

The evolution of technology and emergence of a new market niche - the case of a life science research tool kit

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Abstract

This paper explores the dynamics of technical change and emergence of new market in the life science research sector. We argue that the formation of markets is a process of interactions between networked market actors at the macro and micro levels contingently instituted in socio-cognitive systems along unfolding scientific and technological trajectories. We illustrate our arguments through an in-depth case analysis of the development of site directed mutagenesis (SDM) technology, a radical innovation that has dramatically transformed life science research, and the emergence of the SDM kit market for a period of two decades. The results suggest a dynamic perspective for analyzing new market creation in nascent industrial fields and contribute to the ongoing debate on new market creation.

Keywords: market evolution, technology development, networks

Introduction

All markets have beginnings. But how do they get started? Recently the phenomenon of new markets is of growing interest to researchers (Sarasvathy and Dew 2005), who have approached and explained it from a variety of different disciplines, offering a rich set of explanations. Scholarship in economic sociology, for example, has addressed the issue of how market exchange and market are shaped (Callon 1998; Barry and Slater 2002). These emerging literatures have raised important issues about the role of marketing in market-making and recently are starting to spread to the marketing discipline. By viewing marketing practices as implicated in market-making, these more recent studies (e.g. Araujo 2004) give valuable insights into several important questions concerning the character and interrelationship between marketing practices and market forms. To date, however, the extant empirical studies of performativity focus on clear-cut cases, e.g. the role of financial theory in shaping financial markets (MacKenzie 2003). The interrelationship between market evolution and marketing practices has been a central and yet neglected issue in marketing. This negligence leaves many forms of market unattended, particularly salient are those in the nascent industrial fields under dynamic contexts and “high-velocity environments” (Eisenhardt 1988, p. 816) with frequent changes and extremely ambiguous decision situations.

In the very beginning of business markets, in “high-velocity environments” such as life science research sector in particular, uncertainty pervades. Early on, however, resolving uncertainties requires understanding what these innovations are, for whom they are valuable, and how to use them. In times when understandings about emerging market definitions are vague and sketchy, conventional measures of market share and market growth are either unreliable or unavailable. In the context of emerging technologies, transactions are also equivocal, as producers and consumers have imperfect knowledge of each other’s preferences and capabilities, leading to the misunderstandings as well as corrections that mark practically all markets (Rosa et al. 1999). Consequently under such dynamic context, an understanding of the underlying processes by which markets develop is important.

Building on the argument of White (1981, 2002) and from the research on social construction of technological systems (e.g. Garud & Rappa 1994), Rosa and colleagues (1999) suggest markets and their competitor sets are shaped through a dialogue between producers and consumers, and they focus on market stories as the building blocks of agreements on category definitions. They illustrate how the growth of market stories circulating between producers and consumers can shape demand (Rosa et al. 1999) by stabilizing cognitive categorization schemes that identify different competitors as belonging to a coherent group (Porac et al. 1995; Porac and Rosa 1996). At the center of the analysis by Rosa and colleagues, markets are “knowledge structures” shared by producers and consumers. Initially, these knowledge structures are unstable and incomplete, but over time, they stabilize and come to be generally accepted. Although they acknowledge that firms attempt to influence category definitions to their advantage by selling their stories in various ways, the authors conclude that in emerging markets neither consumer nor producer have “total control over the category’s final realization” (Rosa et al., 1999, p. 74). However, they suggest further research into the possibility that

“producer voice” somehow impacts market formation.

Third-party evaluators play an important role to sort firms and define markets. In securities markets, the works of Zukerman (1999) show a categorical imperative shaped by securities analysts. It follows that in the two-way dialogue between producers and consumers, the third-party behind the stories, such as scientific media, merits further study in the emerging high tech markets.

Inspired by the sociocognitive perspectives, and also informed by the growing recognition that organizations and markets are fundamentally knowledge-based, in this article, we address some of these concerns by arguing for a view of the formation of markets as the process of interactions between networked market actors at the macro and micro levels contingently instituted in socio-cognitive systems along unfolding scientific and technological trajectories. By tracing the development of site directed mutagenesis (SDM) technology, a radical innovation that has revolutionized the means by which mutants are obtained and dramatically transformed life science research, we study the emergence of its kit market for a period of nearly two decades. By focusing on the initial moments of the niche, this study begins from the premise that niches have beginnings and firms have an impact on this emergence through their contributions to the development of consensus that resolves market uncertainties. There are many ways of defining niche, yet conceiving it as “product market” is an important one. Our focus is on the emergence of this new market niche and marketing practices of firms as well as the related issues of technological development. Specifically, the research questions are: (1). How do scientific media shape the emerging market? (2). How do the voices of producers perform this new market? (3). What is the role of consumers/users in this process?

