MAXIMIZING THE RETURNS FROM RESEARCH

To profit from technology, companies need to change their strategy and begin selling the embodiment of that technology at the ever-shifting point of modular decoupling.

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OVERVIEW: *Companies need to match their research activities to the industry situation. Moreover, they can only successfully commercialize a new technology if they control all of the activities with which that technology interacts. Attempting to do otherwise is likely to end in frustration. After a technology is "good enough" for the marketplace, the necessary locus of integration shifts backwards. In these circumstances, companies ought to focus their research activities on individual pieces that add value. Those companies that continue to integrate their research activities across the entire value chain face the possibility of research "leaking" to specialist companies. In short, companies should not employ a one-size-fits-all-forever strategy for capturing value across the life cycles of their technologies. Rather, the right strategy will depend on finding the decoupling point, for each technology, at each point in time.*

Research that creates the right technologies at the right time is critical to competitive success in many industries. Over the long term, research into new materials, components and products provides the fuel that can make products perform better, cost less and generate attractive profits. Yet the promise that research holds is not the reality for many of the companies that invest in it. Development of breakthrough technology often does not lead to breakthrough product sales, even over a very long period, and competitors often appropriate and commercialize new technologies more nimbly than the firms that paid to develop them.

This article proposes a model that can help managers predict whether, when and why technologies that they contemplate developing will create commercial value, and when they will not.

Companies make two types of mistakes, we conclude, that can derail their hopes of reaping commercial benefit from the new technologies they have developed:

1. They can fail to integrate far enough forward to encompass within a single organization all of the unpredictable interdependencies in design and manufacturing

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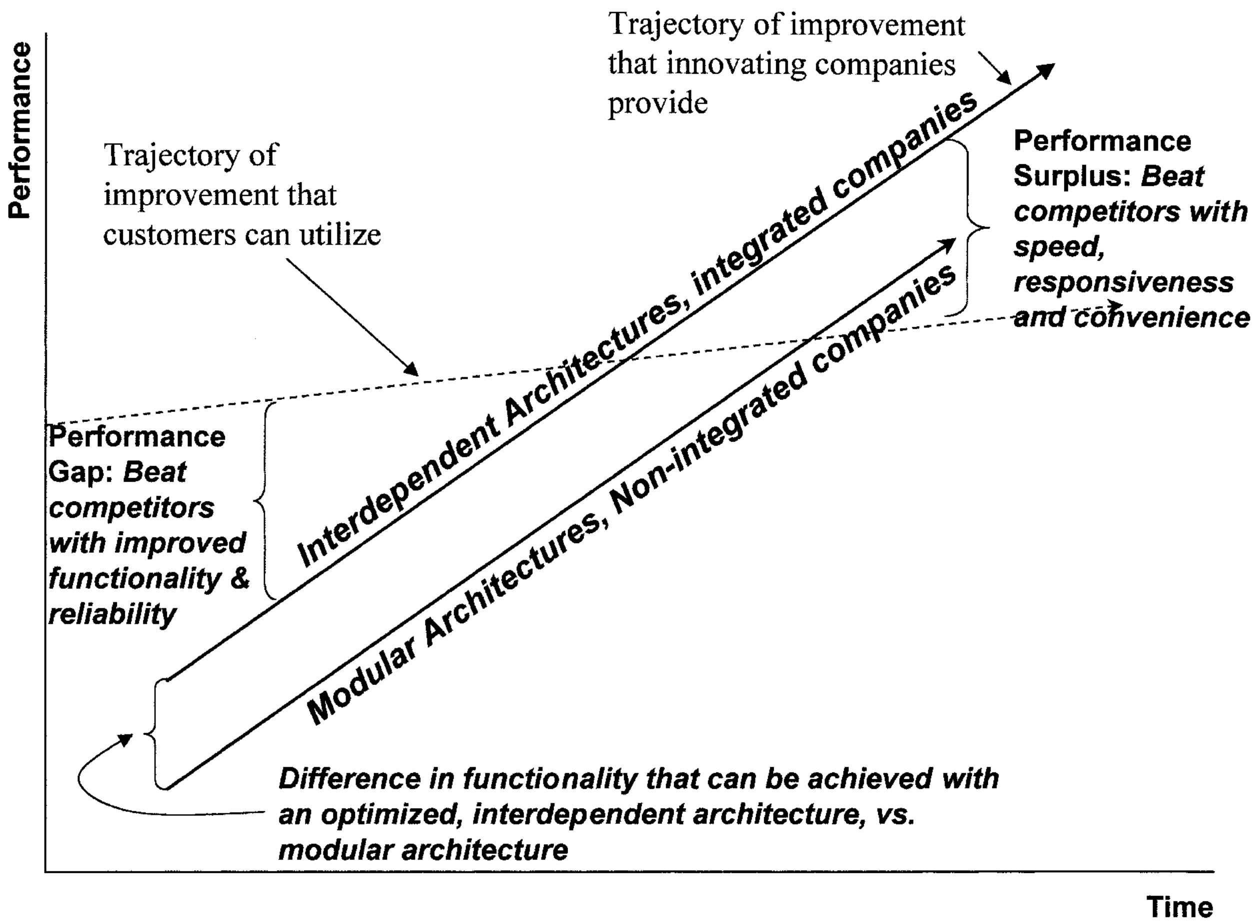

