Technology Management in Media and Information Firms

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4.1 Technology Management

4.1.1 Technology Drivers and Trends

The media sector consists of three broad segments: content creation, distribution, and media devices. This chapter focuses on the devices and their development, and more generally on the technology of media and communications that also underlies distribution networks and content production. The key question of technology management is how to reconcile an unpredictable and disruptive process of innovation with organized business management.

The issues addressed are:

1. How does a media company organize its technology function?
2. How does technology innovation affect media industries?

Technology transforms our lives, our work lives, and the way we produce and consume media. For media firms, technology is destiny; or, at least, it is a trajectory, a direction. Technology has always initiated big media innovations. The printing press created the publishing industry. The telegraph spawned global wireline networks. The phonograph created the music recording industry. Broadcast technology and TV screens shifted mass media to the home. More recently, personal computers (PCs), cellular mobile networks, and the internet have been rapidly transforming the creation, distribution, and location of media.

As mentioned, in the industrial revolution the main technology driver was the ability to create machine-based power as a substitute for human and animal muscle power. For the information revolution the main technology driver is the increased ability to create machine-based information processing as a substitute and complement for human brainpower. This is done through the ability to manipulate subatomic particles (electrons and photons) through a variety of devices, followed by an ability to string these devices together to create systems and applications, which can process all forms of information based on binary signals.

Not long ago, the various types of media employed specialized technology devices: text-based media such as newspapers used the printing press; audio-based media such as music used spinning vinyl records; film had its celluloid photographic technology; TV broadcasting transmitted various analog waveforms, while telephone networks enabled two-way audio signals over copper lines. Each of these media types was based on separate technologies, devices, suppliers, producers, industries, and regulatory systems. But, more recently, all are increasingly based on common technical elements:

- semiconductor electronic components;
- software programs and modules
- radio-frequency transmission and receiving devices;
- information processors;
- display screens;
- optical signal devices;
- storage devices and components;
- battery technology;
- fiber transmission and distribution links;
- signal switching and routing devices;
- information coding methods.

Because these components are usable across most types of media devices, the expectation was that this would also lead to a convergence in the underlying media technologies in media industries and firms, and thus of media themselves.

"Media convergence" thus became a concept much bandied about, but it was slower to emerge in reality. In the 1980s, the conventional wisdom was that the future electronic environment would be dominated by a titanic struggle between the giants AT&T and IBM, then dominant in their respective sectors of telecom and computers. Both were making big electronic boxes that were interconnected worldwide and which generated and controlled flows of digital information. Inevitably, they would become each other's greatest rivals. And indeed, AT&T joined the computer market, after the US government dropped its entry restrictions, while IBM started to operate global satellite communications and data networks. Soon, however, business reality set in. None of the forays proved successful. IBM withdrew from the telecommunications sector while AT&T abandoned its business in computers after incurring huge losses. There were other instances where successful companies moved beyond their core area and failed. Time Warner, in a major merger with AOL, wanted to enter the internet; Microsoft made major investments in cable TV; the Japanese consumer electronics (CE) giant Matsushita (Panasonic) bought a Hollywood film studio; Bertelsmann moved into online activities. The outcomes were disastrous for the companies involved.

Will the same happen to the new set of companies, in particular Google, Apple, Amazon, Facebook, and Samsung? Beyond company-specific rules, the more fundamental reason is that convergence is not the only business trend. A second powerful trend is the acceleration of innovation, and with it the incentives to specialization and differentiation in order to succeed in a highly competitive environment.

While technology has been converging, few firms have succeeded in keeping up with the pace of change in multiple fields. Why not? To answer this question, we will discuss throughout this chapter a major "convergence firm"—the Japanese electronics and entertainment company Sony.

4.1.2 Case Discussion

Sony and the Perils of Technology Convergence

Is Sony the exception to or a confirmation of the frequent failure of convergence companies in the technology field? Sony has been active in many media and media technology sectors: TV sets, radios, audio players, computers, cameras, film production, TV shows, music, film production equipment, game hardware and software, telecom handsets, and financial services.

The question is, can Sony be a technology leader in all these fields? Has Sony's technology strategy of convergence worked?

For 14 generations, the Morita family ran a sake brewery in Osaka. After Japan's defeat in World War II in 1945, Akio Morita broke away from family tradition and started, in a basement, the Tokyo Telecommunications Engineering Corporation, soon renamed Sony Electronics. In 1950, Sony came out with its first breakthrough product, the inexpensive transistor radio, TR-55. By the late 1950s, Sony had become a major producer of radios, television sets, and other home entertainment devices. In the 1970s, Sony changed its strategy from a low-cost producer to a technology leader with a wide array of smartly designed products.

In 1975, Sony introduced the first consumer video cassette recorder (VCR), the Betamax. But its rival Matsushita's Video Home System (VHS) technology prevailed. In 1979 Sony introduced the Walkman as a portable cassette tape audio device and sparked a revolution in portable music and in music cassette sales.

Sony's strategist in the 1980s was Norio Ohga, who had had a career as an opera singer and symphony orchestra conductor. Ohga negotiated Sony's acquisition of CBS Records for $2 billion, and this helped Sony launch the compact disc (CD). Based on the success of the CD, Sony entered the film business as well. In 1989, Morita bought the film studio UA-Columbia from Coca-Cola for $3.4 billion. Nobuyuki Idei, who handled the home video division, succeeded Morita as chief executive officer (CEO). Sony was nicely balanced across its business segments and geographic regions, deriving about a quarter of its sales each from Japan, Europe, the USA, and the rest of the world. Sony became, according to annual Harris Polls, America's number one "best brand" for most of the years 1996–2007, ahead of Coca-Cola, Ford, or General Electric (GE).

After 2000, however, Sony has been under pressure. Worldwide prices for CE products fell. New competitors emerged. Sony's revenues declined, as did its profits and stock price. By 2005, Moody's lowered its long-term credit ratings for Sony from A1 to A2. In that year, Sony's most profitable business was not electronics or entertainment but financial services.

Under fire, Idei's successor Kunitake Ando was forced to step down. Welsh-born Howard Stringer, a former news producer for CBS in New York, became Sony president. He spoke no Japanese, was no engineer, and operated mostly from Sony's American base in New York.[1]

Sony began rebuilding. It sold its real estate assets and financial services, and dropped 6% of its workforce (16,000 employees). It eliminated about 600 products, closing four plants in Japan and another four overseas. Another round of job reductions was started in 2012, totaling over 10,000. But this did not end the problems. Sony's products did not sell as they used to. It lost much money on its TV sets, fell behind in flat screens, laptops, and mobile phones, and was weak in MP3 players, despite the connection to its own huge music division (which also declined.) The questions are, therefore, whether Sony's technology efforts worked well, whether they were well managed, or whether they contributed to the decline of the company.

4.2 How Is Research and Development Managed

4.2.1 The Technology Function

Research and development (R&D) is the creation of new knowledge by the firm and the strengthening of its existing and future operations and products. "Research" expands the firm's scientific knowledge and engineering skills. "Development" applies this knowledge and makes it relevant to the firm's business through new products.

The image of innovation has been that of an individualistic endeavor. Lone (or duo) inventors indeed abound—Gutenberg, Fulton, Watt, Marconi, Morse, Bell, Tesla, the Wright brothers, the Lumière brothers, Jobs and Wozniak, Gates and Allen, Brin and Page. But the reality of corporate R&D is less glamorous than such heroic images of invention. Thomas Edison's major innovation might not have been the real lightbulb but the figurative one: the organized process of invention.

Edison established a free-standing laboratory in 1876 in Orange, NJ. In that laboratory a year later, the Edison team developed a rotating wax tin-foil cylinder with grooves, and created the first CE product. In 1891, Edison's lab came out with an early movie technology. In 1879 the lab developed the light bulb, which led to electric power generation and distribution, which in turn enabled and powered numerous new devices.

Following this model, major companies established large and organized R&D structures. They created sprawling research facilities such as Bell Labs, IBM Labs, RCA Labs, and GE Labs (Figs. 4.1 and 4.2).[2] Similar big corporate laboratories exist in other countries.

This approach has not been the organizational path for start-ups, which follow more the lone-inventor model. However, some of the most innovative technologies were initially spawned inside the large labs by researchers who then went out on their own.

1 Schlender, Brent. "Inside the Shakeup at Sony." *Fortune Magazine*. April 4, 2005. Last accessed August 10, 2012. ► http://money.cnn.com/magazines/fortune/fortune_archive/2005/04/04/8255921/index.htm.

2 AT&T also operated a huge R&D facility at Murray Hill, NJ and several other research centers. Photo used under Creative Commons. Beaumont, Lee "Bell Labs Holmdel." ► https://commons.wikimedia.org/wiki/File:Bell_Labs_Holmdel.jpg.

Fig. 4.1 Bell Labs R&D facility in Holmdel, NJ

Fig. 4.2 Bell Labs R&D Facility in Murray Hill, NJ

4.2.2 Chief Technology Officer

Inside a company, the technology function is often run by an executive with a title such as Chief Technology Officer (CTO) or Chief Scientist. The CTO is the link between business managers and technical personnel. His (or her) role must be distinguished from the Chief Information Officer (CIO), who is responsible for internal information technology (IT) adoption and support. It must be also distinguished from a more recent "C-level" position, that of the Chief Digital (or Data) Officer (CDO). The CDO's responsibility is to ensure that a company's digital databases and content are used effectively. The CIO role, too, has changed substantially over time and assumed greater importance.[3]

The CTO is not a lab director but rather a technical- and management-savvy businessperson (often with a tech background) who shapes part of the overall corporate strategy along the dimension of technology.[4] The CTO's role differs depending on company, industry, and personal qualifications. Generally, she oversees the process of technological innovation in products and operations. To do so, the CTO needs to be a change agent who can identify new technology and bring it into the company. Obviously, large companies are more likely to deploy a CTO than small ones, but conceptually even a grocery store needs someone who takes the initiative to bring in new technology.[5]

The tasks for the CTO are numerous, and include:

- technology assessment;
- supervising innovation and product development;
- selecting key R&D projects for funding;
- integration of R&D with firm strategy;
- placement of R&D;
- procurement and implementation of internal and outsourced technical systems;
- design of technical operations;
- structuring R&D activities;
- organizing the R&D lab;
- cost control of R&D;
- managing the globalization of R&D;
- implementing R&D alliances;
- working with independent developers and "Open Innovation";

3 Before the 1980s, CIOs were called Information Systems Managers. As with the CTO, there is no well-defined model. Strickland, Stefanos A., and Babis Theodoulidis. "Chief Information Officer: A Journey Through Time." Working Paper, Centre for Service Research, Manchester Business School, University of Manchester, 2011.

4 Lewis, W.W. and H. L. Lawrence. "A new mission for corporate technology." *Sloan Management Review* 34, no. 3 (1990). Taken from Smith, Roger D. "The Role of the Chief Technology Officer in Strategic Innovation, Project Execution, and mentoring." *Research Technology Management* 46, no. 4 (August 2002): 3.

5 Smith, Roger. "5 Patterns of the Chief Technology Officers." *Research Technology Management*. Last accessed April 30, 2017. ► http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.158.1721&rep=rep1&type=pdf.

- knowledge management (KM) for R&D;
- participation in standards strategy;
- participation in the internal adoption of technology;
- creating a climate of innovation.

We will now review several of these functions as a way to understand a company's management of technology, a critical function in the media and communications sector.

4.2.3 Key Tasks for the CTO: Technology Assessment

The CTO identifies present and future technology options and assesses their potential role for the company. Factors are technical viability and business potential.[6] A similar assessment effort must be conducted by investors when they evaluate a start-up firm that is based on new technology, or by a company when it tries to acquire another firm that holds special technologies and patents.[7] Technology assessment can use market research to find out what consumers want, but this will often disappoint. In most cases, the CTO must be ahead of consumers.

