. Through hierarchical cluster analysis of these proxies, the sample is divided into three sub-groups to give an indication of differing impacts within the sample, based on firm type. This section provides descriptive statistics from the sample, replicating the Maine and Garnsey (2006) value creation model. Further, the sample is analyzed along the three sub-groups to reveal differing characteristics and differing value creation strategies. The correlation of four key variables with value creation is analyzed, both for the entire sample and for the sub-groups.

5.1 Technology and market uncertainty

Figure 1 depicts the factors which contribute to technology and market uncertainty, including the radical and generic nature of technology, the need for process innovation, the need for complementary innovations, and the upstream position of many advanced materials ventures in the value chain of their target industries. This study provides supporting evidence of how prevalent these variables are in advanced materials ventures. We summarize that evidence here and in **table 4**. In **section 6** and **table 6** we provide evidence of how these variables impact value creation.

Radical technologies are those with the potential to have a high impact on the market in terms of offering “dramatically better product performance or lower production costs, or both” (Utterback, 1994, p. 158). Radical innovation involves more highly qualified scientists and engineers, more external linkages, more capital, longer timelines, and greater risk and uncertainty than incremental innovation (Colarelli O’Connor and Veryzer, 2001; Leifer et al; 2000; Rothwell and Dodgson, 1991). 67% of the sample ventures are commercializing radical technologies, the other 33% of ventures are commercializing technologies that are somewhat radical, in that the technologies enable improvement in known attributes or cost reduction and also overturn existing incumbent technology and production competencies. Thus, the sample ventures have the potential to significantly improve existing products and processes.

Generic technologies have a wide breadth of applications across industry sectors and thus great value creation potential (Keenan, 2003; Martin, 1993; Turner et al., 1990). Examples of generic technologies include steam power, telecommunications, information technology, and advanced materials (Maine and Garnsey, 2006; Rosenberg and Trajtenberg, 2004; Bresnahan and Trajtenberg, 1995). 63% of the sample ventures targeted markets in multiple industries, including the 33% of the ventures which target applications in three or more industries. This is taken as evidence both of the generic nature of advanced materials and the need for dynamic capabilities in scanning and opportunity recognition.

In addition to basic research and invention, commercialization of a radical materials innovation requires expensive process innovation, prototype development and pilot plant development, and often complementary innovations (Williams, 1993, p. 43-44; Hounshell and

Smith, 1988, pp. 262-268, 431-432). In addition to the initial process innovations involved with their own development of new materials, 63% of the materials ventures required downstream process innovations by their customers in order to commercialize their technology. All but one of the firms (98%) were competing with established substitutes in at least one of their target markets. And 70% of the sample ventures required complementary innovations in order to commercialize their technology.

Technology ventures can employ a licensing, manufacturing, service, or hybrid revenue model, and can operate from an upstream or downstream position within an industry value chain. Commercializing a product from an upstream position requires interdependencies with downstream firms, and raises difficulties in assessing consumer needs and problems with managing market experimentation and feedback (Adner, 2006; Christensen et al. 2004). 65% of the advanced materials ventures interviewed by the authors were positioned upstream in their chosen value chains; 90% of the performance material ventures, 78% of the nanomaterials ventures and only 33% of the fuel cell ventures. Of the ventures that were positioned upstream, 35% had two or more intermediaries between themselves and the end consumer. Of these ventures, 40% were performance materials ventures and 60% were nanomaterials ventures.

Many advanced material firms face a lack of continuity, observability and trialability. Their innovation may overturn production capabilities, be difficult for potential customers to observe in use, and/or be difficult for potential users to try before purchasing (Rogers, 1991). All of the ventures faced some lack of continuity for some players further down the value chain, in that the product is either discontinuous from the manufacturer's perspective or that end consumers had difficulty observing the product's benefits and trial products before wide spread use. Most of the ventures (70%) faced these barriers with *either* the manufacturer or the mainstream customer. The remainder of the ventures (30%) faced these barriers with *both* the manufacturer and the mainstream customer. Of those ventures that were facing the highest level of these barriers to adoption, 62% were nanomaterials companies and 31% were performance material companies.

By analyzing these factors which contribute to technology and market uncertainty, we found that 70% ventures in the sample faced medium-high to high technology uncertainty at founding, and 40% of these ventures faced this level of technology uncertainty combined with a medium-high to high level of market uncertainty. The model proposes that successful ventures overcome such sustained high levels of technology and market uncertainty through substantial financing and access to complementary assets. To achieve and maintain this financing and partnership, a firm must usually demonstrate value in specific applications. The manner in which these ventures approached commercialization challenges is summarized in **table 5**.

Governments, in the US in particular, have assisted the advanced materials commercialization process through many firms' early product and process development (Turner et al, 1990; Williams, 1993), and 63% of the companies in the sample have received some sort of government funding and/or contracts. In particular, of the 24 ventures in this sample eligible for the generous US SBIR awards[16], 16 had achieved it. But government funding is generally insufficient financing to enable an advanced materials venture to create substantial value through the commercialization of products. Value creation in this sector usually requires further financing, either through angel investors, direct corporate investment or venture capitalists (VCs). In our sample, 19% of the ventures had achieved direct corporate investment, while 49% companies in the total sample had achieved VC funding. Despite almost two thirds of the

[16] SBIR has 3 levels of awards. Phase I SBIR awards are of the lowest amount (typically $75 K) and are for early stage technology development. Phase II SBIR awards are larger (typically $500K) and generally require a prototype of the technology to be produced. Phase III SBIR awards constitute a contract from a US government department with product deliverables required.

ventures receiving government funding and half the ventures achieving VC financing, 69% of ventures identified financing as a significant or dominant strategic constraint.[17]

Financial requirements vary by revenue model, with the market for technology being less resource intensive than the product market. Among the sample companies, five declined to divulge their revenue models. Of the remaining 38 ventures, 76% participate in the product market, employing either a manufacturing or an outsourced manufacturing revenue model in an attempt to appropriate more of the value created. Many of the ventures also participated in the market for technology, with 13% employing a service revenue model (always in combination with manufacturing) and 37% relying on licensing revenues (less than half of these ventures employed solely a licensing revenue model). Nearly half of the ventures employed a hybrid revenue model comprising two or more models.

