Understanding the Emergence of Radically New Technologies

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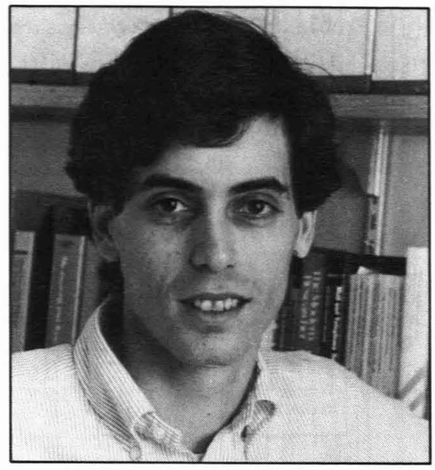

The following paper proposes that in order to understand the development of a radically new technology, one may have to view its emergence in the context of a «R&D community». The functioning of this community may provide industrial managers and researchers some insight into the overall rate of progress toward the commercialization of a new technology. Although it is too early to report specific results, studies currently being conducted at M.I.T. are investigating the operation of a number of different communities and their role in the development of new technologies.

The Challenge of Emerging Technologies

A central task of the research laboratory manager is to determine the optimal allocation of scarce resources among a variety of technologies that could be developed by the research staff. It is a difficult and unrelenting challenge with no clear answers and with the options changing over time. Whether it is a promising new technology on the horizon or a technology currently in development that is proving less promising than initially thought, the laboratory's portfolio of projects is subject to frequent review and reconsideration.

In what directions should a research laboratory expend its effort? What new technologies should be vigorously pursued, and what existing projects should be curtailed? In sorting through these questions, the laboratory manager must assess each technology's potential impact on current business, its risks, its return, and estimate the length of time it might take to reach the marketplace— all with an eye toward what might be done by competitors. The time frame for commercialization of a new technology is particularly critical to the assessment. Even though the potential of a technology may seem significant, its importance will increase or diminish depending upon the length of time it will take to develop.

There is no easy formula for estimating a technology's progress toward commercialization. Over the past several decades the effort to develop the field of technological forecasting has yielded a limited number of approaches, but even so most firms continue to rely heavily on expert judgement. The benefits and limitations of expert judgement are fairly well understood: in short, experts in a given technology are the most knowledgeable to judge it, but they are more likely to overestimate its potential and underestimate the degree of difficulty in bringing it to fruition. Moreover, it is not unusual to find that for every optimistic opinion an equally pessimistic one can be found.

Given that resources are limited, the determination over the worthiness of developing a particular technology may place a laboratory's researchers at odds with one another and the resulting debate can reach an impasse. This can make laboratory life interesting for one who enjoys hearty conversations, but it is no solace for the manager who needs to take action and make effective allocation decisions. Indeed, the entire laboratory atmosphere can become strained, when researchers become impatient with the slowness in approving new projects and managers become impatient waiting for investments in ongoing projects to yield tangible products or processes.

A Recent Example

The discovery of superconductivity at high temperatures in bulk ceramic materials (namely, the compound of lanthanum-barium-copper-oxide) in 1986 serves as a excellent example of the challenge posed by an emerging technology. [1,2] The event, which occurred at the IBM research laboratory in Zurich, Switzerland by two scientists who later were awarded a Nobel Prize for their effort, is considered today to be extremely significant in terms of both its scientific and technological implications and indeed, some believe on the same scale as the discovery of the transistor effect in semiconductor material at Bell Laboratories forty years ago.

Like the transistor, it could ultimately lead to vast improvements in areas such as high-speed computing. However, the realization of a computer with components based upon the new superconductive material is not a trivial task nor is it certain whether it could be achieved—let alone when. Several problems will have to be addressed, such as, refining the crystalline structure of the material, improving its electrical characteristics, fabricating it into useful devices and circuits in high volume, packaging the components, integrating these components into the other parts of the system, and resolving the scientific question of why the materials behave as they do.

The anticipated speed in overcoming the obstacles facing the application of superconducting ceramics can make all the difference in deciding the proper allocation of a laboratory's resources over time. Yet judgments about the probable length of time for the technology's development are vague at best and opinions are often divided. For example, rapid progress leading to even more important superconducting ceramic compounds (yttrium-barium-copper-oxide, in particular) initially generated widespread enthusiasm for near-term commercialization of the technology. However, the reality of what lies ahead has currently given rise to a more sober opinion among some researchers about the long term nature of the effort.