Research site and methods

Life science research tool market is an ideal research setting for studying the emergence of market forms and related marketing practices, because it is an area typical of emergence and constant change. In this paper, the term “toolkit” is narrowed down to refer to commercial research toolkit that usually contain reagents in pre-measured amounts for use in performing a research method and accompanying instructions for performing such a method.

This research focuses on the site directed mutagenesis (SDM) technology and its respective nascent market niche. The case of SDM points to the complexity of the interactions of different market actors and their shifting nature along emerging, hence nondeterministic, trajectories of innovation (Dosi 1982). Uncovering the different facets of market formation requires a comprehensive data collecting efforts using multiple sources and multiple methods. The method is thus comparative and historical and combines qualitative and quantitative data extracted from a variety of primary and secondary sources.

Since research tools are used by life scientists who have an inherent “taste” for research and publication, and who is required to specify the specific research methods and materials used in their published papers for “replication purposes”, the study of scientific and technical papers

can describe and reflect how SDM toolkits have been used in the past decades. The data base used is the electronic library of US National Library of Medicine, the largest database for life sciences in the world. A search was conducted to collect 24,310 scientific and technical papers on SDM from 1975 to 1998. A bibliographic database was created, consisting of 2,241 articles which have cited the use of SDM kits in their researches. A chronological analysis was conducted to understand the technical debated and key developments in the field. Crucial articles, as identified by researchers in the SDM field, were content analyzed to develop the important points and themes underlying the main technological issues.

Results

The research tools phenomenon

One of the most striking technological advances of biotechnology in the 1990s has been the development of drug discovery and research tools. Many “platform” biotech firms focused on the tools market, which is becoming increasingly important both in absolute terms and relative to the other typical market of the biotech companies, notably that of specific products or compounds. These tools are mostly technologies for conducting more efficient laboratory tests, screenings of compounds, and tests of a large number of molecules and substances.

SDM: a radical innovation as a life science research tool

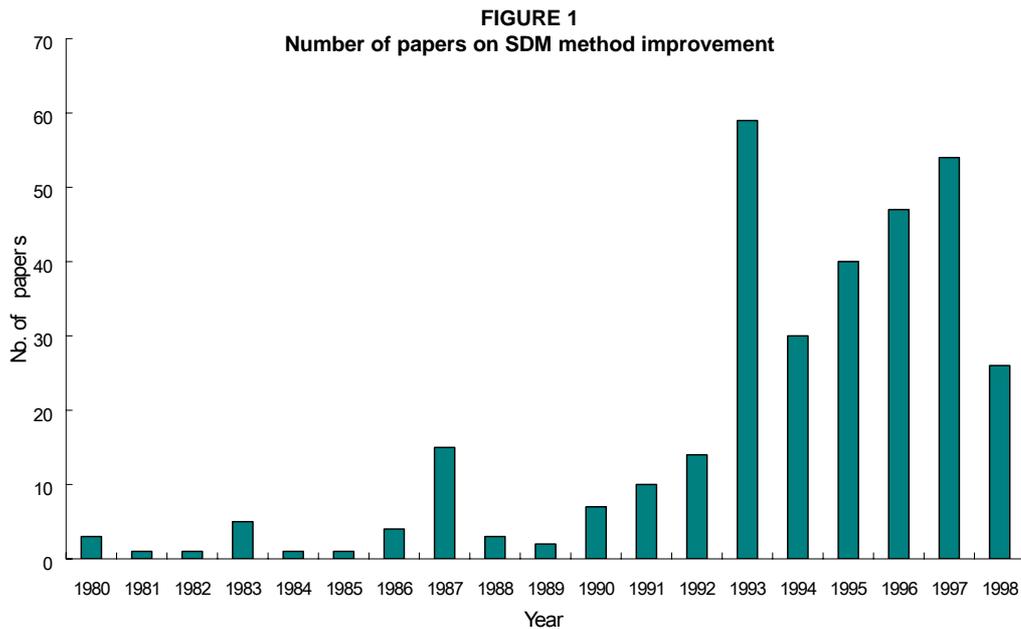
SDM is a molecular biology technique in which mutations are created at defined sites in a DNA molecule and thus to the proteins that they encode. British-born Canadian biochemist Michael Smith first conceived of SDM in the early 1970s and devoted several years to working out the details of the technique. The method provided researchers with a completely new way to study protein function. So central has this technique become to all of biochemistry and molecular biology that Smith shared the Nobel Prize in Chemistry in 1993 with Kary Mullis who developed PCR.