Irrespective of revenue model, government, angel and VC financing is insufficient to enable most ventures to create value unless the venture also has access to external complementary assets through alliance partners. Such partnerships appear to be a prerequisite of venture capital financing in this sector. In our sample, 91% of the ventures had established alliance partnerships which could offer them some access to complementary assets. These partnerships included relationships with suppliers, intermediate component manufacturers and/or potential customers. Of these ventures with alliance partnerships, 63% had substantial access to complementary assets, signifying access to markets, manufacturing or scale up facilities, usually in addition to finance.

In order to secure these alliance partners with complementary assets and to achieve financing, the model points to the importance for these ventures of demonstrating value in a

[17] As 8 ventures did not respond to this question, in this instance, 69% means 24 of the 35 ventures who answered

specific application. Of our overall sample ventures, all but one have developed at least some stage of prototype with which to demonstrate value in a specific application to partners, an early indication of future value.. Of the sample ventures, 23% had not commercialized a product in any form by 2006. Demonstration of value in a specific application can also be proxied through patenting. In terms of number of patents, 54% of the ventures have 0-10 patents, 23% of 11-20 patents, 9% have 21 – 50 patents, and 15% have greater than 50 patents.

5.2 Sub-groups within sample of advanced materials ventures

Our analysis showed that the ventures cluster clearly into three sub-groups (**figure 2**): nanomaterials, fuel cells, and performance materials. The most influential variables in this clustering were, in order of importance identified by hierarchal cluster analysis, access to complementary assets, lack of continuity, observability and trialability, the presence of established substitutes, number of markets targeted and need for complementary innovations. The firms in the fuel cell cluster experienced the greatest continuity, observability and trialability, had the greatest need for complementary innovation, and were predominantly forward integrated in their target markets. Both performance materials and nanomaterials firms had a greater need for process innovations, high barriers formed by a lack of continuity, observability and trialability, and were generally located upstream in their target markets. Performance materials had the least radical technologies of the three groups, and the highest average access to complementary assets. Nanomaterials ventures targeted the greatest number of markets. When the firms are separated in this way, the sub-groups are useful for observing differing patterns and can aid in the detection of potential value creation strategies.

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this question

5.3 The association between tech. uncertainty, market uncertainty and value creation

For the full sample, the relationships of value creation to estimated market uncertainty and to estimated technology uncertainty were investigated. As we observed no strong correlation between value creation and either technology uncertainty or market uncertainty for the sample as a whole, we investigated the sub-groups of performance materials, fuel cells and nanomaterials. Both the performance materials and nanomaterials sub-groups show high estimated market uncertainty and value creation to be positively correlated. Fuel cells show the opposite relationship, with those having higher market uncertainty tending to show lower value created. This suggests that perceived market uncertainty has an impact on value creation, but how it impacts depends on the sub-group. The fuel cell sector replicates the model (**figure 1**) in that high market uncertainty appears to lead to lower value creation. However, contrary to the model's prediction, performance materials and nanomaterials ventures are experiencing the opposite relationship, higher market uncertainty paired with higher value creation: it may be that the perceived increased value of their innovation, once it is demonstrated, is sufficient to overcome the increased uncertainty.

Although this finding is not consistent with Maine and Garnsey's model, other technology commercialization literature, such as Adner's (2006) concept of innovation ecosystems and Christensen et al.'s (2004) forward integration to the decoupling point, provides possible explanations. For fuel cell ventures, both their strategies of relative market focus and forward integration may be attempts to reduce market uncertainty to a level acceptable in the conservative energy market. Overall uncertainty for fuel cell ventures, including that of their innovation ecosystem, may be so high as to require sacrificing the extra value creation of additional markets in order to focus on one or two innovation systems. Similarly, the higher observed forward integration of fuel cell ventures into target market(s) is likely to be an attempt to reduce this increased innovation system uncertainty. For nanomaterials ventures and performance materials ventures addressing less conservative markets than energy, participants in the innovation ecosystems may be more receptive to radical innovation, with its inherent risk/reward profile, and a more cooperative innovation ecosystem may allow them to operate from further upstream in the value chains of multiple target markets.

5.4 Mediating Variables in Value Creation

The association between value creation and the variables of access to complementary assets, access to financing, and demonstrated value in a specific application are assessed in this section. The association between value creation and access to complementary assets is as predicted by **figure 1**, as is the relationship between the mediating variables and demonstrated value in a specific application.

From an examination of this sample, it is clear that the commercialization challenges faced by advanced materials ventures in the journey toward value creation have many similarities (**table 4**). As predicted in the model (**figure 1**), access to complementary assets appears to be a necessity for value creation by advanced materials ventures. This finding also empirically supports Teece’s (1986) propositions about profiting from technological innovation.

Surprisingly, access to finance was not correlated to value creation in the sample as a whole or for the subgroups. This may be because required finance levels vary so widely, by industry, application, and revenue model. Financial requirements can be reduced by employing licensing and/or service revenue models, and by focusing on only one target market rather than attempting to exploit the generic nature of the technology. Almost a fifth of the ventures relied on solely a licensing model, and 35% of the ventures limited their market focus to a single industry.

Demonstrated value in an application is proxied here by the number of patents held by a firm. Our analysis showed a strong relationship between number of patents and access to complementary assets. Although there was still a great deal of variation between the companies at each level of access, those that had the highest number of patents generally also had the best access to complementary assets.

Our findings through analysis of the sample largely replicate the factors proposed in Maine and Garnsey's model (**figure 1**) as influences on value creation. All of the relationships were as expected, with the exceptions that value creation was correlated with ***higher*** market uncertainty for the nanomaterials and performance materials subgroups, and that value creation was not significantly correlated to access to finance. These surprising findings are discussed in **section 7**. Notably, the positive relationship between demonstration of value in a specific application and access to complementary assets is supported by this data. Further evidence consistent with the model is that the strongest relationships found were between access to complementary assets and the ability to create value.

6 High Value Creation Strategies

We turn now to more detailed case study evidence which reveals the commercialization strategies of ventures which achieved a "high" rating of value creation. We report briefly on the two such cases in our dataset. One of these high value creators is in the nanomaterials sub-group and the other is in the fuel cell sub-group. The cases have been anonymized in accordance with confidentiality requests from the firms.

6.1 Case Study Exemplars

***Case Study 1*:** **AM35**, a young nanomaterials venture, pursues a hybrid revenue model with a licensing parent venture and segment specific manufacturing subsidiaries/spinoffs. The venture faced high technology uncertainty and moderate marketing uncertainty at founding. Given these uncertainties and the economic downturn of 2001, it experienced severe financial pressures, and therefore adapted its commercialization strategy.