The technology assessment includes a review of:

- technological claims of the innovation;
- track record of the technology;
- track record of the lead innovators;
- rival approaches and competitive advantages;
- in-house R&D capabilities;
- implementation issues;
- patent and other intellectual property rights (IPR) issues;
- fit with company strategy;
- upside potential and downside risks;
- market opportunity;
- financial requirements to create or acquire the technology;
- financial requirements for product roll-out.

A forward-looking perspective is essential. When he was Microsoft's CTO, Nathan Myhrvoid observed: "my job at Microsoft is to worry about technology in the future. If you want to have a great future you have to start thinking about it in the present, because when the future's here you won't have the time."[8]

However, assessing technology is difficult even for experts. One of the greatest scientists of all time, Ernest Rutherford of Cambridge University, dismissed nuclear energy in a presidential address to the Royal Physics Society in 1933: "Anyone who expects a source of power from the transformation of these atoms is talking moonshine."[9] At the opposite extreme, another famous scientist, John von Neumann, predicted in 1956 that "a few decades hence, energy may be free, just like unmetered air." If two such leading lights can be so wrong, and diametrically so, how can a lesser technology manager have a chance to be right? The answer is that a CTO need not deal with the long-range future of science. Her role has to be to deal with the set of "plausible possibles," that is, with scenarios and opportunities that are composed of already existing building blocks.

How to go about looking forward in such a way? To stay close to the leading edge, information is key. This means close ties to academic laboratories and journals, attendance at trade shows, reading of trade and technology magazines, checking out websites, and the creation of a personal network of respected innovators and business analysts.

Another way to review the state and pace technology advances in a field is to look at published patents in one's sector.[10] Patent applications and grants are useful as a source of information about the "prior art" of technology innovations. Looking at patent applications one can identify competitors, innovators, and potential partners and licensees, as well as the velocity of technology in a sub-area.[11]

As mentioned earlier, in engineering terms the driver of the revolution in IT is our increased ability to manipulate sub-atomic particles—electrons and photons. The components to do so are the building blocks of IT devices, which in turn are constituent parts of systems and networks. These devices are governed by controls—software. The manipulated particles are used for the generation, distribution, storage, processing, and display of various forms of content and of applications.

Progress in the field of electronics has followed broad trends. A major way to assess a specific technology is to compare it with the more general rate of change in the electronic sector. Forty years ago, the computer electronics pioneer Gordon Moore observed that the power of semiconductors doubled every one to two years and predicted that this trend would continue. This rate of progress—about 40% a year—became famous as Moore's Law. And indeed, it described the progress over the next decades pretty well. Computer components became smaller, or more powerful, or cheaper, at roughly the predicted rate. Whereas in 1970 a memory chip would store 1000 bits, it holds up to 8 trillion in 2017 (1 TB). Such progress enables marvels of technology, from CAT scans to video over cellphones. It also provided an important anti-inflationary force to the economy.

Almost immediately, however, people questioned the validity of the law. Some objections were based on specifics of physics, electronics, systems design, and software.

6 Inside Jobs. "CTO." Last accessed July 11, 2011. ► http://www.insidejobs.com/jobs/cto.
7 Smith, Roger D. "The Role of the Chief Technology Officer in Strategic Innovation, Project Execution, and mentoring." *Research Technology Management* 46, no. 4 (August 2002): 10.
8 Smith, Roger. "5 Patterns of the Chief Technology Officers." *Research-Technology Management*. Last accessed April 30, 2017. ► http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.158.1721&rep=rep1&type=pdf.
9 Doyle, Jim. "Energy from Nuclear Fission." June 20, 2011. Last accessed July 12, 2011. ► http://www.btinternet.com/~j.doyle/SR/Emc2/Fission.htm.
10 The US government's website for patent searches is ► http://patents.uspto.gov. IBM's free site ► http://patent.womplex.ibm.com. In Europe, the European Patent Office is at ► http://www.epo.co.at:80/index.htm. And in Japan (with a fee for full text translations) ► http://www.intlscience.com and ► http://www.jpo-miti.go.jp.
11 Department of Commerce. "US Patent Office." May 27, 2011. Last accessed June 12, 2011. ► http://patents.uspto.gov/.

But the basic objection required no knowledge of advanced technology. It was simply that an exponential trend of this magnitude could not continue into the far future. Eventually improvements would become harder, costlier, less important, less profitable, and hence slower in coming.

And yet, confounding the predictions of its imminent demise, Moore's Law has shown remarkable resiliency. Further progress in processing power per cubic inch will come from a variety of exotic sources, such as three-dimensionality of components, carbon nano-tubes, quantum computing, X-ray lithography, system-on-a-chip, and new fabrication systems. Yet the basic point of an eventual slowdown is still valid, even if it is postponed.

Part of the secret for the law's resilience has been that it has moved from prediction to self-fulfilling prophecy. It establishes a time line for progress that everyone in this highly decentralized industry understands. When a company is engaged in developing the next generation of its components, software, or hardware, it knows that the overall pace of technology progresses at the rate of Moore's Law, and it must plan to match it. If it falls behind that pace it must add engineers, money, and partners to its development effort. If it is too far ahead, it might end up designing products that have no complementary devices or content and will not find buyers. If its production costs do not drop fast enough it must compensate by gaining scale or moving to cheaper shores. Thus, like a giant bell tower, Moore's Law has helped to synchronize global electronics.

Similar trends can be observed in the transmission throughput "speeds" achieved by engineers, which leads to ever-cheaper transmission "bandwidth,"[12] or to the increased amount of information that can be stored and processed in less and less space for less and less money. It also translates to an exponential trend in the cost per unit of distribution of information over time.

A firm can look ahead, identify the trends in the underlying components in terms of performance and cost, and then analyze in what direction this is taking the industry. There is no need to resort to science fiction. One can observe the trends, what leading edge adopters are already doing, and what technology companies are offering by way of hardware and applications. Of course, details of developments are unfathomable in advance, but the broad trend is a different story. When radio emerged in the 1920s, it was new, different, and unpredictable. But the same could not be said for broadcast television and satellite television. There, one could make strong predictions about where things would be going, based on the experience of the preceding media generation of radio. More recently, the internet was another paradigm shift whose impact went beyond advance analysis. But once established for text, its application to audio and video were much easier to analyze without resorting to science fiction. We can be quite certain, for example, that the trend of component consolidation will continue toward a computer (or system) on a chip, with multiple functionalities joined together that have been separate in the past, and that connectivity speeds will continue to rise. If there is a problem of analysis, it is often the gold rush mentality permeating the environment, which makes detached analysis difficult.

4.2.3.1 Selection of R&D Projects for Funding

According to one analysis, it requires about 3000 raw ideas to produce one substantially new commercially successful industrial product.[13] These 3000 new ideas are narrowed down to 125 small projects of which approximately nine evolve into significant projects for major development efforts and commercial launches (Fig. 4.3).[14] Of these only one is commercially successful.

With these staggering odds, how is a firm to evaluate how to select among technology ideas?

Innovation is a discovery process and may not necessarily have a sure destination.[15] But it helps to define the task for the R&D project clearly. When Steve Jobs envisioned the iPod, he defined the goal as "1000 songs in my pocket." Once a task is well-defined, it is easier to develop a focused and actionable strategy. (However, many of the most important innovations cannot be willed but emerge serendipitously).

Ralph Waldo Emerson wrote, "If a man can write a better book, preach a better sermon, or make a better mousetrap than his neighbor, though he build his house in the woods, the world will make a beaten path to his door." But this is not necessarily true. Studies show that 40–90% of new products fail, many of them superior to what exists otherwise. Experts and early adopters loved TiVo's digital video recorder, but consumers were reluctant to sign up and the company lost over $600 million by 2005, and subsequently was in the red in six out of eight years because of low demand.

Why do consumers fail to buy innovative products? An explanation is supplied by behavioral economists such as 2002 Nobel Prize winner Daniel Kahneman, who showed, with Amos Tversky, that consumers have a "loss aversion," which means that they fear losses much more than gains of the same magnitude. The problem with introducing a new technology or applications is that is forces consumers to change their behavior, which is never easy. Studies show that people tend to overvalue the benefits of the goods they own and know over new ones, by a factor of 3:1. Innovators, at the same time, overvalue their new products by the same factor. Having put their ideas, hopes, energy, money, and time into a new product, innovators tend to lose a sense of realism.[16] Taken

12 Magee, Christopher L. "A Quantitative Functional Approach to the Study of Technological Progress." Massachusetts Institute of Technology. April 30, 2007.

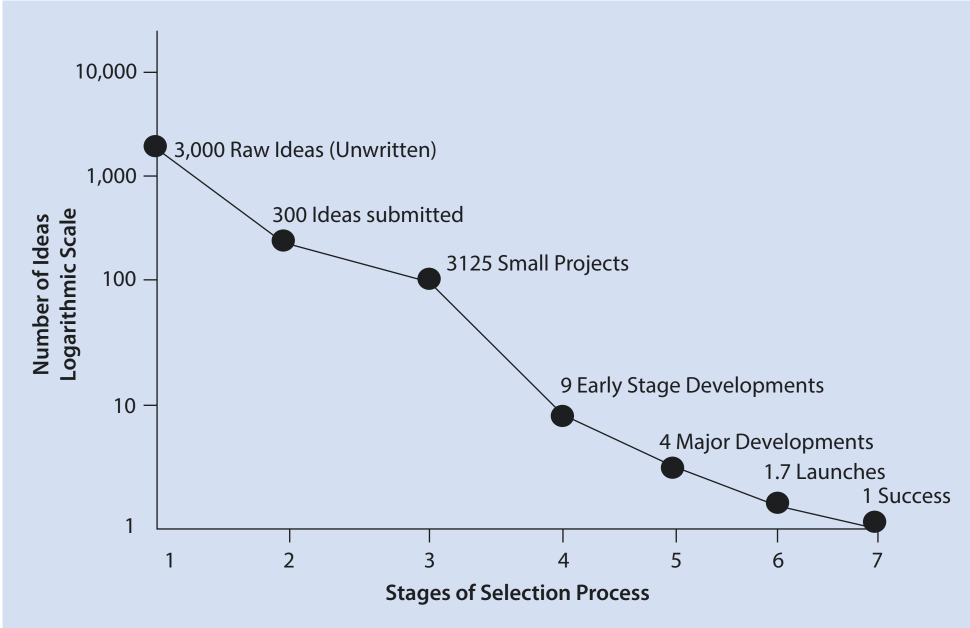
13 Stevens, Greg A. and James Burley. "3000 Raw Ideas = 1 Commercial Success!" *Research Technology Management* 40, no. 3 (May/June 1997): 1–12.

14 Graph based on Stevens, Greg A. and James Burley. "3,000 Raw Ideas = 1 Commercial Success!" *Research Technology Management* 40, no. 3 (May/June 1997): 1-12.

15 Satell, Greg. "How to Manage Innovation." *Forbes.* March 7, 2013. Last accessed May 2, 2017. ► http://www.forbes.com/sites/gregsatell/2013/03/07/how-to-manage-innovation-2/.

16 Gourville, John T. "Eager Sellers & Stony Buyers." *Harvard Business Review* 84, no. 6 (June 2006): 98–106.

Fig. 4.3 R&D project selectivity and success rate



together, there is a mismatch of 9:1 between what innovators think consumers want and what consumers truly desire. A new product must therefore not be better by a small measure, but its gains must far outweigh the potential losses, or consumers will not adopt it.

In every active company, plenty of ideas bubble up that could lead to promising products. But money, time, personnel, and attention are scarcer than ideas. How then does a company select projects for R&D funding? Gut feeling and hunches are one way to go. Another is to formalize the process. There are several approaches:

- scoring;
- demand research;
- an economic-financial analysis:
  - net present value;
  - real options.