Technological progress changes the basis of competition and the nature of product architectures: When products are not good enough, integrated companies need to use interdependent architectures to improve functionality and reliability; when products are more than good enough, non-integrated companies can use modular architectures to produce customized, lower-priced products with "good enough" functionality and reliability.

that are entailed when building products that use the new technology.

2. They can fail to decouple an integrated value chain and begin selling components into the open marketplace after improved technological understanding resolves the unpredictable interdependencies that earlier had been the mandate for integration.

By helping managers predict when and why the extent of integration needs to change, we hope this model can help them improve the life-cycle profitability of their investments in developing new technologies.

When, Where and Why Integration?

As depicted above, industries tend to migrate from a state that favors integrated companies with proprietary product architectures to a state that favors modular products and specialist companies (*1*). This occurs because, in most industries, the pace of performance improvement in products and services outstrips the ability of customers to utilize that progress (*2*).

In the upper-left domain of the illustration, when there is a performance gap—when product functionality and reliability are not yet good enough to address the needs of customers in a given tier of the market—companies must compete by making the best possible products. When competitive conditions compel engineers to make the highest-performing products possible, they must experiment to fit the pieces of their systems together in ever-more-efficient ways to wring the most performance possible out of the technology that is available.

In the race to do this, firms that build their products around proprietary, interdependent architectures enjoy an important competitive advantage over competitors whose product architectures are modular. Interdependence means that the way one component is designed and made depends on the way the other components are being designed and made. In this situation, companies must control the design and manufacture of *every* critical component of the system in order to make *any* piece of the system. There is a significant advantage to being integrated with proprietary, interdependent architectures when the functionality and reliability of products are not yet good enough for the applications in which customers need to use the products.

However, our research shows that companies ultimately "overshoot" what customers in a given market application can utilize and they find themselves on the right side of the illustration where there is a performance surplus. Customers in that circumstance tend to be happy to *accept* improved products, but they are unwilling to pay a premium price to get them. One important reason why some investments in advanced technologies don't pay off is that their effect is to improve the functionality of a system that already is performing more than well enough to address the needs of customers in mainstream applications. High-definition television (HDTV) may prove to be an example of such a technology.

Overshooting does not mean that customers will no longer pay for *any* improvements. It just means that the *type* of improvement for which they will pay a premium price will change. Once their requirements for functionality and reliability have been met, customers become willing to pay premium prices for the ability to get exactly what they want, immediately when they need it, and as conveniently as possibly (*3*).