The venture started with broad target markets and an in-house manufacturing strategy. The management team then temporarily narrowed their market focus to a single market, raised finance, broadened their focus to two target markets, and restructured. They formed a parent company with a licensing revenue model and pursued a segmentation strategy[18] based on market-specific subsidiaries with manufacturing revenue models. Each subsidiary firm was able to concentrate on alliance creation, product development, manufacturing, marketing and financing for a single market. The parent licensing firm held all of the intellectual property and focused on the generic aspects of their technology development and on assisting with alliance creation. **AM35** then broadened their market scope further to four target markets.

AM35's adaptive strategy facilitated its ability to raise financing. The parent firm was able to raise government grants and multiple rounds of VC financing. The subsidiary/spin-off firms were able to raise financing independently, with exclusive rights to the intellectual property in their own market. Access to complementary assets was also enhanced, as each manufacturing spin-off firm was able to focus exclusively on alliance creation within their own

[18] Segmentation of a larger organisation into market focussed subsidiaries has been found to improve performance through its positive impact on flexibility and motivation, as the example of Oxford Instruments reveals (Wood, 2001).

sector, and the parent firm provided assistance by generating interest in alliance creation and feeding potential partners through to the manufacturing subsidiaries as appropriate.

Case Study 2: **AM27**, a fuel cell venture founded more than 10 years before this study, initially adopted a niche strategy to establish itself by capturing a larger share of a small market. The intention was to use its established base to enter a broader market, as recommended by Davidow (1986). The venture faced moderate technology uncertainty and moderately low market uncertainty. While its technology was radical and faced established substitute products, its initial focus on a single market (and subsequent focus on only two markets) and absence of process innovation requirements for downstream parties kept the technology uncertainty at a moderate level.

At the time the firm was founded, it was difficult to secure investment in fuel cells, so it began designing test equipment necessary for fuel cell development, reducing market uncertainty. This "pick and shovel" niche strategy, to use a gold rush metaphor, allowed **AM27** to grow in a smaller market. The revenue stream generated from the test equipment design and service model eventually allowed the company to return a small part of its focus back to the manufacturing of fuel cell technologies, such as back-up power.

The company's hybrid revenue model allowed it to grow to a size where a mid-cap IPO was feasible. A few years after the IPO, the need to expand resulted in the spinning-off a key division, and the acquisition of **AM27**'s main competitor. The company has since branched into a number of applications within the energy market, including a range of complete power stations and smaller units for stationary backup power, and has moved into the transportation market with fuel cell and hydrogen products for mobility applications. It has also acted as a development partner in large hydrogen infrastructure and transport projects with a number of global players.

6.2 Comparison and Contrast of Value Creation Strategies

The high value creators demonstrate the difficulties that must be overcome in the commercialization of advanced materials technology and alternative strategies to overcome these challenges. As depicted in **table 6**, both high value creators commercialized radical technologies, required complementary innovations and encountered some barrier to their technology being observable, trialable, and continuous. There were similarities in their approaches to overcoming these commercialization challenges. Both demonstrated value through the issuing of patents and the creation of prototypes. Both high value creators had issued more than 20 patents, and had created product prototypes or demonstrated their process on a pilot scale before raising VC or public financing. Both had strong access to all required complementary assets for commercialization. Lastly, both had sufficient access to financing, and neither identified finance as a key constraint to growth, although both made creative organizational and revenue model decisions based on increasing their access to financing.

The high value creators both participated in the market for technology to help with access to financing and to demonstrate value, before also participating in the product market. **AM35** employed licensing, manufacturing, and manufacturing with outsourcing revenue models, and used its independent subsidiaries as a vehicle to attract additional financing and alliance partners. **AM27** pursued a service revenue model initially in order to finance their core technology development, and then moved to a hybrid service and manufacturing revenue model.

There were also notable differences. Although both firms focused on substitution applications, the nanomaterials venture also issued patents which would enable new/emerging applications. The nanomaterials high value creator targeted four markets while the fuel cell high value creator focused initially on a single market, and later on two markets. The fuel cell high value creator integrated downstream to reduce uncertainty, while the nanomaterials high value creator operated at a midstream position through an upstream generic parent company and subsidiaries manufacturing components for its targeted market value chains. The nanomaterials venture also creatively raised substantial VC financing to more fully exploit its generic technology, while the fuel cell venture generated much smaller amounts of self-financing through the sale of fuel cell test equipment before raising financing through an IPO.

To broaden our observations, we also examine the subgroup specific strategies of the medium-high value creators, 3 of which are in nanomaterials and 4 in fuel cells (**table 6**). The three nanomaterials ventures all commercialized radical technology and all targeted at least three markets. Two of these nanmaterials ventured participated in the product market exclusively, while one participated in both the product market and the market for technology. All three are positioned upstream in their target markets. Two are geared primarily towards substitution applications while one has a mix between substitution and emerging applications. All had developed strong alliance relationships, giving them access to all required complementary assets. Thus, the medium-high value creators broadly support the same strategies as the nanomaterials high value creator, in exploiting the generic, radical nature of their technology. In contrast, NM low value creators either did not yet have products, or were selling product or services to research laboratories. They had a narrow market focus, targeting either a single market or two markets with substitution applications. The lowest value creator among the nanomaterials venture (which had commercialized products) had a less radical technology, manufactured products for a single target market, was fully forward integrated into that target market, pursued exclusively substitution applications, and failed to develop strong alliance relationships. This low risk strategy led to low rewards.

The four fuel cell medium-high value creators all commercialized radical technology. Two of the fuel cell ventures targeted two markets, while the other two targeted three markets. The two ventures targeting three markets had commercialized a standardized generator which could be sold to various markets without further customization. Two of these fuel cell ventures operated in a midstream position in the value chain of targeted markets, with the other two ventures operating downstream. All participated in the product market, although three of the four ventures outsource some or all of their manufacturing. All four fuel cell ventures are primarily targeting substitution markets. Notably, three of the four fuel cell ventures did not require process innovations from their customers, and the one which did require process innovation did not require process innovation in all of its target markets. Three of the four fuel cell ventures had developed strong alliance relationships. In contrast, fuel cell low value creators targeted niche, low growth markets and did not develop sufficiently strong or relevant alliance relationships. The lowest fuel cell value creator (which has commercialized product) cited finance as a key constraint, targeted a niche market, required both process innovation and complementary innovation in order to commercialize its products, and had insufficient access to complementary assets.