Technical hurdles to practice SDM

Even if as a platform technology, the initial techniques to practice SDM are mostly developed under specific context. Consequently, applying this knowledge and technology developed in a specific context for a specific use, to another context and use, is rarely simple or straight-forward. It is thus not surprising that as with all radical innovations, the wider application of SDM follows from the development and the adoption of sequences of innovations in research materials and complementary techniques. This sequence is generated within the context of an innovation diffusion process whereby diffusion induces further innovation to define an emergent trajectory of learning and discovery. After Smith’s pioneering efforts, several problems existed when trying to perform SDM, thus rendering it into such a bottleneck technology that required researchers a long time period to go through all the steps with low chances of experimental success.

Creating and affirming collective beliefs on SDM improvement: corporate and academic scientists

SDM remained a blunt tool for many researchers even after Kunkel made significant improvement to this technology in 1987. However, in the years immediately following the Kunkel, there occurred a great deal of creative, experimental endeavor on SDM improvement, initiating waves over waves of stories/papers in the scientific community to create and affirm collective beliefs on how should SDM be conducted.



Source: Pub-med, ISI and authors

As indicated by Fig. 1, the number of papers on SDM method improvement in the 1990s is nearly 10 times than over the previous decade. It is interesting to note that there are three peaks which occurred in the year of 1987, 1993 and 1997 respectively. The year of 1987 was when Kunkel introduced significant improvement on SDM, which might have triggered considerable interests and debates in the life science community. In 1993, Michael Smith was awarded Nobel Prize for his contribution to SDM. It is not surprising that in the same year, papers on SDM reached it second peak. The final peak to some extent coincided with growth of SDM kits in the same period. Gradually, from the different SDM methods there emerged ten different academic streams, major leaders of which include Kunkel, Roberts and Zakour (1987), Weiner, Felts, Simcox, and Braman (1993), Sayers, Kerkel and Eckstein (1992), and Deng and Nickoloff (1992). The general trend was that the use of double-stranded DNA templates together with thermostable-polymerase PCR had gradually replaced the use of single-stranded DNA using thermolabile polymerase for *in vitro* mutagenesis. In the different streams, corporate scientists achieved a considerable voice in this SDM debate. Among the papers on SDM improvement, about 10% were contributed by corporate scientists.

The multiple directions of improvements to SDM were of course an advantage, as researchers

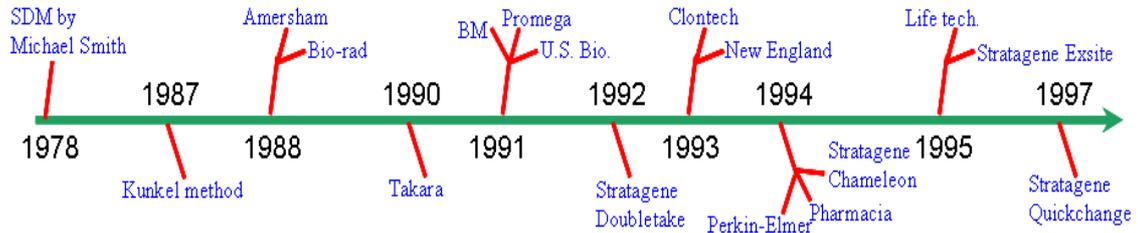
had many choices available to their own uses. More importantly, this boom of papers on SDM techniques started a process of debate and clarification at the level of individual cognition of researchers wherein evaluation routines began reinforcing their beliefs on what SDM was, when, why and for whom they were valuable and reliable. Both academic and corporate scientists debated, interacted and contributed to this process. However, this prosperity in method papers may present a disadvantage at the same time when researchers might be overwhelmed by the available methods and protocols, many of which were still so called "context-dependant techniques", and thus require users to go through the trial-and-error process to adjust the general protocols to their own unique usage situations before they can conduct SDM. This trail-and-error were again laborious, time-consuming and with high risk of failure.

