Systems Sleuth

R&D Funding: Managing the Pipeline

by Kellie T. Wardman and Daniel H. Kim

For 50 years, the U.S. government, universities, and corporate labs have led the world in research breakthroughs and Nobel prizes. Recently, however; global and economic pressures have forced a shift in U.S. science projects toward an emphasis on quick results—a change that may come at the expense of long-term corporate competitiveness.

This shift in research priorities is at the heart of the most massive change in U.S. science since World War II, according to a recent *Business Week* article ("Could America Afford the Transistor Today?" March 7, 1994). Not only did corporations cut long-term research funding by 15% in the late '80s, but now the United States' 2.5 million scientists are being pressured to focus more on short-term goals.

The U.S. government is also placing constraints on the $76 billion of research it funds annually, as it increases spending on "commercially important" technologies. For example, Congress recently ordered that 60% of the National Science Foundation's $2 billion research budget must be spent on technology, products, and jobs that are relevant to national needs.

Scientists argue that these changes in the focus of R&D are leaving two particular gaps in U.S. research: ground-floor research, which includes "undirected" research and the generation of new ideas; and "mezzanine" research, which involves developing prototypes from promising ideas and is therefore high-cost and high-risk.

Some critics of the cuts in research believe such actions will reduce the stream of new ideas and products, and therefore may adversely affect U.S. competitiveness in the future. As inventor Jerry Woodall, who helped create ultrafast light detectors for the Information Superhighway, told *Business Week*, "If nobody supports blue-sky research, 10 years from now we won't have things like my new devices."

Woodall has a point. The progression of research from initial discoveries to useful products resembles an aging chain with inherent time delays that can span decades. The analogy is like a garden hose: if you shut off the spigot, water will continue to pour out of the hose for a while. The water will slowly reduce to a trickle, however, and eventually nothing will come out at all.

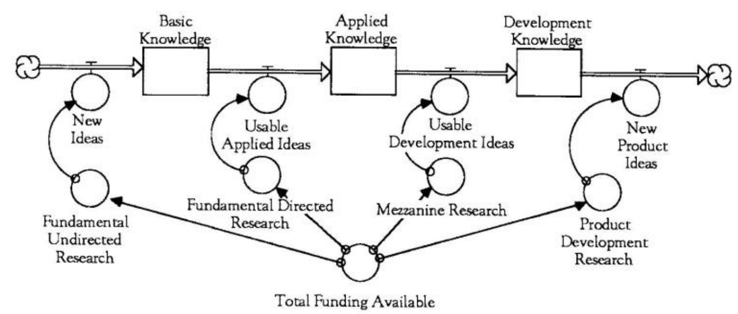
Therefore, the effect of funding cuts at the beginning of the chain may not show up for years. An accumulator and flow diagram of the R&D process illustrates the delays: the different types of knowledge (basic, applied, and development) are represented by the accumulators, while usable ideas flow through the chain as the research progresses over time (see "R&D Knowledge Accumulation"). Although such a diagram may appear overly simplistic, it can serve as a useful framework to see the inter-relationships between the different types of research and their funding. In this diagram, the total funding available for R&D is divided between the types of research, affecting the rate of the flow of ideas through the chain and, ultimately, the development of new products. As the diagram suggests, a potential decrease in new product ideas flowing through the pipeline can have serious consequences for U.S. corporations.

Discussion Questions

- Are there other aging chain structures that affect the delays in the R&D aging chain?
- What are the long-term implications of this shift in research focus?
- What are some of the nonlinearities that can affect downstream research in unexpected ways?
- What might be the sources and lengths of the delays in your own company's R&D chain? What would it take to change any of these factors?

Discussion on next page

R&D Knowledge Accumulation



The cascade of stocks in the aging chain diagram depicts the interdependent nature of the different types of scientific knowledge. The structural delays inherent in this system affect the rate of development of ideas. This rate can be speeded up or slowed down by certain factors, such as focusing more funding in specific research areas.

Discussion

Most breakthroughs in science have come about through the pursuit of knowledge for knowledge's sake—what is usually referred to as basic research. This research, in turn, provides the "raw materials" for converting new-found knowledge into practical applications. As the accumulator and flow diagram shows, proving that something is possible is a long way from ensuring a commercially viable product. Superconductivity is a recent example: initial enthusiasm about its potential has given way to the hard reality of the many years it will take to benefit from its widespread use.