7. Discussion

For the overall sample, our analysis supports the case for the influence of complementary assets on value creation. In line with Teece's (1986) arguments, those ventures with good access to a sufficient range of complementary assets create more value than those with limited or no access to such assets. The majority of ventures had established alliance partnerships with suppliers, intermediate component manufacturers and/or potential customers, who could provide market information, design and manufacturing capabilities, and/or distribution channels.

Surprisingly, we did not find any direct influence on value creation from access to finance. This apparently surprising finding is congruent with what is known about resource economy as an entrepreneurial solution (Hugo and Garnsey, 2005). Our evidence supports previous studies proposing that adapting business models to reduce requirements for external finance can be another means of enabling value creation (Gans and Stern, 1993; Pries and Guild, 2007). An example would be participating in the market for technology rather than the product market. However, there are trade-offs from the various models: for example, a focus on licensing limits overall potential for value capture by excluding downstream activities.

Through analysis at the sub-group level, we found variable impacts of market uncertainty and market breadth on value creation for the different sub-groups. Both the performance materials and nanomaterials sub-groups show high estimated market uncertainty and value creation to be positively correlated. Fuel cells show the opposite relationship, with those having higher market uncertainty tending to show lower value created. A possible explanation for this sub-group difference is that fuel cells face a higher cumulative uncertainty in their innovation ecosystem (Adner, 2006). Accordingly, their customers and investors would place a premium on any reduction of market uncertainty by the venture. In contrast, nanomaterials technologies may be generic enough to enable applications in sectors that are subject to lower cumulative uncertainty. With lower cumulative uncertainty in their innovation ecosystem than sectors targeted by fuel cell ventures, novel performance may be highly valued by nanomaterials customers and these benefits may outweigh increased uncertainty in the minds of investors and potential alliance partners.

The effect of market breadth on value creation also varied by sub-group. The nanomaterials ventures with the highest value creation were those that were targeting three or four markets. Fuel cell ventures showing the highest value creation targeted two or three markets, and standardized their products within these markets. As in the case of the variable impact of market uncertainty, for fuel cell ventures, the cumulative uncertainty involved in the energy market may be so high as to require sacrificing some extra potential value creation in order to either focus on fewer markets and fewer innovation ecosystems or choose applications (i.e. back-up power) where it is possible to offer a standardized modular product. Nanomaterials ventures face lower innovation ecosystem uncertainty in their target markets than fuel cell ventures and this may allow them to concentrate on a greater number of markets in the pursuit of higher overall value creation.

It is likely that the number of markets targeted has an influence that varies across various stages of the value creation cycle. Whereas targeting multiple markets may make it more difficult to demonstrate value in a specific application, for those nanomaterials ventures that succeed in doing so multiple markets increase value creation by diversifying market risk and generating multiple revenue streams (Shane, 2004).

Choices of revenue model and value chain position impact market uncertainty and financial requirements, and thus chances of value creation and capture. Technology ventures can participate in the product market or the market for technology, and can operate from an upstream or downstream position within an industry value chain. Commercializing a product from an upstream position in an industry value chain involves interdependencies with downstream firms, difficulties in assessing downstream consumer needs and problems with managing market experimentation and feedback (Adner, 2006; Christensen et al. 2004). But it is extremely resource intensive to forward integrate into multiple end markets.

Because of these conflicting pressures, the value creation strategies of the two independent high value creation ventures and the seven medium-high value creation ventures in our sample provide useful guidance on strategies which have been successful. All nine ventures commercialized radical technology which required complementary innovations. Eight of these ventures had created strong alliance partnerships with customers and/or firms in possession of complementary assets.

The five successful fuel cell ventures pursued forward integration, a more narrow market focus, and substitution applications to reduce uncertainty and enhance their chances of value creation and capture. Four of the five ventures have developed novel advanced materials into fuel cell products and also developed their own complementary innovations, such as specialized test equipment and hydrogen generation systems. The fuel cell ventures pursued multiple markets in a very different way than the nanomaterials and performance materials ventures - either by acquisition of another fuel cell venture targeting a separate market or by producing a modularized energy generator which could be sold into different markets without customization. With a standardized energy generator, the added complexity of targeting more than one market is greatly reduced. This is consistent with the fuel cell ventures' other uncertainty reducing strategies.

In contrast, the four successful nanomaterials ventures all exploited the generic potential of their radical advanced materials technology by focussing on three or more markets. To enable this, all four started upstream in the value chains of their target markets, and one nanomaterials venture evolved to a midstream position by creating market-specific manufacturing subsidiary and spinoff ventures. None of these high value creating nanomaterials ventures offered standardized products, instead tailoring their product offering to each market and application.

None of the performance materials ventures were high value creators relative to the entire sample of advanced materials ventures. Performance materials ventures were commercializing less radical technology than both other subgroups, were constrained by limited access to finance, and nearly all required process innovations. Few of the companies exploited the generic nature of their technology, with the majority targeting a single market. More than half of these ventures participate in the market for technology, with 40% exclusively licensing their technology. Thus, in following a more conservative strategy, these ventures may have sacrificed value creation.

This paper expands our understanding of methods to extract value from technological innovation, presenting evidence to support three innovation theories, and to partially contradict two others. First, we find support for Teece's (1986) argument that complementary assets are an essential consideration when planning a strategy to profit from innovation. Our findings also imply that that the choice and nurturing of alliance partners is so important that, after key patents are created, higher priority should go to alliance creation and development (which includes R&D collaboration) than to additional patent creation or filing.

Second, as Adner (2006) proposes, the cumulative uncertainty found in an innovation ecosystem appears to impact the commercialization strategy of advanced materials ventures in terms of their target market and alliance partner choices. For innovation ecosystems with higher levels of uncertainty, such as fuel cells used for stationary energy generation, a firm may decide to exploit technology in fewer markets, to standardize a product such that it can be used in a modular fashion across markets, and to target substitute product applications with no need for customer process innovation to reduce overall uncertainty. In support of this logic, we found that lower levels of market uncertainty were correlated with higher value creation for fuel cell ventures, while higher levels of market uncertainty were correlated with higher value creation for nanomaterials ventures and performance materials ventures. Successful nanomaterials ventures have also focused primarily on substitution applications, but each has patents and some development on emerging market applications. Thus, innovation systems with lower cumulative uncertainty appear to reward bolder strategies.