Scoring methods rank potential R&D projects according to several performance dimensions.[17,18] Such dimensions might be the completion probability of a project, its duration, its budget cost, the number of researchers needed to complete the project, the potential use for follow-up products. As an example, assume that five projects (A to E) are assessed (Table 4.1).[19]

Projects are scored along criteria 1–7, with a grade ranging from 1–10 (column 3), and the weighting of the criteria, according to its importance. From 1–10 (column 2). For example, Project A scores a high 10 on criterion 1 and a low 2 on criterion 2. These scores are then multiplied by their weight factor (7.5 and 6.9), resulting in scores of 75.0 and 13.8 (column 4). These criterion scores are then added up, resulting in an overall score of 313.4 for Project A, 286.6 for Project B, and 268.0 for Project C. The projects can be ranked from high to low. Project A scores highest and Project B is second-highest.

However, the scoring method has problems. The formula and its weights tend to be inflexible. Yet if they were flexible and changeable they could be manipulated to get a desired result.

In addition, the decision to proceed with an R&D project is not only a technological one to be made by engineers, because that would lead to "supply-side innovation" and might fail in the market. Almost as important as understanding the technology potential is to analyze the market environment, the demand for a new product, and a competitors rival products. Technologists (and Emerson) often believe that a superior innovation will guarantee acceptance. Regrettably, that is not so. There is a difference between technical promise and business achievement. An R&D project requires, beyond the early technology effort, a sustained level of subsequent investment in commercialization.[20]

The weakness of the scoring method is that a technology-based formula is not linked to a market-based economic and financial analysis. Such an analysis is based on one of several interrelated methodologies: net present value (NPV), internal rate of return (IRR), return on investment (ROI), discounted cash flow (DCF), cost–benefit analysis (CBA), and payback period.

The following is an example for R&D selection based on the NPV and ROI (Table 4.2). Project A contains a new

17 Poh, K.L., B.W. Ang, and F. Bai. "A Comparative analysis of R&D project evaluation methods." *R&D Management* 31, no. 1 (January 2001): 63–75.

18 The Economist. "Out of the Dusty Labs – The Rise and Fall of Corporate R&D." March 1, 2007. Last accessed May 2, 2017. ► http://www.economist.com/node/8769863.

19 Rengarajan, S. and P. Jagannathan. "Project selection by scoring for a large R&D organization in a developing country." *R&D Management* 27, no. 2 (April 1997): 155–164.

20 Leonard-Barton, Dorothy and William A. Kraus. "Implementing new technology." *Harvard Business Review*. November 1985. Last accessed May 2, 2017. ► https://hbr.org/1985/11/implementing-new-technology.

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Table 4.1 Ranking and scoring R&D projects

Criterion no.	Weightage factor (WF)	Project A		Project B		Project C	
		Marks	Marks × WF	Marks	Marks × WF	Marks	Marks × WF
1	7.5	10	75.0	10	75.0	8	60.0
2	6.9	2	13.8	10	69.0	8	55.2
3	6.8	10	68.0	2	13.6	2	13.6
4	7.0	10	70.0	10	70.0	8	70.0
5	4.6	8	36.8	2	9.2	2	9.2
6	5.1	8	40.8	8	40.8	10	51.0
7	4.5	2	9.0	2	9.0	2	9.0
Total score			313.4		286.6		268.0

Table 4.2 ROI of projects

Year	0	1	2	3	4	Net profit	ROI	NPV	ROI_D
Project A	−9000	−1000	4000	6000	10,000	10,000	1.0	4304	0.435
Project B	−3000	0	0	3000	6000	6000	2.0	3047	1.016

technology development with high initial research expenditures of 9000. However, the project is expected to have high returns after year 2. In contrast, Project B is a project with modest research expenditures (3000). However, it will not generate revenue for two years owing to authorization procedures. After the first two years, Project B is expected to produce significant returns in years 3 and 4.

If we compare net profits, Project A is superior (10,000 vs. 6000). But what about the return on investment? ROI is found by dividing net profit by the investment. For project A, this would be $\frac{10,000}{10,000} = 1.0$. For project B it is $\frac{6,000}{3,000} = 2.0$. Now, project B seems superior.

But this does not take into account the time-value of money. Some of the revenues are realized in future years down the road. To take this into consideration one discounts the future earnings by a discount rate, say 10% per year. We then obtain NPVs for A and B of 4304 and 3047. Now, Project A seems the superior option. Lastly, if the ROI is used with the time value of money considered (i.e. discounted) as would be the economically proper way, it would be, for A, $\text{ROI} = \frac{4304}{9000+900} = .4347$, and for B, $\text{ROI} = \frac{3047}{3000} = 1.0157$. Thus Project B is the superior choice.

These financial methodologies' chief problem is that it is difficult to forecast future net revenues. It involves subjective projections of sales, prices, the state of the economy, and the effectiveness of competitors. Company projections of future market penetration are often overly optimistic. One must also pick the appropriate discount rate, and that rate varies with risk.

One major problem with the financial analysis of R&D projects is the use of accounting information as the foundation for the data. In accounting, R&D is treated as an expense and not an investment. "Generally Accepted Accounting Principles" (GAAP) establish that R&D be fully expensed in the year it is spent rather than treated as investment that gets spread (amortized) over several years. Yet to expense an R&D project suggests that the project's value is used up during that year. This makes no sense since R&D is an investment in the future. Because of such expensing of R&D, many high-tech firms have a high multiple of their share price relative to earnings (P/E-ratio). Current earnings (E) are depressed by being charged with a high R&D expense, while their stock prices (P) incorporate investors' expected future payoff from that R&D and are thus relatively high.[21, 22]

21 Higgins, Robert. *Analysis for Financial Management*, 8th edition. (New York: McGraw-Hill/Irwin, 2007), 368.

22 The expensing of R&D rather than its capitalization amortization makes less of a difference as long as there is no growth in R&D expenditure. IN steady state, leaving R&D investment off the balance sheet (and amortizing them) and instead expensing them immediately has the same effect on earnings. Penman, Stephen H. "Accounting for Intangible Assets: There is Also an Income Statement." *Abacus* 45, no. 3 (September 2009): 358–371.

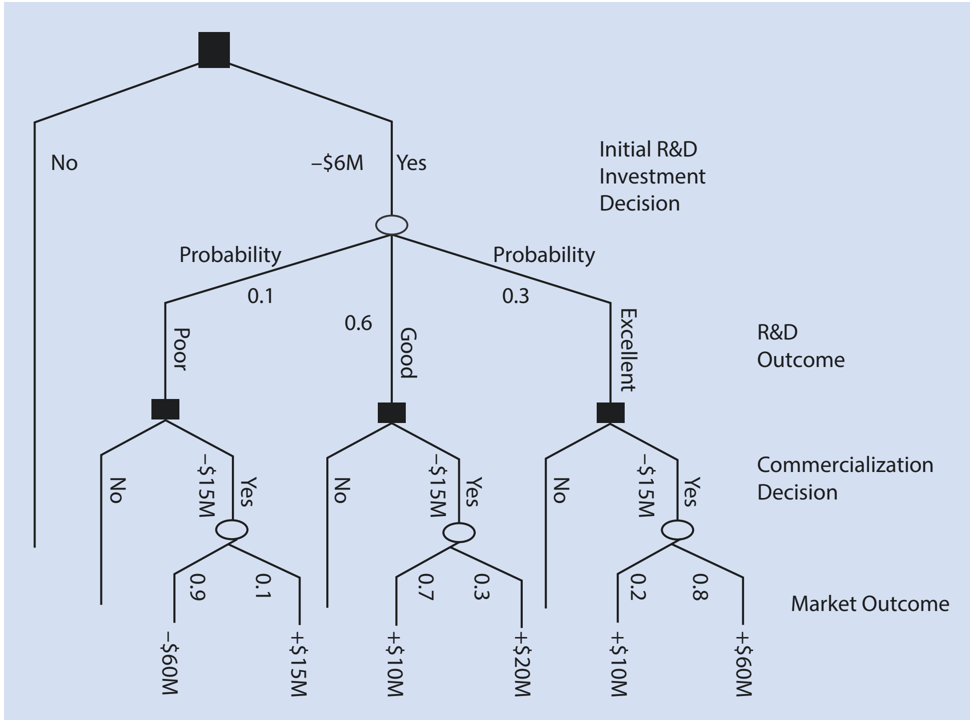

Fig. 4.4 Decision tree for R&D investment

A related financial approach to the valuation of competing R&D projects is to use the Real Options approach.[23] We discussed this approach in the preceding chapter on production. An NPV analysis assumes a one-time go–no go investment decision for an upfront investment. There is no possibility to stop, review, abort, and cut one's losses. It's all or nothing. Instead, one should view the R&D investment decision as decomposed into several stages, and each investment is like an "option" to proceed to the next stage.[24] The Real Options approach analyzes an investment as such a multistep process in which a company can take a first step in a project and then determine whether to proceed to a second investment. Instead of a one-time binary yes–no decision the investment decision becomes a series of several smaller yes–no steps.

The implication of this methodology can be significant. The NPV analysis, by overlooking the option potential of R&D thus biased against longer-term and riskier projects which may have a major impact on the company's future. Similarly, the NPV analysis does not incorporate the implications to a company of not pursuing an R&D project, which may foreclose many future options.[25] Suppose that an R&D project is proposed to develop a 3D printer for creating musical instruments such as flutes or clarinets. Financial returns on the products are uncertain.[26] The results of the proposed R&D project are also uncertain.[27] The decision tree in Fig. 4.4[28] shows these possibilities.

Suppose a firm considers a project with a total upfront cost of $21 million. This can be decomposed into two phases. The R&D stage would cost $6 million. It comes with a serious uncertainty whether it will be accomplished. This uncertainty will be resolved after one year. A "good" result has a probability of $p = 0.6$. There is a smaller chance ($p = 0.3$) of an "excellent" result, but also a non-trivial chance ($p = 0.1$) of a "poor" result. After the one-year R&D stage, there is a commercialization phase which requires an additional $15 million in investment. Then the product is released. Possible returns range from +$60 million to –$60 million.

Table 4.3 uses the numbers of the decision tree to calculate four different evaluations of the proposed project, based on different decision rules. Three of them are calculations dealing with the uncertainties of the market and the R&D. The *NPV #1* analysis assumes that one always chooses the most likely outcome. A 12% discount rate is used to bring the future $15 million commercialization investment to the present value in one year and the $10 million return to the present in two years. This results in an NPV of –$11.4 million.[29] The project would not be approved.

23 Bodner, Douglas and William Rouse. "Understanding R&D Value Creation With Organization Simulation." *Systems Engineering* 10, no. 1 (Spring 2007): 64–82.
24 Morris, Peter A., Elizabeth Olmstead Teisberg, and A. Lawrence Kolbe. "When Choosing R&D Projects, Go with Long Shots." *Research-Technology Management* 34, no. 1 (1991): 35–40.
25 Mitchell, Graham R. and William F. Hamilton. "Managing R&D as a Strategic Option." *Research-Technology Management* 50, no. 2 (2007): 41–50.
26 Boer, Peter F. "Risk-Adjusted Valuation of R&D Projects." *Research-Technology Management* 46, no. 5 (September 2003): 50–58.
27 Faulkner, Terrence W. "Applying Options Thinking to R&D Valuation." *Research-Technology Management* 39, no. 3 (1996): 50–56.
28 Based on Faulkner, Terrence W. "Applying Options Thinking to R&D Valuation." *Research-Technology Management* 39, no. 3 (1996): 50–56.
29 Faulkner, Terrence W. "Applying Options Thinking to R&D Valuation." *Research-Technology Management* 39, no. 3 (1996): 50–56.