The emergence of SDM kits: another story of path creation and dependence

Given the many different methods of SDM that are mostly context-dependent, it is clear that more general purpose SDM tools suitable for different usage situations in life science research were needed to provide researchers with more handy ready-to-use methods. To this end, companies had either made further adjustments to existing techniques so that they could produce kits that can become more general technologies applicable to different usage situations, or based on existing methods to develop new techniques by their own corporate scientists that have an advantageous combination of features as compared to other techniques for SDM. These useful features include: (1) low secondary mutation frequency, (2) high mutation efficiency, and (3) a minimal number of steps, thereby permitting the generation of host cells containing the mutant sequences in even less than 24 hours. These SDM Kits are developed commercially by firms for scientists to conduct more efficient laboratory tests. They provide one or more of the enzymes or other reagents for use in performing the subject methods. Kits may contain reagents in pre-measured amounts so as to ensure both precision and accuracy when performing the subject methods. Kits also contain instructions for performing the SDM methods. The crucial point for kits is that they transform a radical innovation into a routine laboratory procedure and these new ways of performing SDM are embedded in existing practices of SDM, as exemplified by the booming SDM improvement papers.

Following procedures discussed by Van de Ven and Poole (1990), a chronological list of events in the development of SDM was created in Fig 2. Over the period from 1988 to 1997, there were totally 15 different SDM commercial kits. With larger firms such as Amersham and Bio-rad as pioneers, entrepreneurial firms such as Stratagene soon joined in the play. It is interesting to note that Stratagene is the only company which had developed four different types of SDM kits, while others introduced just one. Furthermore, Takara is the only Japanese firm in this emerging market. From the timeline it is also clear that these companies were quick to start to develop SDM toolkits. Only one year after Kunkel's method, Amersham and Bio-rad began to market their SDM kits.

FIGURE 2
The evolution of SDM and its kit 1978 – 1997.