Third, when a market for emerging technologies and concepts exists, and when a technology venture has strong intellectual property rights, it may be successful by utilizing a licensing or service model to avoid the financial requirements and risk involved in building, acquiring or accessing complementary assets to pursue a manufacturing revenue model (Pries and Guild, 2007; Gans and Stern, 1993; Arora et. al., 2001). As advanced materials technology ventures frequently have strong intellectual property, do not have downstream assets, and are constrained in their financial resources, markets for technology should be strongly considered. However, our evidence suggests that, to become a high value creator, an advanced materials venture must eventually move into the product market.

Fourth, as Christensen et al. (2004) propose, forward integration to the decoupling point is a useful strategy to reduce market uncertainty for technology ventures and is utilized by the majority of fuel cell ventures in our sample. However, forward integration is expensive and may not be possible over multiple markets. Fuel cell ventures mitigate these expenses by creating standardized modular products. The nanomaterials ventures in this sample - all of which customize their products - could not possibly have integrated downstream in each of their target markets. Thus a nanomaterials or performance materials venture which follows the Christensen et al. (2004) advice on forward integration may forfeit value creation through constraining its market breadth.

Lastly, Neckar and Shane (2003) argue that ventures with generic technologies face lower market uncertainty as the venture has several chances to successfully commercialize their technology. Shane (2004) also argues that such ventures are better able to raise financing because of this lower market uncertainty. To the contrary, Davidow (1986) proposes reducing market uncertainty through targeting a narrow market segment. Fuel cell firms, with higher levels of innovation ecosystem uncertainty, appear to largely follow Davidow's logic. Nanomaterials ventures, on the other hand, appear better able to raise financing and create value by embracing the radical, generic nature of their technology and thus targeting several market segments, which lends some support to Shane's (2004) arguments. However, for nanomaterials ventures, higher value creation was associated with higher market uncertainty.

This discrepancy highlights the lack of consensus about the impact of generic technologies on market uncertainty and whether increased uncertainty is beneficial or detrimental for early stage technology ventures. We argue that the generic nature of advanced materials technology increases market uncertainty at the technology level and has an indirect influence on market uncertainty at the firm level. We also argue that increased market uncertainty will enhance or stymie value creation by an early stage technology venture depending on conditions in the targeted innovation ecosystem(s). If investment in the venture mirrors the conditions of a real option, increased uncertainty is acknowledged to be valuable (Leuhrman, 1998). Thus, in regimes of low innovation ecosystem uncertainty, an exclusive partnership with (or equity investment in) a highly uncertain early stage venture is considered desirable by corporate alliance partners and by venture capitalists. However, if the overall ecosystem is already highly uncertain, partners and investors may not value the exposure to the venture's risky strategy.

8. Conclusion

This paper makes four main contributions. The first contribution is to provide detailed value creation evidence from a sample of 43 advanced materials ventures. The second contribution is to find a natural division of advanced materials ventures into sub-groups, and to compare and analyse these sub-groups. The third contribution is to analyse potential value creation strategies for advanced materials ventures. The fourth contribution is to expand our understanding of strategies used to extract value from technological innovation.

Data collection and analysis on 43 advanced materials ventures largely replicate earlier findings in demonstrating the radical and generic nature of advanced materials commercialization. In particular, we found supporting evidence for the widespread need for complementary innovation and for customer process innovation, and of the high demands made on the customers for these innovations in terms of difficulties with observing and trialling the advanced materials innovations. Although no clear relationship was found between access to finance and value creation, the essential role of access to complementary assets in value creation was confirmed.

The sample was investigated for heterogeneity in response to the view that the advanced materials sector is too broad to treat as a single entity (Turner et al, 1990). Through hierarchical clustering analysis of the variables in **figure 1**, the sample was divided into 3 sub-groups, namely performance materials, nanomaterials, and fuel cells (**figure 2**). We found that the propensity to integrate downstream was markedly different by sub-group suggesting strategic differences between them in terms of value chain position: 100% of the performance material ventures, 72% of the nanomaterials ventures and only 27% of the fuel cell ventures were positioned upstream in their target markets at founding. Another notable finding was that, for fuel cell ventures, decreased market uncertainty was correlated with value creation, whereas with nanomaterials and performance materials ventures, increased market uncertainty was correlated with value creation.

Two high value creators and seven medium-high value creators emerged from the sample, and suggest subgroup specific value creation strategies for advanced materials ventures. The successful nanomaterials ventures exploited the radical and generic nature of their technology, were positioned upstream or midstream in their chosen target markets, and participated in both the market for technology and the product market. The successful fuel cell ventures had a narrower market focus, were positioned downstream or midstream in their target markets, chose target markets with low innovation ecosystem uncertainty and in which no customer process innovations were required, often standardized their products across markets, and participated dominantly in the product market.

In context of the technology commercialization literature, we provide support for three theories about the extraction of value from technological innovation; namely, the high importance of complementary assets in creating value from technological innovation, the relevance of the innovation ecosystems of target markets, and the role of markets for technology in helping a venture create value. We find that advice on forward integration and breadth of target markets is specific to technology subgroup, in that nanomaterials ventures garner greater financing and experience more success with greater breadth and operating upstream or midstream in their target markets, while successful fuel cell firms are integrated further downstream in their target markets and have a more narrow focus. Thus, embracing uncertainty appears to enhance value creation for nanomaterials and performance materials ventures but diminish value creation for fuel cell ventures.

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Table 1: Technology Commercialization Recommendations for Licensing and Reducing Market Uncertainty