The perils of this situation are readily apparent to the laboratory manager: if one accepts the opinion that such a computer can be realized within five years, the appropriate allocation of resources will be substantially different than if one holds the opinion that such a computer can be realized only within fifteen years. Ironically, it was the same firm, IBM, which beginning in the early 1970s attempted to develop a superconducting computer (in this case, using niobium alloys), but had to scale back its effort in 1983 after reportedly spending as much as one-hundred million dollars without success. [3]

The case of superconducting ceramics is not unique. In the past, managers have wrestled with similar decisions and they will continue to do so in the future. Time and again, they must grapple with the laboratory's research agenda, seeking to understand what new technologies are gaining momentum and what ones are grinding to a halt at the researcher's bench. But what can be done to aid industrial managers and researchers in this challenge?

The Role of R&D Communities

A research program currently being conducted at M.I.T. is seeking to assist research laboratory managers in understanding the rate of progress in the development of radical technologies in order to improve their effort to optimize resource allocation. [4,5] The study focuses on the community of researchers that coalesces around a technology: that is, the scientists and engineers who are committed to solving an interrelated set of scientific and technical problems, who may be organizationally and geographically dispersed, and who communicate with each other.

The study seeks to uncover the relationship between the structural and behavioral dynamics of this «R&D community» and its rate of progress in solving the myriad of problems it faces. The theoretical basis of the study supports the contention that certain changes in the structural and behavioral dimensions of the community may be related to the acceleration or deceleration of a technology's progress toward commercial introduction.

Despite the fact that the research community is a familiar concept in the context of the **scientific** world, its place in the realm of **technological** development is largely ambiguous. It is well understood that scientists (particularly those employed in university or government) are members of communities, the so-called invisible colleges, where information flows with relative freedom between laboratories. These communities provide the mechanism by which members mete out recognition and rewards and set the direction for future research.

In contrast, technological development is typically seen as the domain of engineers and the industrial firms that employ them. Firms operate to establish proprietary know-how, which then can be leveraged to develop new products or processes that surpass those of competitors. Secrecy, competition, and managerial direction are the **sine qua non** of the technological landscape. Given this traditional conceptualization of technological development, it appears that the notion of a community of researchers is at once incongruent. However, a closer examination of science and technology yields exceptions to such broad stereotypes. To view scientific communities as friendly clubs in which members freely share their ideas is misleading. Community members are not immune to fierce competition; they often race to stake intellectual claims (typically in the form of journal articles, but increasingly in the form of patents) and, even though it may be contrary to established scientific norms, acting to guard the flow of information about their research.

Likewise, the world of technology is equally as complex. Firms compete, but they also cooperate with each other, allowing technical information to flow among engineers in different organizations. Some engineers attend conferences, present technical papers, and publish the results of their work in peer-review journals sponsored by professional societies. Like scientists, they too, may see themselves as members of a particular R&D community, which extends beyond the boundary of their firm. Indeed, some are scientists, in that they are trained in the scientific method and may have doctoral degrees.

A Few Preliminary Observations

Although it is too early to discuss the specific results of our research, it is possible to make some preliminary observations. First, our research indicates that the R&D community can be global in scope and can include thousands of individual researchers in a variety of organizations, such as universities, private firms, new ventures, quasi public corporations, and government research institutes. Moreover firms in a given R&D community span many different industrial sectors, such that many are not in direct competition in the marketplace.

In addition, some communities are heavily populated by academic researchers, while others are more dominated by researchers from industry.

Second, we find that communites can have a long history, but that typically they experience a period of very rapid growth, which can be thought of as a «bandwagon» phase. The level of participation in a community can fluctuate widely over the years, with periods of tremendous enthusiasm among researchers only to be soon followed by periods of despair. Thus, we observe a great amount of movement of researchers between communities pursuing different technologies.

Third, there is evidence that as a community grows, it develops an elaborate interpersonal communication network among researchers in different organizations; that is, what some might call a community «grapevine». This grapevine facilitates the rapid transfer of information throughout the community, and thus enhances researchers' ability to best understand and solve the problems confronting them.

In conclusion, to the extent that researchers in a newly emerging technological field consider themselves members of a R&D community, this community may play an instrumental role in influencing the rate and direction of the technology's development. Contrary to established opinion, the development of a new technology may not simply be the activity of a handful of engineers, or of a firm, but instead many individuals working in numerous organizations spread throughout the world.

A final example of interest is that of the development of solid state electronics technology. Although history tends to remember only a few of the inventors and their inventions, such as with the Shockley, Bardeen and Brattain and the transistor, a careful historical account shows «It is...unrealistic to see the transistor as a product of three men, or of one laboratory, or of Physics, or even of the forties. Rather its invention required the contributions of hundreds of scientists, working in many different places, in many different fields over many years.» [6]

Our research is dedicated to understanding the role played by this larger movement of researchers that may be responsible for the emergence of a new technology into the marketplace.

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