"Modular" architectures help companies to compete in the manner required in the era of performance surplus on the right side of the illustration—to be fast, flexible and responsive. Modularity helps companies introduce new products faster because they can upgrade individual subsystems without having to redesign everything. Modularity enables product designers and assemblers to mix and match best-of-breed components to give every customer exactly what he or she wants. Assemblers and designers can take advantage of competitive sourcing markets to produce lower-priced end products. Although standard interfaces inherent in modular architectures invariably force compromise in system performance, on the right side firms have the slack to trade away some performance.

Modularity has a profound impact on industry structure. Whereas firms in the interdependent world had to make all of the key elements of the system in order to make any of them, in a modular world firms can prosper by outsourcing or by supplying just one element of the product system.

Strategies to Profit from Investments in Research

What kinds of research programs can create commercial traction and growth in these different circumstances? It is in the left-side, not-yet-good-enough sector of our

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diagram that advanced research programs generally create the most value. Entrant companies that focus on one piece of a product system rarely succeed in commercializing radically new technologies in not-yet-good-enough circumstances because breakthrough technologies are rarely plug-compatible with existing systems of use. There are typically many interdependencies that mandate change in other elements of the system before a viable product that incorporates a breakthrough technology can be sold. The new-product development cycle in these instances is tortuously long and expensive, because most pieces of the system-in-use need to be redesigned before the new technology can be used.

The use of advanced ceramics materials in engines, development of color television and, more recently, high-definition television, the building of superconducting electric motors for ship propulsion, and the transition from analog to digital to all-optical telecommunications networks could all be accomplished only by extensively integrated companies whose scope could encompass all of the interdependencies that needed to be managed. This is treacherous terrain for entrants. If no company controls all of the pieces that add value and are interdependently affected by the new technology, then its commercialization is akin to pushing a string—a lot of activity happens at one end while nothing moves at the other.

We shall illustrate this now with three examples of companies' efforts to commercialize advanced technologies: superconducting ceramics, Kevlar-brand industrial aramid fiber, and advanced disk drive magnetic storage technologies.

Superconductors

The discovery of high-temperature superconducting ceramic compounds in the 1980s merited the Nobel Prize for IBM scientists. Electric motors are one promising application for this discovery because the horsepower-to-weight ratio of a motor using superconducting wires is easily 10 times greater than for motors made from conventional copper wire. Consequently, one would think that superconductor technology would quickly gain traction in applications where minimizing size and weight are valuable. But it's not that simple! Wires made from these materials are nested within an electric motor whose design must be modified significantly in order to take advantage of the properties of the superconducting materials.

An important application of large electric motors is in ship propulsion systems—but to take advantage of the reduced size and weight of a superconducting motor, the ship's design must be modified. The ship, in turn, is nested within a logistics system whose schedules and economics must be modified in order to take advantage of the properties of the faster, lighter-weight ships that superconducting motors can enable. Unless one company controls all of these elements of the nested system, individual companies, beginning farthest upstream in the value chain, must invest to make their piece of the system available to others and then wait until other companies act to incorporate the new technology in their new product design.

Technology developers must integrate forward to the point at which there is a modular interface with the next stage of value-added.

DuPont Kevlar

Commercialization of the miracle aramid fiber now known as DuPont Kevlar illustrates how subtle but complex these interdependencies can be (*4*). DuPont scientists first formulated Kevlar in 1965. Given the fiber's properties, tire cord seemed to be an obvious and attractive market application. The company worked closely with several tire manufacturers to fabricate and test a range of Kevlar-belted tires in low-volume production runs. The tires' performance was outstanding—better than that of steel-belted radial tires. On the basis of these tests, DuPont spent $400 million to build a Kevlar tire cord plant. It turned out, however, that in volume manufacturing there were problems with the adhesion of the Kevlar cord with the tire rubber that had not appeared in the handcrafted test tires. Kevlar just wasn't plug-compatible with the automobile tire system in use.

To manage the resolution of these interdependencies, DuPont would have had to become a tire manufacturer, or simply wait and hope that the tire companies would resolve the interdependencies on their own. It turned out that the tire makers weren't motivated to do so, because steel tire cord was much more plug-compatible. The first application in which Kevlar came to be used was bullet-proof fabric. In contrast to tires, this was an application in which the fiber was relatively plug-compatible with existing weaving technologies (*5*).