	Theory/ Empirical	**Industry/ Context**	**Level(s) of Analysis**	**When to License**	**Methods for Reducing Market Uncertainty**
Teece 1986, 2006	Theory	Capturing profit from Innovation	Innovation & Firm	In strong appropriability regimes and when no specialised assets are required	Contract out, avoid commercialization until a dominant design has emerged (unless in a position to impact the dd)
Arora, Fosfuri and Gambardella, 2001	Theory & Empirical	Markets for Technology	Technology sector & Firm	when a MFT exists; when a firm is limited in downstream complementary assets, such as production and distribution; when IPR is strong; if you do have downstream assets, then license when downstream markets are homogenous	NTBFs remain upstream & participate in the market for technology
Gans and Stern, 1993	Theory	Product Market vs. the Market for Ideas	Firm	Strong IPR; when firm has a weak position relative to specialized complementary assets	Align commercialization strategy with firm's commercialization environment (ito IPR and Overturning/Reinforcing Incumbent Complementary Assets)
Christensen, 2004	Theory	Value Chain of Innovation	Firm	When decoupling point is directly after your IP	Forward integrate to decoupling point
Adner, 2006	Theory	Innovation Ecosystem	Innovation Ecosystem & Firm	----------	Pick innovation ecosystem with lowest market uncertainty.
Gambardella, 2008 (DRUID)	Theory	Markets for Technology	Technology & Firm	When it will not impinge on your core market profitability; for generic technologies, license into fragmented markets	License generic technologies in multiple markets
Davidow, 1986	Theory	Marketing High Tech Products	Product and Firm	----------	Pursue a Niche Market Strategy
Shane, 2004	Theory & Empirical	University start-ups	Technology & Firm	----------	Commercialize in Multiple Markets
Maine and Garnsey, 2006	Theory & case studies	Advanced Materials ventures	Technology & Firm	When constrained in financial resources and able to demonstrate value in a specific application	Limit number of markets, choose near term substitution markets with lower hurdles in terms of regulations, complementary innovation, and process innovation

Figure 1: Value Creation through Commercializing Radical Generic Technology

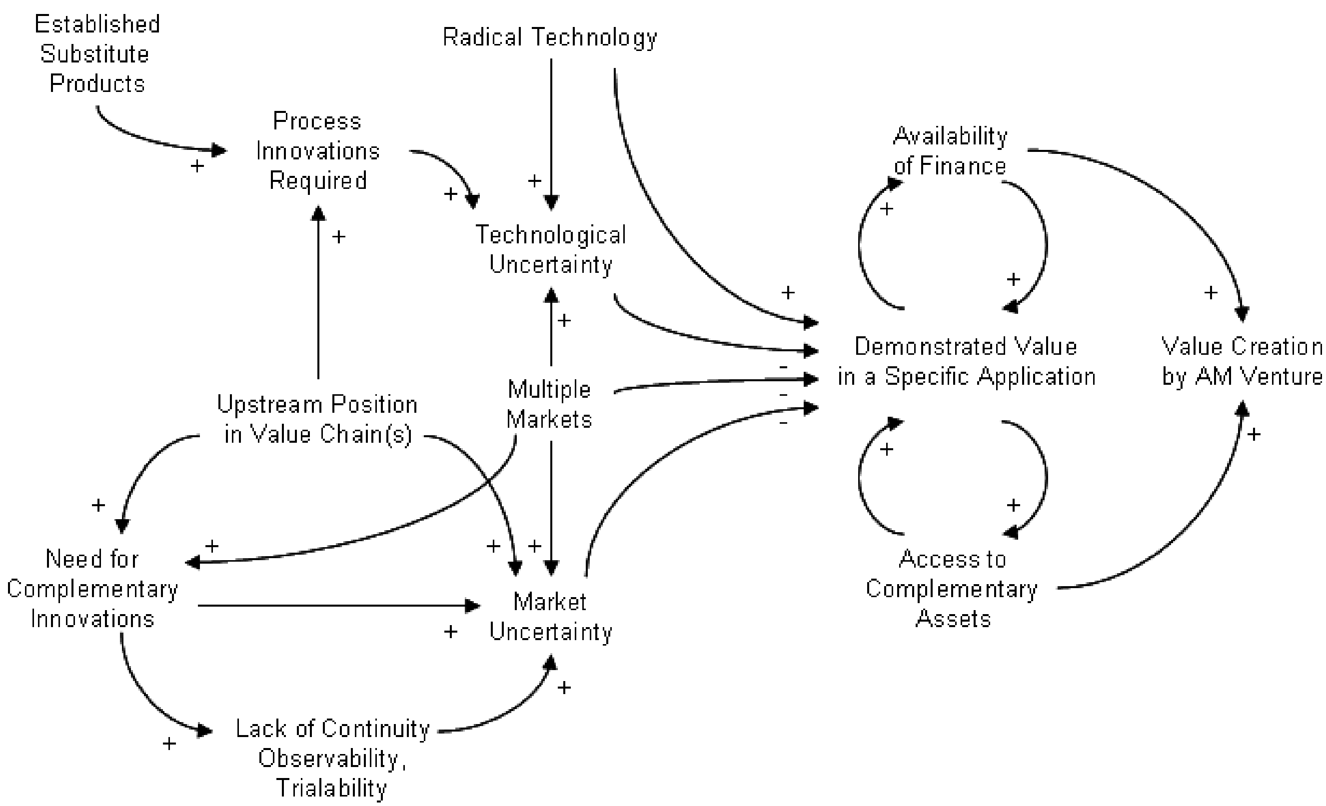


Table 2: Effects of model variables on uncertainty at the firm level

Factor	Influences	Effects
Radical technology	Technological uncertainty	-Requires extensive development, external linkages and long lead times -May result in highly differentiated products and/or substantially increased profit margins (Utterback, 1994; Leifer, McDermot et al., 2000)
Customer process innovations - *changes to the manufacturing process to enable desired properties to be achieved and to reduce unit cost*	Technological Uncertainty	- Materials innovations often call for process innovations by downstream manufacturer customers (Williams, 1993) -May deter technology adoption if it requires new skill sets from customers and/or if it overturns existing capabilities (Abernathy and Clark, 1985)
Multiple Markets (generic technology)	Technological uncertainty	-Requires more complex allocation of resources and division of effort, more financing, and more complementary assets -Necessary product attributes differ for customers in diverse markets, as do regulatory approvals, design standards, and the need for complementary innovations (Maine and Ashby, 2002; Christensen, Musso et al., 2004). -Focussing too broadly may decrease the chance of succeeding in any specific application
Upstream Value Chain Position	Market uncertainty	-Difficult to access market information and assess consumer reactions (Williams, 1993; Maine and Garnsey, 2006) -Often requires downstream identification of and reliance on alliance partners to integrate activities and reach market (Dodgson, 1992; Christensen, Musso et al., 2004). Forward integration to the decoupling point decreases market uncertainty, but requires more financing and more complementary assets
Requires complementary innovations – dependent on additional *component or system innovation*	Market uncertainty	-New technology and production competencies from downstream manufacturers increases adoption delays and difficulties obtaining prototypes (Hounshell, 1988) -May hinder adoption if new skill sets are needed from customers (Rogers, 1983) -Increases lack of continuity, observability and trailability
Lack continuity, observability and trailability	Market uncertainty	-May hinder adoption if product utility is not readily visible to customers and difficult to trail