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Table 4.3 Evaluation methodologies of a project

Valuation method	Year 0	Year 1	Year 2	NPV
NPV #1: The most likely option	−6	$-\frac{15}{1.12}$	$\frac{10}{1.12^2}$	−$11.4
NPV #2: Consider market uncertainty	−6	$-\frac{15}{1.12}$	$\frac{(0.3)(20)+(0.7)(10)}{1.12^2}$	−$9.0
NPV #3: Consider all uncertainties	−6	$-\frac{15}{1.12}$	$\frac{(0.3)\left[(0.8)(60)+(0.2)(15)\right]+(0.6)\left[(0.3)(20)+(0.7)(10)\right]+(0.1)\left[(0.1)(-15)+(0.9)(-60)\right]}{1.12^2}$	−$5.4
Option valuation	−6	$-(0.3)\frac{15}{1.12}$	$(0.3)\frac{(0.8)(60)-(0.2)(15)}{1.12^2}$	$2.2

The *NPV #2* calculation incorporates the various possibilities of the market return, and looks only at the most likely R&D outcome. The *NPV #3* analysis factors in both R&D and market uncertainties and computes the probability-weighted expected values for each stage. In these calculations, too, the NPV comes out negative (the right most column). All three approaches assume that once the initial R&D investment has been made, the firm will continue with the product development. All of them yield negative NPVs, and this would stop the project from being launched. In contrast, the options analysis does not assume a commitment to the commercialization investment until one knows the outcome of the R&D phase. In the example, the commercialization investment will be undertaken only if the R&D result was "excellent," which would happen with a probability of (p = 0.3). There is, of course, a 0.7 chance that such an excellent result will not be reached. However, in that case the project would be fully terminated and the loss to the company would therefore be much smaller than if it had committed itself to the subsequent stages. At each step, a similar decision will be made, whether to pull the plug and cut one's losses, or to plow forward. In the example, such a way to proceed does produce a positive NPV, ($2.2), which means that the investment should be undertaken.

4.2.3.2 Portfolio of R&D Projects

If a company can pursue several R&D activities and have a portfolio of projects there are benefits, because the overall riskiness is reduced. Some projects fail while others succeed. But there is more to a portfolio approach than just the averaging of risk. When the company can choose projects whose success potentials are negatively correlated with each other, the risk of the collective R&D portfolio is lowered. This is similar to a portfolio of financial assets that are negatively correlated, and which we discussed in ► Chap. 3 Production Management in Media and Information. For example, if the firm pursues two rival research leads, one of which will work while the other will fail, though it is unclear *ex ante* which one will be which, the individual risk is 0.5 and the average risk of 0.5, but the portfolio risk is reduced to zero.

The two projects are assumed to have the same expected value, in other words potential payoff multiplied by its probability. The one with the greatest risk (the long shot) is the better choice, because of its higher upside. This may be surprising, but it is based on the fact that if in the early stage either project fails the much larger follow-on investment necessary for a project's commercialization can be avoided. Only the initial R&D investment is lost. Thus the riskier project cannot lose more money than the safer project. But the upside is higher for the riskier project in its commercial stages, and the riskier project therefore has a higher expected payoff if the R&D is successful. The safer R&D project is better only in rare situations: for a very low-risk project, or when the initial R&D investment is high relative to the total value of the company.[30]

A final observation: these technological and financial analyses are not be quite sufficient for an optimal selection of projects. Timing, marketing efforts, and market forces may greatly affect the success of a project. But this should not leave a company to rely on pure intuition. A formal framework of analysis forces disciplined thinking as a complement, not a substitute, for good judgment and vision.

4.2.4 Integration of Technology with Firm Strategy

Beyond the technological and economic performance of R&D there is also a question: is the R&D project aligned with the company's overall strategy?

R&D budgets are set for one or several years, but within the budget, decisions about projects are often left largely to R&D management. There is no assurance that the R&D

30 Morris, Peter A., Elizabeth Olmstead Teisberg, and A. Lawrence Kolbe. "When Choosing R&D Projects, Go with Long Shots." *Research-Technology Management* 34, no. 1 (1991): 35–40.

organization, left to its own devices, will pursue programs with a priority on how they relate to corporate strategy, either in focus or in business risk.[31]

Normally, R&D should not drag the company into a strategy different from the one it planned.[32] But there must also be flexibility to capitalize on fortuitous discoveries that are outside the strategic focus of the firm. Usually these should be sold or licensed to others,[33] but there can be exceptions. The 150-year-old Finnish company Nokia was mostly a paper product producer with a small electronics sideline before it seized on the newly opened Scandinavian cellular phone market, the world's first, and became for several years the leading global mobile handset manufacturer.

A company needs to consider a basic question when considering new technologies. How would the new technology affect its ability to create a competitive advantage?[34] The development of technology must be directed by business strategy; but at the same time technology developments define the opportunities to which the strategy must respond. Technology strategy and business strategy are therefore a dialogue.[35]

A major strategic decision for the firm is to select the scope of its activity. It could be a narrowly focused specialist or, alternatively, a broadly based diversified technology developer. Diversification has certain advantages in reducing risk. It allows for synergizing across several product lines and to what economists call "economies of scope"—cost saving in development, production, and marketing of multiple products.

But there are also disadvantages to diversification. In a fast-moving field, if a company is not fully focused on a particular product it may lose its competitive edge for that product. Diversification may also lead to a lower scale than for the specialist firms. Intel is a specialist focusing on microprocessors, and all its R&D goes toward making that product line better, faster, and cheaper. Andy Grove, famed former CEO of Intel, recalled: "The most significant thing was the transformation of the company from a broadly positioned, across-the-board semiconductor supplier that did OK to a highly focused, highly tuned producer of microprocessors, which did better than OK…" Specialized firms may have competitive advantages in their narrow field, with resultant market power.

But specialization means putting all your eggs into one basket.[36] Demand might fizzle or competitors might emerge. Staying specialized without the certainty of weak competition and ongoing demand is risky.[37] Intel, for example, missed out on components for the emerging portable computing devices of smartphones and tablets. Apple and Samsung, on the other hand, have multiple products to fall back on if their smartphones do not work out. But being a jack-of-all trades has disadvantages, too, where competition is strong in each segment. In recent years the debate between specialization and diversification has tended to go in favor of specialization.[38] Thus, a company must find the optimal degree of specialization, somewhere in the spectrum between a single-product orientation and a loose agglomeration of products.

One must also think about innovation across time.[39] The strategic question is how much of a firm's activity level should rely on improving already well-established products and how much of it should be based on products that must be newly developed. The answer would define the extent of R&D that must precede actual production by years. Reliance on the former to a firm's current strength but leaves it vulnerable in the future. Conversely, reliance on future products leaves it vulnerable to risk if things do not work out.

A useful perspective is that of the "three horizons" (Fig. 4.5).[40] One author, Tim Kastelle, suggests that a firm should create a balance between "improving existing products and processes," "searching out adjacencies," and "exploring completely new markets."[41]

The first horizon (H1) involves implementing innovations that improve current operations. Horizon two (H2) innovations are those that extend current competencies into new but related markets. Horizon three (H3) innovations are the ones that will change the nature of the industry. In general, H3 innovations tend to be radical rather than incremental. H1 is low risk, low return, while H3 are high risk, high return. H1 R&D projects, dealing with a firm's core technologies, are typically necessary but not sufficient to achieve competitive advantage. They have well-defined commercial objectives. The likelihood of technical success is relatively

31 Erickson, Tamara J. et al. "Managing Technology as a Business Strategy." *MIT Sloan Management Review*. April 15, 1990. Last accessed May 2, 2017. ► http://sloanreview.mit.edu/article/managing-technology-as-a-business-strategy/.

32 Say, Terry, Alan Fusfeld, and Trueman Parish. "Is your firm's tech portfolio aligned with its business strategy?" *Research-Technology Management* 46, no. 1 (January/February 2003): 32–38.

33 Smith, Roger. "5 Patterns of the Chief Technology Officers." *Research-Technology Management*. Last accessed April 30, 2017. ► http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.158.1721&rep=rep1&type=pdf.

34 Mitchell, Graham R. and William F. Hamilton. "Managing R&D as a Strategic Option." *Research-Technology Management* 50, no. 2 (2007): 41–50.

35 Erickson, Tamara J., et al. "Managing Technology as a Business Strategy," *MIT Sloan Management Review*. April 15, 1990. Last accessed May 3, 2017. ► http://sloanreview.mit.edu/article/managing-technology-as-a-business-strategy/.

36 Hesseldahl, Arik. "Intel Fights Back as Chips Are Down." *Businessweek*. January 17, 2007. Last accessed June 1, 2011. ► http://www.businessweek.com/technology/content/jan2007/ tc20070117_984122.htm.

37 Yager, Tom. "What's a Monopoly to Do?" *InfoWorld* 27, no. 33 (August 2005): 52.

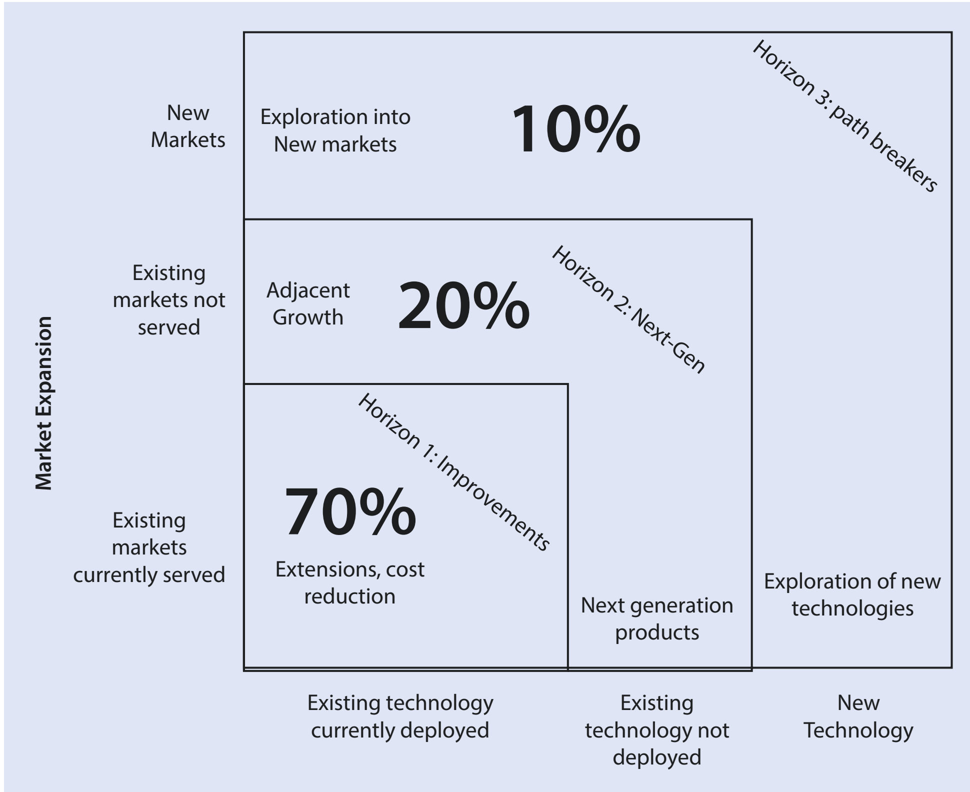
38 Ante, Spencer E. "The Info Tech 100; Constant reinvention of who you are, what you produce, and how you sell it is critical for any tech player." *BusinessWeek*. July 2, 2007. Last accessed May 3, 2017. ► https://www.bloomberg.com/news/articles/2007-07-01/the-info-tech-100.