A general rule emerges

Already from these two cases, a general insight begins to emerge about whether, when, why, and how a company should attempt to commercialize new technologies developed in its labs. The rule is this: The company developing a new technology must plan to integrate forward from the point at which a new technology is developed, across every interdependent interface in the chain of value-adding activities out to that point at which there is a modular interface with the next stage of value-added. We call this the *decoupling point* in a value chain. At this point, the company should sell whatever embodies its technology into the external marketplace.

This decoupling point might come when the new technology is embodied in a material, a component, a subsystem, a complete product system, or a product system and its requisite after-purchase services. In the case of Kevlar tire cord, the decoupling point was between the tire and the automobile. In bullet-proof fabric, the decoupling point was between the fiber and the fabric. In superconducting wire, this point may well be between the ship operators and their customers!

As a general tendency, the speed with which new technologies find a viable commercial market is heavily influenced by marketers' ability to find an application in which there are few value-adding steps between the technology and the decoupling point. For example, Phillips Petroleum's invention of polypropylene had one of the shortest time-to-profitable-market cycles of any new plastics technology. Why? The first application was the hula hoop, where there was only an extrusion machine between the technology and the decoupling point—a delighted child. In contrast, advanced materials whose marketers have targeted commercial aircraft as their initial market have often taken longer than two decades to reach profitable commercial volumes, because there are many expensive interdependent steps between the technology and the decoupling point.

Advanced magnetic recording technologies

The disk drive industry illustrates how the decoupling point can shift as a technology becomes mature, and as new, less-mature technologies are introduced. How far forward did IBM need to integrate in order to profit from its invention of the disk drive? From the time that it introduced its first one in 1956 until the late 1970s, the design of most disk drives was *interdependent with the design of computers.* Independent disk drive companies like Pertec struggled to remain viable because of the myriad and unpredictable interdependencies in design, manufacturing and service that arose at the boundary between their drives and their customers' computers. In contrast, IBM and Control Data could cope with these interdependencies because they were integrated across the interfaces in the design, manufacture and maintenance of disk drives and computers. Because of their integration, they enjoyed a combined market share of over 85 percent for more than 15 years.

By the mid-1980s, however, a clean modular interface between the disk drive and computer had become defined. From this time on, it was no longer necessary for any firm to be integrated across that interface. It became the decoupling point in the value chain. The disk drive industry consequently came to be dominated by independent disk drive makers such as Seagate, Quantum and Maxtor. For a time, IBM refused to sell its drives in the open market, seeking to preserve the proprietary integration that previously had been so important. This caused IBM's disk drive division to flounder badly, until in the early 1990s it acquired organizational and strategic autonomy from IBM's computer business. As soon as it could begin selling disk drives into the open marketplace at this new decoupling point, IBM's market position in disk drives strengthened smartly.

Thin-film read-write heads (introduced in 1979) and magneto-resistive heads (introduced in the early 1990s) were two of the most important and sophisticated magnetic recording technologies that IBM has ever developed. In both cases, independent recording head suppliers such as Applied Magnetics and Read-Rite developed their own versions of these technologies and tried to sell their heads in the open market, yet they struggled for years to become viable suppliers of the new-technology heads. Why?

The answer is in the decoupling point. In both of these cases, companies *had* to be integrated as far forward as the design and manufacture of the complete disk drive (but no farther), because the unpredictable interdependencies in design and manufacturing that these new head technologies created were confined within the drive itself. Independent suppliers struggled to make and sell these advanced heads because their engineers could not interface intensively enough with their customers' engineers to address the unpredictable interdependencies that use of their heads created within their customers' disk drive designs. While the independent firms floundered, IBM designed its heads into proprietary, interdependent disk drive architectures. In particular, its use of magneto-resistive heads in 2.5-inch drives through most of the 1990s garnered gross margins three times higher than the industry average. IBM controlled over 80 percent of the market because it was integrated forward to the decoupling point.