Figure 2: Dendrogram of clusters

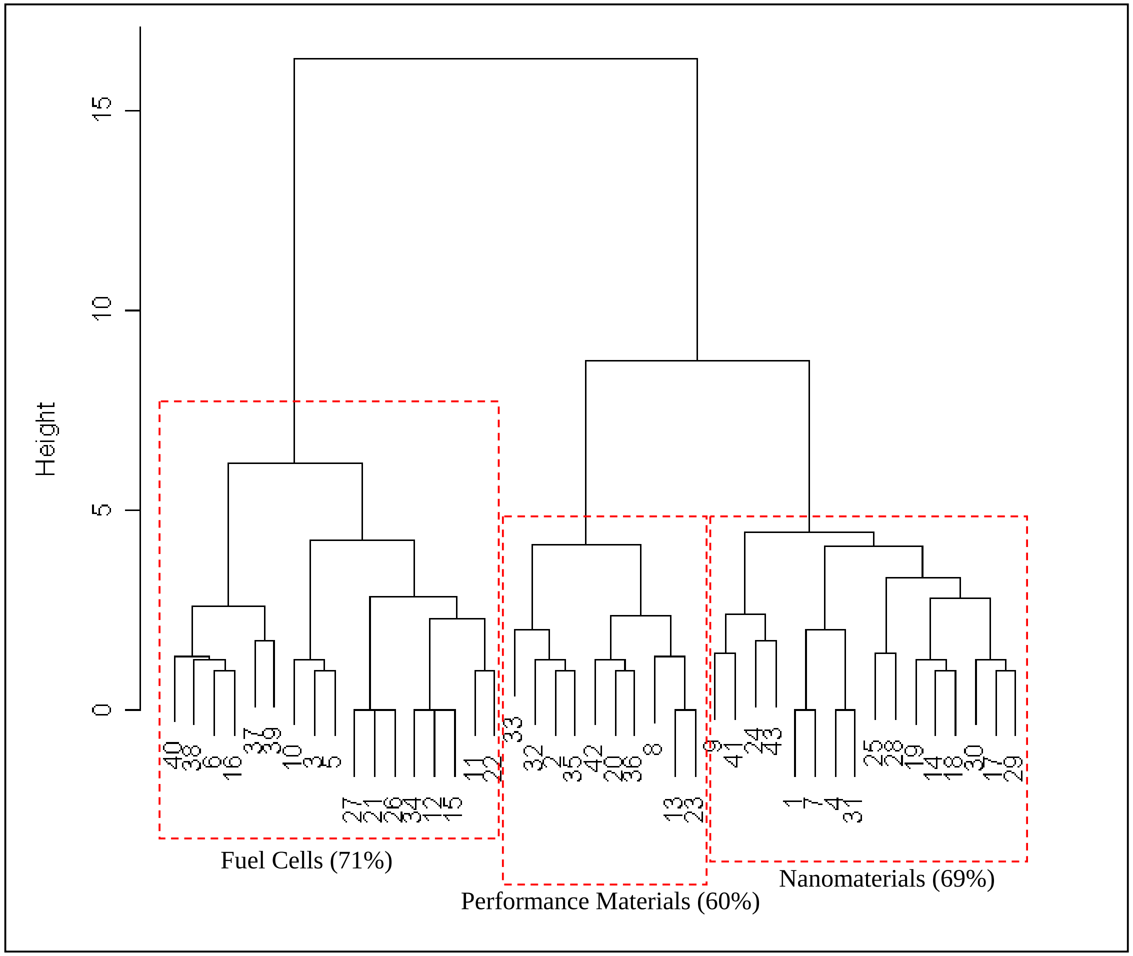
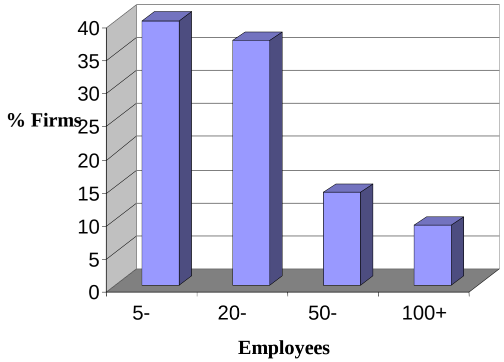


Table 3: Operationalization of Variables from Value Creation Model

Conceptual Construct	Proxy measure	Scoring
Process innovation required by customer	Score out of 2	2 if the firm requires downstream process innovations by customers 0 if they do not
Radical technology	Score out of 2	2-drastically improved performance, production cost or both 1-enable improvement in known attributes or cost reduction
Upstream position in value chain	Score out of 2	2-two or more intermediaries between firm and final customer 1-one intermediary between firm and final customer 0-sell directly to end consumer
Requires complementary innovations	Score out of 2	2-Adoption relies on complementary innovations 0-none required
Multiple markets[19]	Score out of 1	1-Firm is targeting 3+ markets 0.5-Firm is targeting 2 markets 0-Firm is only targeting one market
Lack of continuity, observability and trialability	Score out of 2	2-difficult for the manufacturer and the consumer to trial before widespread use 1-difficult for the manufacturer or the consumer to trial before wide spread use 0-no lack of continuity
Market Uncertainty	Percentage of score out of 6. Ex: 5/6= 83% *and* Rank in comparison to rest of sample	Sum of the scores for lack of continuity, observability and trialability, upstream position and need of complementary innovations, resulting in a score out of six. When examined on a scatterplot, the firms also received a score of low, low-moderate, moderate, moderate-high or high
Technology Uncertainty	As above for score out of 5. *and* Rank in comparison to rest of sample	Sum of scores for radical technology, required process innovations and multiple markets, for a total score out of five. When examined on a scatterplot, the firms also received a score of low, low-moderate, moderate, moderate-high or high
Access to Complementary assets	Score out of 2	0 indicating no access, 1 representing some access, (or full access to some assets but not to other necessary assets), and 2 for access to all required complementary assets.
Access to Finance	Score out of 10	Each venture was allocated one point for angel financing (and/or minor government grants), one point for SBIR grants, two points for public venture funding, two points for direct corporate venture investment, and four points for venture capital funds.
Demonstrated value	Patents issued	Number of US patents issued
Value Created	Revenue over time	2006 firm revenue / firm age in current form

[19] We define markets as unique industry segment, such as automotive, consumer electronics, biotech/healthcare, sporting goods, energy, etc., as the potential alliance partners and desired product attributes vary significantly between these divisions, whereas they do not vary as significantly between applications within these markets.