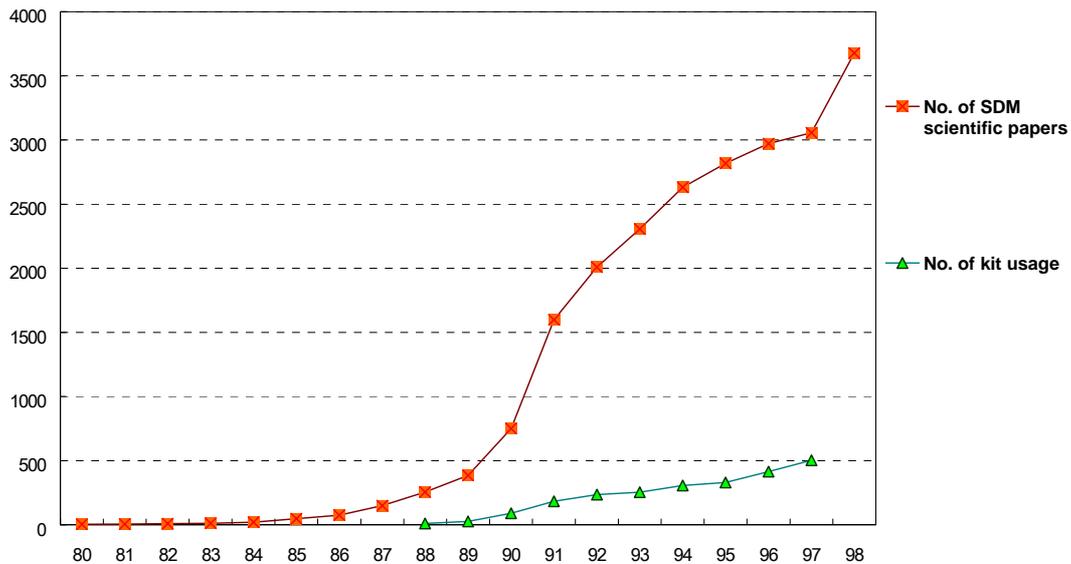


Source: Pub-med, ISI and authors

Scientific media as a market making institution

In the very beginning of this new niche, scientific papers are one of the few available sources of information for reducing emerging market uncertainty. Substantial amount of scientific information is codified in standard languages, as exemplified by the diffusion of SDM research findings through journal articles which serves as the market institution that facilitates communication and exchange among independent parties. The applications of SDM in scientific research from 1987 to 1998 are illustrated by Fig 3. The data show that the use of SDM increased dramatically in the 1990s than in the late 1980s. By the year of 1998, the number of papers achieved a record high of nearly 4,000, an indicator of the formation of a large SDM scientific community.

FIGURE 3
Co-evolution of innovation adoption



Source: Pub-med, ISI and authors

In Table 1 we see the significant correlations between the number of papers practicing SDM and number of usage of SDM kit over the period 1988–1997. In spite of its elementary nature,

this exercise clearly signals the presence of connected and co-evolving aspects of the innovation adoption sequence where advances in SDM kit niche are strongly associated with growth of scientific community around the shared SDM knowledge.

Table 1
Correlations between papers practicing SDM and number of times of SDM kit usage

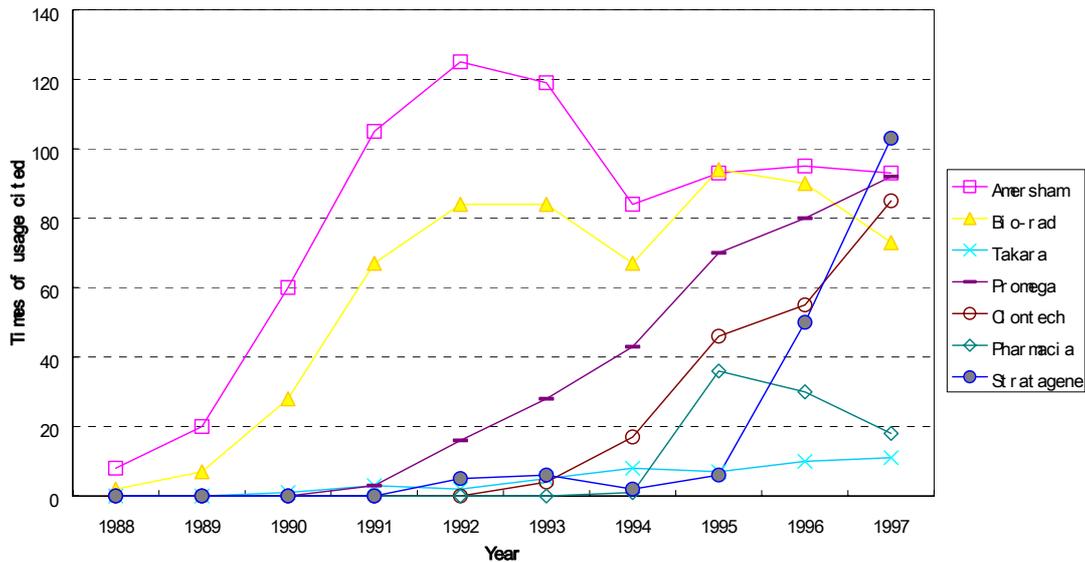
		SDM Paper	SDM Kit
SDM Paper	Pearson Correlation	1	.966**
	Sig. (2-tailed)	.	.000
	N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

This exercise, together with other qualitative evidence from our interviews and paper content research, suggests that there was a reciprocal interaction in the scientific media between the voices of producers and customers which gave rise to two cyclical processes. One was a process of debate and clarification at the micro level of individual cognition wherein evaluation routines began reducing confusion and reinforcing researchers' beliefs on what SDM is, how SDM kits qualities are; when, why and for whom they are valuable and reliable; and how new kit technologies are embedded in existing SDM practices. The other was a process of institutionalization at the macro level of shared cognition (Garud and Rappa 1994) wherein using SDM kits in experiments emerged as accepted lab norms in practicing SDM technique, thus new roles and institutions were created while existing institutions were modified to create a particular context in which users made sense of these kits with new technologies. Eventually, new market was made through these processes as social constructions whose meanings emerged from buyer-seller agreement via scientific papers, a framework within which the emerging product-market operated. Until competing producers, journal reviewers and customers develop stable, well-understood schemes for sorting out competing category claims, category ambiguity raises uncertainty about the value of the new products, which dampens demand (Rosa et al., 1999).