After six or seven years in the market, however, these technologies became well enough understood that most interdependencies became predictable, and the critical parameters of head and disk drive design were specifiable and measurable. From that time on, it was no longer necessary for a head supplier to be integrated into the design and manufacture of disk drives in order to profit from these recording head technologies. When the head had become the decoupling point, specialist head manufacturers such as Yamaha could become capable suppliers, and non-integrated disk drive assemblers could successfully source heads from third-party suppliers.

Again, IBM attempted to remain integrated for too many years after the decoupling point shifted, enabling competing firms to profit from technology that IBM originally developed. IBM needed to have become a head supplier when the decoupling point shifted in order to continue being the dominant supplier of the technology that it developed.

A third valuable magnetic storage technology that IBM developed during this period was thin-film disk technology. This technological achievement was no less impressive than its advanced head technologies. But in contrast to heads, IBM struggled from the beginning to keep the returns from its disk technology for itself because of the decoupling point's location. Even though the technology *within* the disk was radically new, the algorithms that defined how the coercivity, thickness and lubricity of the magnetic material interacted with the other elements of the disk drive's design were so well understood from the outset that there were few unpredictable interdependencies between use of thin-film disks and the design or manufacture of other subsystems within the drive. This meant that the disk itself was the decoupling point.

From the very beginning, IBM would have needed to sell *disks*—not just to its own disk drive assembly operation, but into the open market as well. IBM's integrated organization, which was such a strength in the interdependent world of immature recording head technologies, conferred no advantage in the modular world of thin-film disks. The company's attempt to keep modular disks proprietary slowed it down, creating the opportunity for venture capitalists to entice engineers to leave IBM and Xerox to form specialist companies such as Komag (*6*). They entered the market at the decoupling point and captured a significant portion of the returns from IBM and Xerox's research.

Locating the Decoupling Point

What these cases from disk drive history add to the decoupling point rule that we stated above is that companies should not employ a one-size-fits-all-forever strategy for capturing value across the life cycles of their technologies. The right strategy depends upon where the decoupling point is, for each technology, at each point in time.

How can managers tell when the decoupling point is going to shift? When the four conditions that follow become satisfied. The first three are technical; the fourth is commercial:

1. Engineers at a stage of value-added are able to specify accurately each of the parameters that their suppliers in the adjacent upstream stage of value-added must meet in order for what they provide to be used with predictable effect.

2. The specified parameters can be measured unambiguously.

3. There can still be interdependencies between the way the component is designed and made, and the way the rest of the system must be designed and made. But these interdependencies must be understood and predictable.

An easy way to sense that these three technical conditions are coalescing is that engineers begin trying to build visual models of their product via computer simulation. They can only do this when the rules of cause-and-effect have become clear enough.

4. The fourth condition is that there be no chicken-and-egg problem of supply and demand at the interface: a tangible market for the new technology must exist at the next stage of value-added.

Color television remains the clearest illustration of this principle; its introduction was delayed because broadcasters wouldn't buy equipment to broadcast in color unless customers had sets that would receive in color. And customers would not buy sets that would receive in color unless broadcasters bought equipment to broadcast in color. Because RCA owned NBC, RCA was uniquely positioned to break the chicken-and-egg dilemma and introduce color televisions.

Almost always, it is the activity just *before* the decoupling point where the most attractive profitability in the value chain can be achieved. The reason for this is that performance in a modular product is not determined within the product's architecture, but within the subsystems from which the modular product is assembled. At the stage of value-added just before the decoupling point, performance differences are determined primarily by the interdependent architecture and less by the components that are used.

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In the case of disk drive technologies, this point originally was at the interface between the mainframe computer and the system user. It then shifted progressively back to the disk drive, and then to the key components or sub-systems within the drive that defined the drive's performance. This is also why the most attractive point of profitability comes in selling ink jet printer cartridges with embedded print heads, rather than ink jet printers themselves; why semiconductor equipment manufacturers historically have been more profitable than the fab operators that buy and use the equipment, and so on (*7*).