39 Kastelle, Tim. "Innovation for Now and for the Future," *The Discipline of Innovation*. August 17, 2010. Last accessed May 5, 2017. ► http://timkastelle.org/blog/2010/08/innovation-for-now-and-for-the-future/; The concept goes back to Baghai, Mehrdad, Stephen Coley, and David White. *The Alchemy of* Growth. New York: Perseus books, 1999.

40 Based on Kastelle, Tim. "Innovation for Now and for the Future," *The Discipline of Innovation*. August 17, 2010. Last accessed May 5, 2017. ► http://timkastelle.org/blog/2010/08/innovation-for-now-and-for-the-future/; The concept goes back to Baghai, Mehrdad, Stephen Coley, and David White. *The Alchemy of* Growth. New York: Perseus Books, 1999.

41 Kastelle, Tim. "Innovation for Now and for the Future," *The Discipline of Innovation*. August 17, 2010. Last accessed May 5, 2017. ► http://timkastelle.org/blog/2010/08/innovation-for-now-and-for-the-future/; The concept goes back to Baghai, Mehrdad, Stephen Coley, and David White. *The Alchemy of* Growth. New York: Perseus books, 1999.

Fig. 4.5 Investment horizons in innovation



high, and the costs and benefits can be defined fairly well. In contrast, R&D in H3 projects is speculative and its budget requirements largely conjecture. The R&D projects of the H2 are somewhere in-between. They deal with key technologies. Thus a firm should have a portfolio of three broad classes of technologies, with the first to maintain its position in the market; the second to provide competitive advantage, and the third category, that of "pacing technologies," aims to advance the market significantly.[42] A firm should think of its innovation efforts as a portfolio, with innovation taking place across all three time horizons. The balance is based on the firm's risk tolerance and on industry volatility.

The three kinds of innovation need a different mix of input and skills. H1 innovations require mostly money and people. H2 innovations go deeper and need a corporate culture of creativity and management that is willing to push forward and onward. H3 innovations require top management to make bets on careers and even the company. The major career risk is that of management, not of the researchers. The company must give its staff much leeway, lower controls, and avoid negative feedback for the failure of crazy ideas.

A company like 3M, which pioneered Scotch tape and Post-it notes, derives up to 30% of its revenue from products launched in the past five years. It emphasizes H2 and H3 strategies in its R&D. The company, and similarly Google, uses a 15% or 20% rule, where certain employees are expected to devote a fixed portion of their time to projects unrelated to their job, that is, H2 and H3 type work.[43] Even so, both companies' main R&D efforts deal with improving existing products (H1), not on yet unborn technology generators. For Google, much of the R&D work is on innovations in its core products: the search engine, maps, online ads, and so on. The company's public relations narrative – such as self-driving cars, and so on—tends to project a more ambitious agenda than warranted by reality. Google, too, uses a 70/20/10 split, with most innovation efforts going to improving existing activities.

The last type of innovation tends to differentiate leaders from followers. But they are gambles, and investments in potential breakthroughs are hard to justify in conventional business terms of ROI. One must think of them as buying options on future opportunities. Ideally, a relatively modest investment—and downside risk—creates the potential for a large upside. The problem with a breakthrough R&D strategy is that it might either fail to deliver, or actually succeed in technological terms and yet be too far ahead of market readiness in terms of complementary products and consumer demand.[44] Figure 4.5 is technological in nature–will it work?—and does not consider markets—will it sell and be profitable?

How can a company analyze the market for its innovations? In the first instance, it helps to look at demand, and

42 Erickson, Tamara J., et al. "Managing Technology as a Business Strategy," *MIT Sloan Management Review.* April 15, 1990. Last accessed May 3, 2017. ► http://sloanreview.mit.edu/article/managing-technology-as-a-business-strategy/.

43 Satell, Greg. "How to Manage Innovation." *Forbes.* March 7, 2013. Last accessed May 5, 2017. ► http://www.forbes.com/sites/gregsatell/2013/03/07/how-to-manage-innovation-2/.

44 Clayton, Christensen M. *The Innovator's Dilemma.* (Boston: Harvard Business School Press, 1997), xv.

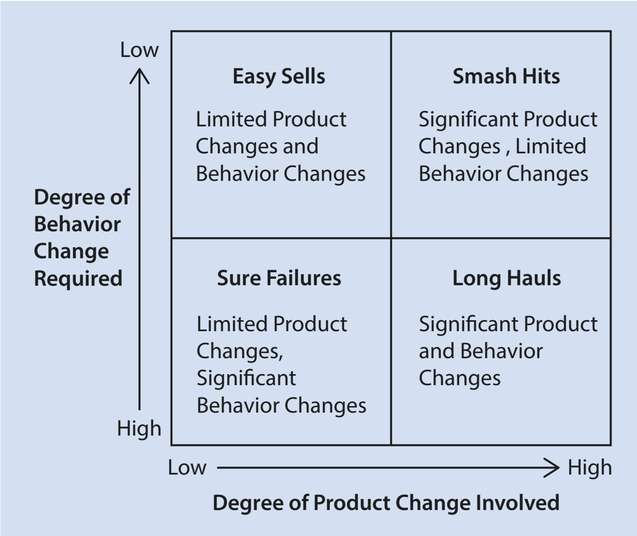


Fig. 4.6 Dimensions of consumer acceptance

to organize innovations by consumer acceptance. Four such categories are "easy sells," "sure failures," "long hauls," and "smash hits" (See Fig. 4.6).[45] They are ordered in a matrix whose two dimensions are product improvement (the horizontal axis) and the change required from the consumer (the vertical axis). Some innovations require a major behavior change and the others less so, but they may offer major improvements that could conceivably overcome this.[46] Companies may create great new products, but this may not mean much if it requires major behavior change. It is easier to change technology than behavior.

Easy sells - The product benefit improves modestly, and requires only limited adjustments in behavior. Examples: a move from iPhone 7 to iPhone 8, or another James Bond movie.

Sure failures - The innovation has only limited benefits in performance but requires a significant behavior change. Example: transitioning from the standard QWERTY keyboard configuration to the Dvorak keyboard that is slightly faster, but requires relearning the "muscle memory" of typing.

Long hauls - These innovations provide a technological improvement, but require a significant behavior change. Initially at least adoption will be slow because consumers resist the switch. An example is satellite radio. Even the cellular telephone took a fairly long time to spread (25 years to reach an 80% adult subscribership). If the product does not sell itself, and a company business plan is overoptimistic about adoption rates of the new product, it will fail.

Smash hits - The innovation generates major benefits with only slight behavior change. Example: the Google search engine.

An illustration of these categories concerns the TiVo DVR and the DVD player, both products of the late 1990s. By 2005, the USA had 20 times more DVD players than TiVo DVRs, even though the value of a TiVo player was much greater (recording TV shows, skipping advertisements, etc.) Consumers were familiar with music CDs and needed no behavior change, in contrast with TiVo which required a new viewing behavior.

Yet many companies do not have enough resources to wait patiently for demand to grow. The second option is to have innovations that offer a quantum leap in improvements (in the order of almost three times of previous performance, as we have discussed) to overcome consumer conservatism. But such innovations are rare. The third alternative is to target consumers who are either early adopter types, or who are not yet users of legacy products and thus have no commitment to them.[47]

Market demand does not provide a full answer either. An innovation must also be profitable. Demand for the product helps, of course, but the cost side of investments and operating expenses is also a factor. This is dealt with graphically in Fig. 4.7,[48] which shows a "bubble diagram," where projects are mapped according to three dimensions: NPV (the horizontal axis), a measure for profitability; the probability of R&D success (the vertical axis) and the required investment (the size of each bubble).[49] The overall size of the bubbles adds up to 100%. The bubble diagram model helps management to make resource allocation decisions given the finite resources of budget and people. The sum of the areas of the circles is a constant, zero-sum game. The model then forces management to consider tradeoffs. If one adds or enhances one bubble = one project, then some other projects must be reduced or dropped.

There are four different types of projects:

- *Pearls* (upper left quadrant). Such projects have a high probability of success (low risk) and a high yield. In Fig. 4.7 the company is engaged in two pearl projects, one of them with a high investment need. But profitability is high, which justifies the project.
- *Oysters* (lower left). These are long-shot projects with a high expected payoff but low probability (high risk) of technical success. A technical breakthrough will generate strong payoffs. The company has three such projects but funds them at a low level, thus protecting its downside.
- *Bread and Butter Projects* (upper right). These are safe choices. The probability of success is high, but the rewards are low. Examples would be improvements of existing products. As discussed above, a firm might put 70% of its R&D budget into such projects. And indeed the company has several such projects, and more than half of its R&D investments are allocated to them.
- *White Elephants* (lower right). These are low-probability and low-reward projects. Nevertheless, the company has several of such projects. This seems to be a flawed allocation of scarce resources.

45 Graph based on Gourville, John T. "Eager Sellers & Stony Buyers." *Harvard Business Review,* 84, no. 6 (June 2006): 98–106.

46 Gourville, John T. "Eager Sellers & Stony Buyers." *Harvard Business Review,* 84, no. 6 (June 2006): 98–106.

47 Gourville, John T. "Eager Sellers & Stony Buyers." *Harvard Business Review,* 84, no. 6 (June 2006): 98–106.

48 Based on Cooper, Robert. *Winning at New Products.* New York: Basic Books, 2011.

49 Cooper, Robert G., Scott J. Edgett, and Elko J. Kleinschmidt. "Portfolio Management in New Product Development: Lessons from the Leaders – II." *Research-Technology Management* 40, no. 6 (1997): 43–52.

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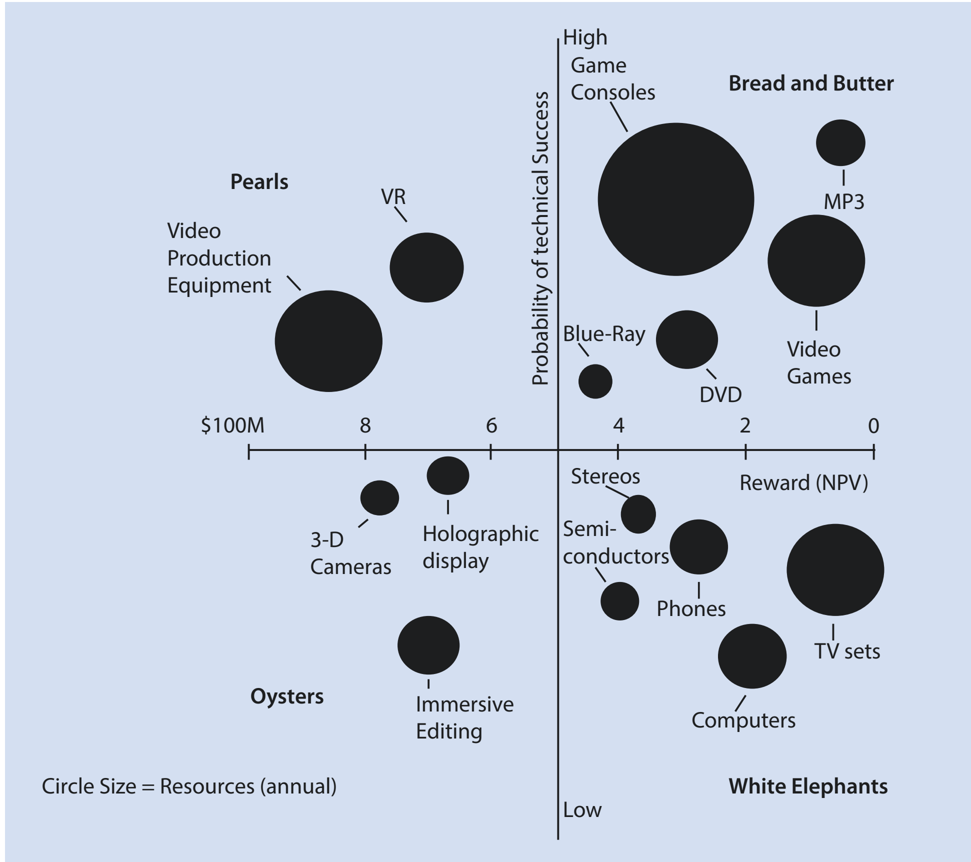

Fig. 4.7 Risk-reward bubble diagram

4.2.5 The Placement of R&D—In-House, Acquired, or Co-Developed?

The question of in-house versus outside innovation is not simply one of yes/no but also one of "what" and "where." Rarely would a firm innovate on its own all of its components and all the elements of its value chain. It would instead focus on one or several aspects and leave the others for development by outside vendors. Why should it develop its own cameras or computers? The important question for companies to consider in R&D is therefore where is the right "decoupling point" of its internal technology development? Which part of its value chain does it create and innovate on its own, and which does it acquire from others, either off-the-shelf or by special commission? Advantages of development inside the company include proximity of R&D to production and marketing; the protection of business secrets; a clear ownership of the IPRs; better cost control of projects; and greater familiarity of the firm with the needs of customers and markets. But an outsourcing of R&D has advantages too. Outsourcing allows firms to take advantage of specialists with experience and economies of scale. For example, for content-oriented media companies, technology R&D is not a core competency. Even for technology companies such as device manufacturers and network operators, the outsourcing of some or all of the R&D is part of a larger trend of separation of production and development. In some cases, production-oriented firms sub-contract their R&D. In other cases, conversely, R&D-focused firms will outsource production. And in some cases, "virtual companies" outsource both.