Securing a viable long-term R&D policy requires understanding and managing the dynamics of the aging chain structure. The speed with which knowledge accumulates along the chain can be affected by many factors. First, there are the structural delays that affect the rate of accumulation of each kind of knowledge along the chain. It takes time to research, document, and disseminate new knowledge as it is being generated. It also takes time for people to receive, review, and digest the new knowledge and find ways to use it.

Other factors, such as the number of qualified scientists devoted to different types of research, can influence the delays in the R&D system. The development of scientific talent can be seen as another aging chain structure: it begins with grade school children taking an interest in science and continues to the Ph.D. level, where graduate students choose their field based in part on the current job market. The long delays in the development of scientific talent means that we may not feel the repercussions of shifts away from basic science for 20 to 40 years. One expert stresses that it therefore is critical to invest in developing scientific talent to ensure that we can "power up research if once-sleepy fields are transformed by discoveries."

Another important factor that affects R&D is the design, development, and manufacture of sophisticated research equipment. This includes not only the physical products used by scientists, but also the process knowledge of how things are made. The development of equipment and expertise also has inherent delays and outflows that affect the R&D aging chain. Industries that are dependent upon the existence of robust R&D investment could disappear if the research base that demands their products dries up.

Dangerous Long-term Shifts

Obviously, the flows can be influenced at each point by concentrating more resources in specific areas, e.g., Product Development Research, or by decreasing the amount of funding in other areas, e.g., Fundamental Undirected Research or Mezzanine Research. Given the long delays involved, making major shifts in such funding decisions can produce undesirable long-term results that are difficult to remedy quickly.

The development of scientific talent begins with grade school children taking an interest in science and continues to the Ph.D. level, where graduate students choose their field based in part on the current job market.

This trend toward applied research, for example, though promising in the short-term, sets the stage for some dangerous long-term dynamics. A redirection toward product development research will probably have better commercial payoffs in the short term, which will lead to even stronger arguments in favor of the shift. This success may then affect long-term policy decisions, where the bias toward product development research will grow and investment in basic research will continue to dwindle (reminiscent of the "Success to the Successful" archetype).

A shift in long-term policy may set up a reinforcing cycle where increasing rounds of investments in product development will lead to increased commercial success, further reinforcing the belief that the shift is the right decision to make. In the meantime, however, cutbacks in basic research will begin to empty the pipeline of new ideas, which will make it increasingly difficult to develop new products. When that happens, rather than investing in basic research (because it will take so long), the tendency will be to crank up product development funding even more and fund basic research even less (see "Nonlinearities in Knowledge Accumulation").

A Balanced Approach

Some industry experts offer other justifications to challenge possible shifts in long-term policy. Eastman Kodak chief executive George M.C. Fisher, for example, argues that the current changes in research are based on fallacy in that "many failures of US companies to roll out new products lie not on research, they say, but in flawed business visions" (*Business Week*).

This possibility is evident in the many examples of companies that developed research, but then watched another company take over and benefit from its successful application. *Business Week* cited such examples as Xerox's development of the personal computer followed by Apple Computer's commercialization of the product, or IBM's development of high-speed microprocessors that were then made profitable by Hewlett-Packard and Sun Microsystems.

Even when U.S. companies *do* allocate money for long-term research, it is not without expectation of high returns. Some companies are actually reducing the time they will wait for a return. A senior executive at Texas Instruments, for example, reported that since the mid-1980s, the average payoff required of long-term research has been halved to about five years. Other companies ask for even quicker response—at Communications Intelligence Corporation, "long term" has been redefined as two years.

To ensure that we maintain a balance in working with these issues, Alfred P. Sloan Foundation president Ralph E. Gomory advocates a two-part approach, according to *Business Week*. First, in order to remain competitive, we need to make certain that the U.S. stays on the cutting edge in all major areas of science. Second, we need to increase funding for results-oriented work and invest in areas that promise high return. Other experts also suggest trimming in areas where progress has slowed.