Figures 3a and 3b: Sample breakdown by employees and revenue



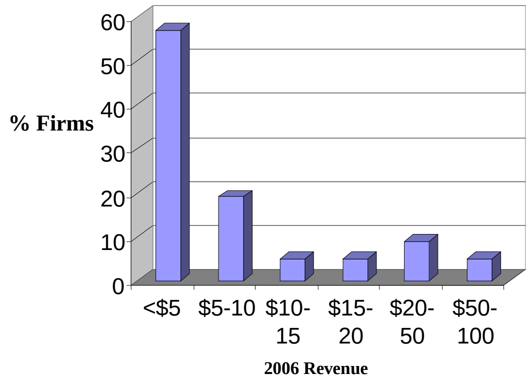


Table 4: Prevalence of model variables among sample companies

Variable attribute	Description	Sample firms experiencing
Radical technology	*2-drastically improved performance, production cost or both* *1-enable improvement in known attributes or cost reduction*	67% are commercializing radical technologies (2) 33% somewhat radical (1) 0% non-radical
Multiple markets (Generic technology)	*Generic technology with potential applications in a number of industry sectors*	37% target one market 63% target more than one market 33% target three or more
Process innovation required	*Require downstream process innovations by customers*	63% of firms
Established substitutes	*Compete with existing products*	98% of firms
Requires complementary innovations	*Adoption requires complementary innovations product innovations or customer skills (1 or 0)*	70% of firms
Upstream position in value chain	*2-two or more intermediaries between firm and final customer* *1-one intermediary between firm and final customer* *0-sell directly to end consumer*	65% upstream Of those 54% at level 2
Lack of continuity, observability and trialability	*2-difficult for the manufacturer* and *the consumer to trial before widespread use* *1-difficult for the manufacturer* or *the consumer to trial before wide spread use* *0-no lack of continuity*	30% complete lack (2) 70% significant lack (1) 0% completely continuous

Table 5: Aggregated Sample Analysis

	Sample of Advanced Materials Ventures
Age♦	1-35 years (median age of 7 years)
Radical Technology	73% of firms had highly radical technology, the remaining 27% had moderately radical technology
Ownership	16% of the companies are public, the rest are all privately held ventures
Technology Uncertainty at Founding	Ranges from Medium to High, with 72% of venture >= medium high
Market Uncertainty at Founding	Ranges from Low to High, with 35% of ventures >= medium high
Current and Future Target Markets	Consumer electronics, power generation, biomedical, aerospace, automotive, transportation, sporting goods, other. 63% of firms are actively pursuing multiple markets. Of these, 52% firms are actively pursuing 3 or more markets.
Revenue Models	76% participating in the product market; 50% participating in the market for technology
Successful Commercialization Strategies	Reduce uncertainty through forward integration and market focus; Exploit generic nature of radical technology
Access to Complementary Assets	Moderate. 19% of the firms have corporate funding. 91% of the firms have alliance partners, but only 63% have serious alliance partners with firms who can provide access to complementary assets such as product design, manufacturing, OEM relationships, and customer relationships. 42% of firms in the sample have military grants or contracts.
Access to Finance	16 US firms have SBIR funding and 51% of firms in the sample have VC financing. 18% have corporate financing. However, finance was considered a strong constraint to growth for 24 ventures. Out of the sample, 9 firms declined to give a rating, and only 18% rated access to finance as a weak constraint to growth with a score of 4/10 or lower. 19% firms had patient angel investment but only 7% were solely angel backed. 1 acts as a technology incubator
Demonstrated Value in Specific Application	All but one company had a prototype in some stage of development as of 2007 54% of the ventures have 0-10 patents, 23% of 11-20 patents, 9% have 21 – 50 patents, and 15% have greater than 50 patents.
Value Created#	As of 2006, 77% of firms had successfully commercialized products. 30% of those firms were founded more than 10 years ago. Although there are resources coming into the companies, very few have high revenues: 58% of firms are currently generating between $0-5 million USD. Only 23% of firms have annual revenues greater than $15 million USD, and 70% of these were founded more than 10 years ago. Only 5% of firms have a revenue growth rate of over $5Million/year, 50% of these was founded more than 10 years ago, the other grew partially through a merger.

♦ As of 2006, in firm's current form

#Value creation proxy= average revenue from 2005 - 2008 divided by age in current form:

$0-0.5M/yr (L); $0.5 M/yr – 1M/yr (L-M); $1M/yr - 3M/yr (M); $3M/yr - $5M/yr (M-H); $5M/yr+ (H)

Table 6: Cross-Comparison of Nanomaterials and Fuel Cell High and medium-High Value Creation Ventures

Venture	**AM35**	**AM4**	**AM18**	**AM31**	**AM27**	**AM34**	**AM15**	**AM3**	**AM19**
Value Creator	High	Medium-High	Medium-High	Medium-High	High	Medium-High	Medium-High	Medium-High	Medium-High
Subgroup	Nano	Nano	Nano	Nano	Fuel Cell	Fuel Cell	Fuel Cell	Fuel Cell	Fuel Cell
Market Uncertainty	M	H	M-H	H	L-M	M	L-M	L-M	L-M
Technology Uncertainty	H	H	H	H	M	M-H	M-H	H	H
Radical[20]	H	H	H	H	H	H	H	H	H
# of Markets	4	3	4	3	2	2	2	3	3
Value Chain Position	Midstream	Upstream	Upstream	Upstream	Downstream	Midstream	Downstream	Downstream	Midstream
Obs., Trial, Continuous[21]	M	H	M	H	M	M	M	M	M
Requires Cust. Process Innovation	Yes	Yes	Yes	Yes	No	No	No	No	Yes
Complementary Innovation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Revenue Model	L, M, MO	M	L, O	M	M, S	M, MO	M	M, MO	MO
Demonstrated Value / Patents	21-50	51-100	0-10	21-50	101-150	21-50	0-10	0-10	51-100
Access to Comp. Assets[22]	H	H	H	H	H	H	H	H	M

[20] A measure of the level of differentiation of enabled product attributes and/or the decrease in manufacturing cost
[21] A measure of the level of ease of observation, trial and continuity of the enabled product attributes
[22] A measure of the venture's access to the complementary assets required to commercialize their product