The manufacturing contractors are known as Electronic Manufacturing Services or Original Equipment Manufacturers (EMS or OEM firms). A major OEM, Flextronics, produces handsets for mobile device companies located in high-cost countries. The world's largest PC maker, largely unknown outside the industry, is Quanta, a Taiwanese company. It manufactures computers for most major brands around the world.[50] Apple outsources part of its manufacturing to Foxconn in China. One of Foxconn's plants employs 230,000 workers, 60,000 of whom live in factory dormitories. Outsource manufacturers such as Selectron, Flextronics, Celestica, SCI Systems, Foxconn, and Jabil Circuit increasingly do the design and R&D of various products, not just the manufacturing. Alternatively, specialty boutique design companies perform the R&D. At its most extreme, only the marketing is still done by the name-brand company, and even that could be contracted out.

50 Funding Universe. "Quanta Computer Inc." Last accessed July 11, 2011. ► http://www.fundinguniverse.com/company-histories/Quanta-Computer-Inc-Company-History.html.

Several research studies find that the outsourcing of innovation activities can lead to faster product development, innovation, and cost savings. But other studies are more skeptical.[51] Some companies start out by looking to the outside in order to find good ideas. A proper reward system need to be in place that encourages the rapid adoption of outside ideas.[52]

4.2.6 The Organizational Structure of R&D Activities

Among the most important issues facing a large company is how to position its R&D within the larger multidivisional corporate structure. The R&D will either be centralized, decentralized, or somewhere in between. Control and funding are the central issues.

In industrial firms, R&D was often a top-down structure. Major firms created sophisticated stand-alone laboratories. Bell Labs won six Nobel prizes, and IBM's Zurich Research Lab earned two such prizes. Xerox's Palo Alto Research Centre (PARC) innovated PC elements such as the computer mouse, the Ethernet protocol for computer networking, and the graphic user interface (GUI).[53] But a centralized research system creates a distance from the production and design activities of the firm. In contrast, a fully decentralized R&D structure permits various company units to pursue goals closer to the product lines. In such a system, the corporate-level R&D is limited in scope and focuses on the identification and evaluation of emerging technologies which have no home yet in the company. Hitachi and Intel are examples, with little corporate-level R&D.

Intermediate arrangements are "centrally led" or "centrally supported" R&D. Typically, the corporate center handles the *research* part of R&D, covering more basic technology which might have applications across the company, while the refinements and applications into products—the development—is handled by divisional labs. But such a separation is rarely neat and can be difficult to implement. Toshiba structures its R&D into three separate layers—research at the central corporate level, product development at the divisional level, and production engineering at the business unit level. Toshiba's corporate research labs focus on basic and advanced research. Such projects typically last for about five years. Divisional units carry out product and process technology developments, with projects typically lasting between two and five years. They serve several business units.

Historically, the relation of corporate and divisional R&D has gone through cycles, with central R&D strong as in the 1970s, decentralized, divisional R&D rising in the 1980s, and after 2000, central R&D being emphasized again.

A related organizational question is how an R&D lab should be structured. It could be arranged according to research disciplines such as typically found in universities; for example, chemistry, metallurgy, or electronic engineering. This promotes specialization and makes it easier to hire promising young scientists. The disadvantages are an orientation to "science" rather than commercial innovation, a work pace under less time-pressure, and greater difficulty in conducting cross-disciplinary R&D. In contrast, the R&D activity can also be organized by type of activity, such as basic research, applied research, development, design, engineering, prototyping, and testing. This is a more ad hoc structure whose staffing might fluctuate greatly.

A third approach is to organize an R&D department by product line, such as storage devices, TV sets, and tablets. Advantages are a stronger customer focus, easier co-ordination, and smoother integration with business activities.

A fourth option is to organize the R&D department by project, such as a new type of flat screen. Such a system frequently operates on a matrix basis, drawing experts from different parts of the company, labs, and scientific specialties. In a matrix structure, staff and managers from a product line unit or functional area may be involved in several projects.

When innovation is rapid and complex, an R&D structure organized by function (that is, specialist groups) is more effective than a product-oriented structure that centers on outputs.[54] This is also the case where expensive equipment is required. On the other hand, advantages for an output-focused R&D structure (that is, based on products or projects) exist where diversification is high while cross-product synergies are low.

Another dimension for the organization of R&D is its geographical location. Global companies conduct R&D globally. Technology has few frontiers, though some countries have tried to erect protectionist barriers around "their" companies and "their" technologies. Pioneers of R&D internationalization have been high-tech companies with global markets, headquartered in a relatively small home country with finite technology resources. Examples are Philips in the Netherlands, Ericsson in Sweden, and Nokia in Finland. European companies perform about one-third of their R&D outside their home countries. Another reason for an international distribution of facilities is

51 Stanko, Michael A. and Roger J. Calantone. "Controversy in innovation outsourcing research: review, synthesis and future directions." *R&D Management* 41, no.1 (2010): 8–20.

52 Huston, Larry and Nabil Sakkab. "Connect and Develop: Inside Procter & Gamble's New Model for Innovation." *Harvard Business Review*, March 2006. Last accessed May 3, 2017. ► https://hbr.org/2006/03/connect-and-develop-inside-procter-gambles-new-model-for-innovation.

53 The Economist. "Out of the Dusty Labs – The Rise and Fall of Corporate R&D; Technology R&D." March 1, 2007. Last accessed August 10, 2012. ► http://www.economist.com/node/8769863.

54 Chiesa, Vittorio. *R&D Strategy and Organization* (London: Imperial College Press, 2001), 149–192.

the politics of trade, since the location of an R&D facility may be part of a company's efforts to gain market access. The third reason is the relative cost, which favors low-cost R&D in India or China. Other locational factors are governmental subsidies, strong universities with a large pool of graduates, harmonious labor relations, and a favorable regulatory and tax system.[55] Some tech companies from around the world have created small innovation labs in Silicon Valley as footholds in order to remain up to date with emerging technologies and develop deeper relationships with start-ups.

There are, however, also reasons against international R&D. These include an immobility of top research personnel, a lack of critical mass when R&D is dispersed, language and cultural problems, political instability, the diffusion and potential loss of company know-how, and significant co-ordination and transaction costs.

4.2.6.1 Case Discussion

How Sony's R&D Is Organized

Sony's R&D outlays were considerable. In 2008, they were $5 billion and in 2013 $5.7 billion.[56] Its R&D priorities were in its digital image sensor business (supplying camera components to smartphone makers),[57] the 4 K PlayStation and artificial intelligence.[58] Samsung's R&D expenses were about $14 billion, higher than any other information and communications technology company. Microsoft expenses were $10 billion, Google $8 billion, and IBM and Cisco $6 billion each. R&D as a percentage of revenue was 7% for Sony, slightly higher than for Samsung and IBM, much higher than Apple (2.5%) but lower than for Microsoft, Google, and Cisco, all with about 12–13%.

Thus, Sony spent a lot on R&D and also achieved much innovation, if patents are a measure. In 2013 Sony filed 2241 US patent applications, Samsung 4945, and Panasonic 2232. In 2015, Sony had 2448 US patent applications, Samsung 5059, and Panasonic 1474.[59]

But Sony's R&D system was not well-coordinated. It was and spread out across divisions and countries. Its R&D strategy was to give its various labs quite a free hand. At times, different divisions developed incompatible products.

Sony's R&D is based on a corporate (central) research lab with six separate sub-labs. The corporate lab is used for the development of next-generation products with wide applications, such as OLED video display screens. Additionally, there are network-level, as well as division-level, and regional zone-level R&D labs.[60] The zones are Asia, the USA, and Europe. The aim was to better co-ordinate R&D activities within each region, and among regions. CTOs were appointed for each zone and given much authority. A relatively informal and non-bureaucratic cooperation between them was encouraged. The idea was to establish personal relationships and teamwork in order to achieve global synergy. Another goal of the structure was to access state-of-the-art research in the USA and Europe, and to lower costs by operating labs in China and India. An example is Sony America's Zone R&D, which spearheaded the development of the Cell processor (jointly with IBM and Toshiba). (This example also illustrates that rather than outsourcing its R&D, Sony's R&D has increasingly become a collaboration with major partners.)

Sony has international R&D facilities in Asia, the USA, and Europe, each specializing in one or more fields of technology. For example, the Sony China Research Lab in Beijing (2005) focuses on security technology, intelligent media, solar cells, and wireless networks. Sony opened seven R&D labs in the USA since 1987. The research focus there includes the Advanced Video Technology Center (AVTC) in San José, California (1994), which focuses on HDTV, and the Open 3D Research Center in Las Vegas (2010), specializing in 3D TV and film in collaboration with CBS. Research in Europe is done in Brussels, Alsace, Paris, Stuttgart, Barcelona, Lund (Sweden), Basingstoke (UK), and Pencoed (UK). The Sony Computer Science Lab in Paris focuses on personal music experience, computational neuroscience, developmental cognitive robots, and self-organizing communication. The European Technology Center in Stuttgart focuses on sensing systems, material science, and automotive entertainment.

4.2.7 Open Innovation—Community-Based R&D

Another way to organize R&D is to link it with developers and with users. The two are overlapping. A structured and company-led approach is where the company builds basic platforms (hardware, software, or both), and aims to create uses and users. To do so it provides specifications of the product to developers to induce them to create applications. This creates a symbiotic relationship, where both the platform company and the applications firms benefit from the creation of synergies and network effects. An example is Apple with its iPhone apps.

55 For example, IBM had 12 corporate research centers worldwide in 2017, with over 3000 employees in R&D centers in the USA (Hawthorne, Yorktown Heights, Almaden, Austin), Australia (Melbourne), Brazil (São Paulo and Rio de Janeiro), China (Beijing), Kenya (Nairobi), South Africa (Johannesburg), Israel (Haifa), India (Delhi and Bengaluru), Ireland (Dublin), Japan (Tokyo), and Switzerland (Zurich). (Accessed at ► http://www.research.ibm.com/labs/)

56 PricewaterhouseCoopers. "2013: Top 20 R&D spenders." Last accessed on June 21, 2016 at ► http://www.strategyand.pwc.com/global/home/what-we-think/innovation1000/top-innovators-spenders#/tab-2013.