Nonlinearities in Knowledge Accumulation

The complexity of aging chain dynamics contains important nonlinearities of which we need to develop a better understanding if we are to manage the R&D process more effectively. One issue is the need to have a certain critical mass of knowledge, scientists, and equipment. For example, if the accumulator of new Basic Knowledge gets below a certain level, the accompanying decrease in the output of usable ideas may drop much more rapidly than the drop in the Basic Knowledge base itself (see "Nonlinearities in Knowledge Accumulation"). Similarly, if the concentration of scientists in a particular field drops below a critical level, it may have an adverse effect on the productivity of the remaining members. Trying to identify and manage those critical threshold values will be an important factor in the success of U.S. R&D.

Many scientists and industry experts are already concerned that we may be dropping below critical mass in some areas, and they caution that the current shift in research leans too far in the short-term direction. The U.S. has led the development of the aerospace, drug, and nuclear power industries since World War II, and some believe that if current research shifts away from basic research, "entire industries may never be born."

According to *Business Week*, major U.S. companies spend less than 22% of their R&D budgets on long-term projects. The Japanese, on the other hand, allocate nearly 50% of their research funds toward the long-term, according to the industry-sponsored Council on Competitiveness. Cuts are not just occurring in specific areas of research, however. "In a survey by the Industrial Research Institute of 253 big R&D spenders, 41% say they would reduce total R&D in 1994, versus 20% that plan increases. Three times as many plan to cut long-term research funding as to raise it" (*Business Week*). Meanwhile, although the Japanese only spend $26 billion annually on R&D, this figure is rising by almost 8% per year. This, according to *Business Week*, is "a red flag for the U.S."

Managing Aging Chain Structures

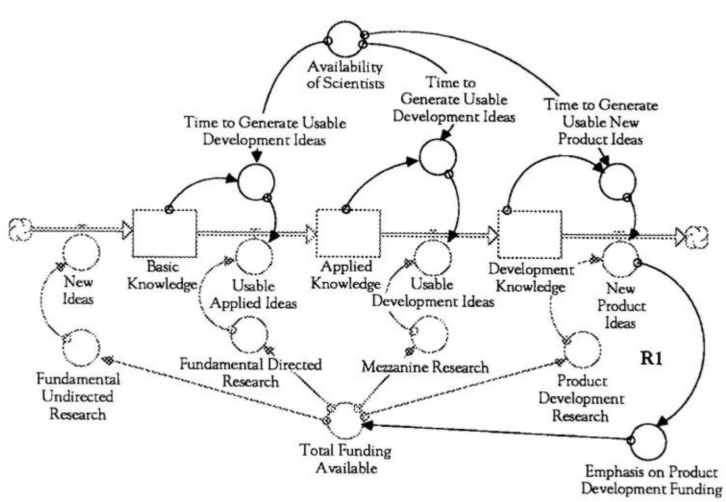
Managing aging chain structures poses a generic challenge for most organizations with R&D departments because they must wrestle with the same issues that the U.S. is facing at a national level. There is no single right answer, since the unique circumstances and goals of each organization will determine the appropriateness of actions taken. There are, however, some basic issues that should always be made explicit and should be addressed whenever one is dealing with an aging chain structure:

- Identify and quantify the nature and length of delays inherent in the system. This includes identifying parallel structures that are relevant, as well as citing specific actions that can affect the length of the delays.
- Identify any nonlinearities that may have a crippling effect on the system so you can avoid dipping below critical values. For example, if you hire new people too rapidly, the ratio between new and experienced people can get so high that overall productivity can plummet.
- Think through how short-term policies can reinforce themselves over and over again, at the expense of long-term health.

Understanding aging chain dynamics requires more than a simple pen-and-paper sketch of the accumulators and flows—it eventually requires building computer simulation models in order to see the long-term dynamics. Identifying the key structures, however, is an important first step toward building a better understanding.

If you have any comments on this article or R&D issues, please write: Feedback/Followup, The Systems Thinker, *PO Box 120 Kendall Square, Cambridge, MA 02142-0001.*

Nonlinearities in Knowledge Accumulation



As the current shifts in R&D focus play out, cutbacks in basic research will begin to empty the pipeline of new ideas, which will make it increasingly difficult to develop new products. When that happens, the tendency will be to increase product development funding and fund basic research even less. This will set up a short-term reinforcing cycle of success (R1).