Fundamentally, scientific media have served as an important market institution for reducing emerging market uncertainty, helping to establish the stability of shared meanings on SDM kits among different market actors and thus shaping their practices in this emerging market. Scientific media facilitates the process of a gradual definition of the property of the product, shaped in such a way that it can enter into the consumer's world and thus a product is progressively transformed into a good (Callon and Muniesa 2005). In this way, firms build attributes of their technologies directly into emerging institutional structures.

FIGURE 4
The emerging SDM kit market reflected in scientific papers



Source: Pub-med, ISI and authors

Fig. 4 maps the evolution of SDM market from 1988 to 1997. Rapid technological change and frequent new product introductions are typical for this market niche. Larger companies, such as Amersham and Bio-rad pioneered in introducing their SDM kit, but soon after smaller entrepreneurial firms such as Stratagene started to take the lead.

Producer voice: a further analysis

In looking at the “producer voice”, we start from the observation that many firms often widely disclose parts of their knowledge, which then become available to other firms, including competitors (Hicks 1995). In developing the new market, the SDM firms strived to achieve a leadership position and a strong voice in the scientific research community through publishing scientific papers by their corporate scientists. These scientists not only have shaped the development of SDM techniques, but more importantly contributed the wider adoption of the SDM kits built on their highly cited research results. These publications of corporate scientists appeared to have market-making functions, which define product quality (Callon 2002). Similar to Podolny, Stuart and Hannan (1996) who suggest that both the definitions of product market niches and firms prospects in them can be explained by examining the networks that result from competition in related fields such as research and development, the quality and life chances of research tools can be explained by similar networks such as the competitive paper citation networks that emerge from academic scientific papers. Among the successful players as illustrated by Fig. 4, the former little-known entrepreneurial firm Stratagene achieved a leading market position by 1997 against other much larger players such as Bio-rad and Amersham. A comparison of the papers published on SDM has shown that Stratagene scores the highest in number of papers and in paper citations, which to some extent implies a high quality of its SDM kits. Essentially these voices of firms create and constitute new objects, concepts and positions around their SDM kits, or alternatively modify existing ones.

Since the citation of a product in published research is an indicator of customer's positive opinion on the product utility, the citation serves as an innovation diffusion facilitator among the consumers where later users follow early adopters who may take the risk of going against the traditional "trial and error" research paradigm and who sometimes may be criticized as having the "over-reliance-on-kit syndrome". Thus, in an effort to dissolve potential threats to diffusion, the kit companies, Clontech for example, have established databases on company website to count for the citation of SDM kits in published research. By doing this, the producers make their own voices by echoing those of consumers in such a way that can construct suitable shared meanings and start a bandwagon effect around their technological innovation of SDM kit. Over the years, the kit category growth might be the result of competing firms bringing distinctly different groups of customers into the market.

Discussion and conclusion

This research suggests that formation of markets is a social process of interactions between networked market actors at the macro and micro levels. Through contributions to scientific journals, actors on both sides of the market helped to reduce SDM market uncertainties and contributed to the stabilization and assimilation of SDM kit product concept, quality meanings and consumption norms. Part of the value of the study is to show how the creation of a system of conventions and collective beliefs that apply to particular class of transactions overcomes the initial obstacles to trade (Casson 1982) in the earliest moments of markets. For research in technology and innovation, this study offers new insights into the adoption of radically innovative technologies. What becomes clear from the case is that the voices of firms work to affect the social context of SDM technology and its respective kits.

Furthermore, the role of demand during specific stages of the evolution of an industry has been shown in many previous studies to be relevant. In computers for example, experimental customers have been major actors in the emergent phase of the industry (Bresnahan and Greenstein 2001). In instrumentation (Von Hippel 1988) and machine tools, lead users have played a major role in innovation. In our study, scientists has been shown as both innovators of SDM techniques and as consumers of SDM kits, thus having dual contributions to the market formation, with which one could link performativity of codified knowledge and the division of innovative labor.

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