57 Kennedy, Joshua. "3 Changes to Watch at Sony (SNE)." *Investopedia*. January 26, 2016. Last accessed June 21, 2016. ► http://www.investopedia.com/articles/markets/012616/3-changes-watch-sony-sne.asp.

58 Davies, Jamie. "Sony leans on AI to give technological advantage." *Business Cloud News*. May 18, 2016. Last accessed June 21, 2016. ► http://www.businesscloudnews.com/2016/05/18/sony-leans-on-ai-to-give-technological-advantage/.

59 USPTO. "Ranked List of Organizations with 40 or More Patents, as Distributed by the Year of Patent Grant and/or the Year of Patent Application Filing, Granted: 01/01/2015–12/31/2015." Last accessed June 21, 2016. ► http://www.uspto.gov/web/offices/ac/ido/oeip/taf/data/topo_15.htm#PartB.

60 All R&D labs were assigned fairly generic "three missions" and "six goals." The "three missions" were globalize domestic R&D efforts; establish a "global human information network." The six goals were clear vision and policy; clear target and differentiation of R&D strategy from rivals; strategic selection and precise focus of R&D themes; fair evaluations; highly skilled ("best of the best") staff for R&D; mobility of technology and R&D staff within a global Sony; export of Sony's R&D function and strengthening of overseas labs.

For some companies, therefore, a major management strategy is to encourage developer-based innovation. They may provide independent developers access to their software or platforms. They do so by granting interoperability arrangements via application program interfaces (APIs) that enable the outside programs to link up and thereby make the device more versatile and powerful.[61] Developers then compete with each other's applications software. The credit card company Visa, for example, gives developers access to hundreds of its financial payment APIs.[62] The social media company Facebook offers a Games Developer Center that features a variety of interoperability arrangements, monetization tools, and services for game developers.[63] The goal is to drive traffic to the Facebook site. Amazon and Microsoft provide developers with internet of things (IoT) software development kits so that they can build IoT apps and products. These starter kits include tutorials/quick start guides/demos, software and some hardware devices, such as sensors, actuators, and self-configurable and programmable development boards.

Going one step further is *user-generated innovation.*[64] Advantages are reductions in a company's development time and cost, but even more so a potentially better match of product with customer needs, given that the latter are directly involved. It also raises user loyalty because they are more involved. The company can import low-cost, high-quality ideas from a wide array of experts and test these ideas, as well as its own, by a "peer-review" process by a "smart crowd."[65] An example is the car maker BMW, which set up a Customer Innovation Lab, which is an online toolkit to help customers develop ideas and innovations for automobile telematics and driver assistance systems. BMW then chooses the best ideas which are implemented by its engineers. Another example: the Swedish appliance company Electrolux created in 2016 a global innovation contest for the use of technology to enhance the food industry. People could submit short ideas and a 30-second video; these were put up online, voted on by users, and the finalists were then judged by a jury. The selected winner received $10,000 and help to bring the idea to market with Electrolux. The winning submission was a wrist-worn bracelet which scans the barcode on a food item and then suggests recipes to cook with it as well as other items that need to be purchased to complete the recipe.[66]

Taking still another step is "open innovation," where there is no company in charge, only a community of users, developers, and volunteers who come together in a loose and decentralized collaboration to create an innovative product or service. In computer software, there has been community development in the form of Open Source software such as Apache and Linux, where numerous people contribute.[67] It is an important challenge for company R&D leadership to find ways to integrate such largely uncontrolled and dynamic innovation with proprietary corporate R&D.

4.2.7.1 Case Discussion

Sony and Community-Based Innovation

There is no indication that Sony has been effective in integrating the user community with its products. This would be particularly important as CE evolved from hardware devices into online services.

Sony built a highly interactive user-community to exchange user-generated content and applications. This includes the PlayStation Community, which has reportedly done an exceptional job at providing an online space where gamers can connect. Users can link to their specific interests and support needs. The community is connected to PlayStation's social media channels on YouTube and Twitter. New features on the PS4 console enable users to directly upload in-game clips online, which adds significant attraction. Such content can be virtually unlimited in scope and scale. It adds value to the product and builds user awareness, which benefits sales.[68] The aim was to make Sony's products more popular and attractive through a network effect.

At one point, Sony made an effort to generate user involvement on the content side. It bought a YouTube-like video platform, Grouper, and renamed it Crackle. Users were able to download Crackle content onto such devices as game consoles and media players. But the reverse direction, in which users contribute content, did not take off successfully and was dropped. Sony also

61 In some cases, such access to the APIs has been mandated by governmental regulators in order to enable competition in the applications.

62 Thurai, Andy. "How APIs Fuel Innovation." *Wired*. Last accessed June 21, 2016. ► http://www.wired.com/insights/2013/12/how-apis-fuel-innovation/.
PYMNTS. "Visa's Developer Platform Begins With An 'I'." February 5, 2016. Last accessed June 21, 2016. ► http://www.pymnts.com/news/payments-innovation/2016/visas-developer-platform-begins-with-an-i/.
Tibco Mashery. "Driving Innovation and Revenue with Partners and Developers." September 22, 2015. Last accessed May 9, 2017. ► https://www.mashery.com/sites/default/files/Edmunds-Case-Study.pdf.

63 These tools include Achievements API, Scores API, App Notifications, Requests, Feed Gaming, and Facebook SDK for Unity. The Facebook Games Developer Center offers information such as games overview, API migration guide, tutorials, production and checklists, game monetization, and more.

64 Von Hippel, Eric. "Horizontal innovation networks - by and for users." *Industrial and Corporate Change* 16, no. 2 (2007): 293–315.

65 Rigby, Darrell K. and Barbara Bilodeau. "Management Tools & Trends 2013." *Bain & Company*. 2013. Last accessed May 9, 2017. ► http://www.bain.com/Images/BAIN_BRIEF_Management_Tools_%26_Trends_2013.pdf.

66 IdeaConnection. "A Timely Idea to Inspire Healthy Eating." January 16, 2017. Last accessed May 9, 2017. ► https://www.ideaconnection.com/open-innovation-success/A-Timely-Idea-to-Inspire-Healthy-Eating-00623.html

67 Von Hippel, Eric. "Horizontal innovation networks - by and for users." *Industrial and Corporate Change* 16, no. 2 (2007): 293–315.

68 Hong, Pat. "10 Exceptional Examples of Brand Communities." *Linkdex*. January 15, 2015. Last accessed May 9, 2017. ► https://www.linkdex.com/en-us/inked/10-exceptional-examples-of-brand-communities/.

developed a cloud-based music streaming subscription service MusicUnlimited. In 2015, it was reported that MusicUnlimited had as few as 20,000 subscribers.[69] The service folded in 2015 and was rebranded as PlayStation Music (as a Spotify channel for use just on PlayStation). In comparison, in 2016 the rival service Spotify had 70 million free subscribers and 30 million paid subscribers, while Pandora had 76.3 million free accounts and 3.9 million paid accounts.

The emergence of a user community has worked against Sony in several significant instances. In 2005 Sony installed on its music CD a hidden Digital Rights Management (DRM) program to protect the music from unauthorized copying. This DRM program worked like spyware and self-installed itself onto users' PCs. It also interfered with some Windows functions and opened the PCs to outside malware without the user's knowledge. This led to a worldwide outcry by internet users. As a result, Sony had to recall half a million music discs and on top of this faced class action lawsuits. Similarly, Sony, a major producer of laptop batteries, was forced to recall about 10 million batteries worldwide since there was a chance they would overheat and explode. The cost to Sony was about $500 million.[70] The news spread rapidly through the user community, and was then amplified by the general press.

4.2.8 Budgeting for Innovation

The cost of R&D has been climbing. This is not surprising since the "easy innovations" are done first and the cost of subsequent innovation increases. A second reason is that the average economic lifespan of innovation has shortened owing to increasing competition, globalization, and convergence. Costs are also going up, owing to the acceleration of the process. Often company managers, under competitive pressure, demand that technology developers speed up their activity—but they need to understand the cost implications. Compressing R&D project time may greatly raise its cost relative to speed-up gains. The reason is that each R&D step builds upon the results of previous tasks. To accelerate a project requires for some of the steps to overlap and to begin with less information. Several approaches may have to be tried concurrently rather than sequentially. A study shows that a 1% reduction in the duration of a project can increase costs at double that rate.[71] It is therefore crucial to control R&D-related costs while maintaining innovation.

Lowering R&D-related costs can be achieved in a number of ways, such as:
- consortia (cost-sharing R&D with other companies);
- outsourcing;
- inbound and outbound licensing;
- modularization (the use of R&D elements across several products).

The broader question is how much money a firm should put into R&D. The largest technology firms in electronics spend billions of dollars annually on this area. Microsoft, IBM, Intel, Google, Nokia, Panasonic, HP, and Sony all devote well over $5 billion a year to it. In 2013, Samsung spent $14billion in R&D, over 6% of its revenues. Qualcomm spent 20% of its sales revenues on R&D, about $150,000 per employee. But how much should a company spend? Often there is no shortage of good ideas and worthy projects, but their aggregate will be unaffordable.

Of course, the firm's financial condition is relevant. When things are tough, R&D is often one of the first things to be cut from corporate budgets. The famed AT&T Bell Labs shrunk in the 1970s from 25,000 to just 1000 researchers in 2003. Its 1975 budget, which had been, in 2003 dollars, $3.24 billion,[72] had dropped to $115 million that year.[73] While cutting out R&D may make sense in the short term, in the long term it is like eating one's seed corn.

One way to estimate a target R&D budget is to compare the firm's R&D with that of competitors, in absolute terms or by the ratio to sales. A second way is to adjust one's R&D spending to that of rival companies' flow of new products, so as to match or surpass it.

A third, and finance- and economics-oriented method would be to determine the incremental profit from incremental R&D spending. But that is easier said than done. One would need to have an idea of the productivity of R&D spending. Productivity can be measured by an output, for example by the number of patents. (While each patent tends to be distinct in terms of effort required or its value, when the number is large the differences tend to average out.) Information about these patents is publicly available. In 2006 Sony held 14,000 US patents, Samsung 14,000, and Matsushita/Panasonic 25,000. During 2013, Sony added 3194 new ones, Samsung 5181, Panasonic 2742, and Google 1851.[74] One can relate this to R&D budgets. On average, Sony spent $2.0 million on a patent in R&D expenses, Samsung spent $2.7 million, and Google $4.3 million.

69 Resnikoff, Paul. "Sony Music Unlimited Had Just 20,000 Subscribers Before Folding…" *Digital Music News.* May 12, 2015. Last accessed May 9, 2017. ► http://www.digitalmusicnews.com/2015/05/12/sony-music-unlimited-had-just-20000-subscribers-before-folding/.

70 Farivar, Cyrus. "Sony battery recall approaches 10 million, costs mounting." *Engadget.* October 19, 2006. Last accessed May 9, 2017. ► https://www.engadget.com/2006/10/19/sony-battery-recall-approaches-10-million-costs-mounting/.

71 Graves, Samuel B. "Why Costs Increase When Projects Accelerate," in *Measuring And Improving The Performance And Return On R&D.* (Arlington, VA: Industrial Research Institute), 316–318.

72 Noll, A. Michael. "Telecommunication Basic Research: An Uncertain Future for the Bell Legacy." *Prometheus* 21, no. 2 (June 2003): 177–193.

73 The Economist. "Out of the Dusty Labs – The Rise and Fall of Corporate R&D." March 1, 2007. Last accessed May 2, 2017. ► http://www.economist.com/node/8769863.

74 USPTO. "Patenting by Organizations 2008." Last accessed May 9, 2017. ► http://www.uspto.gov/web/offices/ac/ido/oeip/taf/topo_08.htm.