In our view, this explains in part why research activities continue to win enthusiastic funding in the pharmaceutical industry and portions of the chemical industry—because the interdependencies in the downstream value chain (at least historically) have extended all the way to the salable product that the sponsoring companies have viewed as their core commercial business. In industries where research spending has been curtailed significantly, as in some electronics and electromechanical equipment companies, the decoupling point has moved up the value chain to a material, component or subsystem. But because the research-sponsoring companies (such as IBM, Xerox, Lucent, and GE) have typically viewed complete product systems rather than components and materials as their core business, other firms that sold products at the decoupling point have appropriated much of the profit generated by the technology that these integrated firms developed. When companies such as these fail to change strategy to begin selling whatever it is that embodies the technology at the ever-shifting point of modular decoupling, they lose their ability to appropriate the attractive returns on their investments in research.

The strategies of integration that are so central to profiting from research, therefore, require repeated re-assessment. We shall close with a final example of this. Pharmaceutical firms, as we have mentioned, have long been able to create and capture substantial value from research. The discovery, design and delivery of drugs required mastering numerous interdependencies with the design and execution of clinical trials, which in turn had complicated interdependencies with manufacturing and marketing. High fixed costs created steep scale economies, so that bigger was indeed better.

There are signs, however, that circumstances may be changing. Modularity is creeping into the system—meaning that research organizations that were a capability in the past could be a disability in the future. Scientific progress is unlocking the human genome, portending better-understood rules and computer simulations to do research. The success of biotech firms shows that specialized firms can develop promising drugs, while other firms can manage their clinical trials and others can manufacture and market them. Companies such as InnoCentive are acting as matchmakers between research-seeking companies and scientists. The decoupling point, in other words, is creeping back up the value chain. The largest pharmaceutical companies have responded by getting even larger. In our view, they may be swimming in the wrong direction, against a very strong current. To maximize returns on their investments in research, they too may need to begin to market their technology earlier, as the decoupling point shifts. ⦿

References and Notes

1. Christensen, Clayton M. and Michael E. Raynor. *The Innovator's Solution.* Boston: Harvard Business School Press, 2003. In particular, chapters 2, 5 and 6 address these issues.

2. This phenomenon and its causes were evaluated in Christensen, Clayton M. *The Innovator's Dilemma.* Boston: Harvard Business School Press, 1997. The references in that book, in turn, can lead interested readers to a range of antecedent studies published in academic journals.

3. This observation is consistent with one of the fundamental paradigms of microeconomics: marginal price will equal marginal utility. When there is performance gap, every improvement yields greater utility, which merits higher prices. But when there is performance surplus, the marginal utility that customers derive from further improvements in performance is minimal, and therefore the marginal price that they will pay for those improvements becomes minimal.

4. This history is recounted more completely in Hounshell, David A. "DuPont Kevlar Aramid Industrial Fiber." Harvard Business School case #391–146; and in "Touch Fiber: DuPont's Difficulties in Selling Kevlar Show Hurdles of Innovation." *The Wall Street Journal,* Sept. 29, 1987, p. 1.

5. Chris Musso, a doctoral student in materials science at MIT, is engaged in a thesis research project whose likely result will be a model that identifies the factors that determine how long the commercialization cycle for new materials is likely to be. Musso's work also promises to be able to quantify the impact that each of these factors has on time-to-profitable-volume. We are hopeful that the factors in Musso's model will be generalizable to many different types of new technologies, in addition to new materials. Readers who are interested in learning about Musso's research can contact him through Professor Clayton Christensen at the Harvard Business School.

6. Xerox also developed this technology in its Palo Alto Research Center, in an effort parallel to that of IBM.

7. The reasons for this are described in chapters 5 and 6 of Christensen, Clayton M. and Michael E. Raynor. *The Innovator's Solution.* Boston: Harvard Business School Press, 2003.