But patents are only an intermediate input to a company's financial success. Optimization occurs when the marginal R&D dollar produces $1 in extra NPV. Similarly, for process innovation, where innovation reduces production costs, optimization occurs when the change in production cost/incremental R&D spending = −1. Some of this kind of information might be available to a firm from its internal sources, but normally it is hard to isolate.

Several R&D performance measurement techniques have been developed. According to one study, US industrial firms use more than 50 metrics to monitor their R&D function.[75] These come in several categories.

Quantitative Metrics

- *Input measures* include the number of scientists employed, or total R&D expenditures.
- *Output measures* include the number of patents filed, cost reductions, and the number of new products released.
- With economic values assigned to such measures, one can calculate the ROI attributable to an investment in R&D.

Examples of Quantitative Metrics[76]:

$$\text{R \& D effectiveness index} = \frac{\text{Revenue Generated from Products Introduced in Last Three Years}}{\text{Total R \& D Costs}}$$

$$\text{R \& D innovation index} = \frac{\text{Revenue Generated from Products Introduced in Last Three Years}}{\text{Total Revenues}}$$

$$\text{New Sales Ratio (NSR)} = \frac{\text{Annual Sales of New Products}}{\text{Total Annual Sales}}.$$

$$\text{R \& D Cost Savings Ratio (CSR)} = \text{Cost Savings Resulting From New Technology}$$

The advantage of quantitative metrics is that they seem relatively easy to use. But simplicity may conceal problems. For example, the revenue associated with a patent varies greatly in magnitude.[77]

Qualitative Metrics

Qualitative metrics rely on expert judgments on the performance of individual scientists, teams, groups, or departments. They are similar to the evaluations of academic departments or researchers by peer reviewers. These evaluations can be transformed into numeric scores and related to R&D spending. Both quantitative and qualitative metrics have advantages as well drawbacks, and they can be combined into a single and integrated metric.

4.2.9 Implementing R&D Alliances

Companies may acquire and create new technology through R&D alliances with other firms. The advantages are numerous: the pooling of talent; economies of scale and scope; risk-sharing; leveraging comparative advantages; attracting talent; stimulating internal innovation; increasing overall technological innovation capabilities; increasing speed; reducing costs through sharing; and rapid access to new or proven technologies.

There are also disadvantages to such collaboration. They include transfer of know-how to rival firms; the transaction cost of co-ordination and contracting, loss of control; lower ability to profit from the innovation; and potential conflicts. In order for R&D alliances to succeed there must be technological and strategic compatibility, a more efficient innovation process, and improved market access. These factors are hard to co-ordinate effectively, and a majority of R&D alliances fail.

An important portion of alliances are with universities. Private capital plays a role in the commercialization of innovations but not directly in the funding of basic research, the results of which are distant and speculative. Basic research is therefore mostly conducted in government labs and universities.[78] Many research ideas are created inside the universities and they flow through them from multiple directions.[79] Companies benefit from collaborations with leading research universities, which give them early access to basic research and researchers. Examples are the symbiotic relations of Silicon Valley companies with Stanford and Berkeley, of Route 128 corridor businesses in Boston with Harvard and MIT, and of the North Carolina Research Triangle firms with Duke, the University of North Carolina, and North Carolina State.

A firm may use universities as suppliers of useful research. Intel, for example, selects academic scientists and teams to develop technology that results in patents. Both company and university research benefit. Research funding from a corporation allows universities to conduct more advanced and expensive research.[80]

75 Werner, Bjorn M. and William E. Souder. "Measuring R&D Performance—State of the Art." *Research Technology Management* 40, no. 2 (March–April 1997): 38–46.

76 Whiteley, Roger et al. "Evaluating R&D Performance Using the New Sales Ratio." *Research-Technology Management* 41, no. 5 (September–October 1998): 20–22.

77 Werner, Bjorn M. and William E. Souder. "Measuring R&D Performance—State of the Art." *Research Technology Management* 40, no. 2 (March–April 1997): 38–46.

78 Waites, Robert. "Reinventing Corporate Research." *Research-Technology Management* 45, no. 4 (2002): 15–22.

79 Tennenhouse, David. "Intel's Open Collaborative Model of Industry-University Research." *Research-Technology Management* 47, no. 4 (2004): 19–26.

80 The Economist. "Out of the Dusty Labs – The Rise and Fall of Corporate R&D." March 1, 2007. Last accessed May 2, 2017. ► http://www.economist.com/node/8769863.

4.2.10 Knowledge Management (KM)

In far-flung organizations, knowledge of the flow of R&D and its absorption between various levels is important.[81] As the past CEO of Hewlett-Packard, Lew Platt, exclaimed with exasperation: "If HP knew what HP knows, we would be three times as profitable." KM is the organization and distribution of information, experience, "tacit knowledge," and wisdom inside the company. It aims at sharing knowledge while also protecting it. It is crucial for any company to effectively manage the flow of internal and external technical information.

There are a variety of KM tools. Documents can be tagged with metadata, which makes them searchable. This avoids having to replicate information that has already been created and to put together pieces into a bigger whole, which is often a foundation of innovation. Software can also be used to limit who has access to what material. Other tools are knowledge mapping of resources, creation of communities of practice, and social software for interaction.

At its most fundamental, KM is like creating an internal search engine that makes company-generated information accessible throughout the organization, and even to customers and vendors. It reduces duplication and assists coordination.

The search engine operation is one of passive KM, or a "pull" model. A further step is to target people and functions inside a firm in a "push" model of knowledge distribution, and to do so in a selective and fine-tuned fashion.

Realizing that their R&D knowledge is valuable, firms have appointed chief knowledge officers. Dow Chemical concluded that it needed to better use its knowledge base, particularly the knowledge embodied in patents. A newly appointed VP of Knowledge found that 30% of Dow's 29,000 patents were not worth maintaining. Many of them were licensed to other firms, and others were given to universities as a tax-deductible donation. This saved the firm roughly $50 million over ten years, and helped the firm grow patent income from $25 million in 1994 to an estimated $125 million in 2000.[82]

4.2.11 Standards Strategy

CTOs are often a company's liaisons on technology matters to the outside research community—universities, government labs, professional associations, and other companies. In particular, companies need to deal with standards bodies and standardization efforts. Standards are quite prevalent in most parts of media technology. Examples are the times a DVD spins per second, or the number of scan lines or the ratio of width to height of a TV picture. A standard tries to create common parameters. In some cases, such as driving on the left side of the road or the right, the substance of the standard is less important than its existence. This example also shows that standards can co-exist, with different regions, car makers, and car owners going their own way (though one hopes not on the same road). In media technology, standards are widespread; almost equally as widespread are the struggles over them. Behind many standards is a saga of rivalry, conflict, intrigue, and diplomacy. Examples are the original analog color TV broadcast protocols (NTSC in the USA vs. PAL in parts of Europe and SECAM in other parts), for video cassette recorders (Sony's Betamax vs. Panasonic's VHS), for mobile wireless (GS vs. CDMA), or for high-definition DVDs (Blu-ray vs. HD-DVD).

Standardization promotes interoperability, which leads to more choice for consumers. Standards enhance compatibility and generate greater value for users through the creation of larger networks. Adhering to an existing standard allows a company access to a larger market, with scale and potentially reduced costs.

The alternative to standards is a proprietary technology. In some cases, it becomes so prevalent as to constitute a de facto standard for most market participants. An example is Microsoft's DOS and then Windows operating system, which was not "standardized" with other companies or countries, but which emerged as the de facto way in which much of the microcomputer industry functioned.

The benefits of standards include expanded network effects.[83] Standards enhance compatibility, but proprietary technology may fail if other competitors have a similar product which is non-proprietary or easy to license. Examples are the failure of Sony's Betamax VCR system versus the open VHS. Deciding between openness or control is never easy, but it typically depends on a company's ability to create alliances with others.

A second benefit of standards is reduced uncertainty for consumers. An example is, from the 1980s, AM stereo, which was killed in buyers' confusion over what would ultimately prevail. The third benefit is reduced consumer lock in. A single standard with several providers helps consumers in not getting locked in with a particular company. Standards create competition *in* the market rather than competition *for* the market. With setting of standards, competition shifts from features to price. The more specific the standard, the less variation a product will have. Therefore, price becomes the major differentiating factor.

There are also disadvantages to formal standardization. To reach an agreement on a standard can be costly and time consuming. Lagging companies may try to slow down the process in order to catch up. There is often politicization, and companies try to enlist their governments as a "national champion" that benefits the country.

Standards can be mandated by governments and other bodies, as was the case for the European GSM standard for mobile phones or China's mobile phone standards. Standards

81 McCormick, John. "5 Big Companies That Got Knowledge Management Right." *CIO Insight*. October 5, 2007. Last accessed June 14, 2012. ► http://www.cioinsight.com/c/a/Case-Studies/5-Big-Companies-That-Got-Knowledge-Management-Right/.

82 Burton-Jones, Alan. *Knowledge Capitalism*. (New York: Oxford University Press, 1999), 159–160.

83 Shapiro, Carl and Hal Varian. "Waging a Standards War." *Information Rules*. (Boston: Harvard Business School Press, 1999), 228–233, 238–242, 273–276.

can be established co-operatively within an industry, such as the Entertainment Software Ratings Board. Alternatively, standards can be left to the market where they may emerge non-cooperatively, several technology approaches battling it out while smaller firms join one coalition or another or wait for a winner to emerge.

In the media field, standards tend to be set by various international or domestic industry organizations or governmental, intergovernmental, and semigovernmental organizations.[84]

It is important for a company to play the standards game well. Standards can determine company success as well as market structure. Yet generally speaking start-up companies and their investors are unfamiliar with the role standards play, and ignore the standards process until they are forced to follow it. Standards can determine company success as well as market structure.

Several factors give a company advantages in standards battles[85]:

- an existing strong base of users;
- patents and licenses;
- first mover position in introducing new technology, marketing it early, and establishing it as the industry standard;
- complementarity with other firms' products;
- brand name and reputation;
- alliances.

Media device buyers often do not just pick the device but the entire business/technology environment. A company, therefore, must be part of an ecosystem, not just a product. To be so, it must recruit partners and build strategic alliances.

There are also "open standards" in which a company, a coalition of companies, or a group of researchers declares a technology standard and invites others to join without license payments and with an ability to contribute to upgrades of the standard. Examples are the Unix or Linux operating systems.

The downside of network externalities is that they make it difficult for a small new technology network to emerge even if it is superior. The collective switching costs are too high. These costs are a strong advantage for incumbents and incumbent technology. Examples are the QWERTY keyboard, which is inferior to the Dvorak layout, or the GSM mobile telephone standard. To deal with such consumer inertia, an innovative company can either choose a strategy of backward compatibility with existing standards or a revolutionary strategy so superior that it will make users switch.

Is it better to go for openness or for control? For a firm, proprietary control is better if the product is a success. But consumers fear a lock-in and are reluctant to commit when there is a credible rival system that is incompatible and is either based on a rival proprietary standard or is non-proprietary and hence reduces consumer risk.

Thus, if a company succeeds in creating self-reinforcing network effects, a proprietary system will be better. But that is not easy to achieve on one's own. Practically speaking, there is a gray zone between openness and control with a lot of intermediate arrangements.[86] A firm might have an openness strategy for the basic technology but retain exclusive control over upgrades, so as to avoid fragmentation. Sun with its Java software was an example.

An openness strategy is important when no firm is strong enough to dictate technology standards. The various providers must then work together to create a critical mass.

If a firm falls behind in a standards war it should avoid lowering its prices, because this would signal that its product is inferior. Instead, it should target the product, based on its strengths, to a committed core of consumers, thereby creating the potential of a word-of-mouth marketing for a future round. An example is Apple's approach to its computers and operating systems.

The winner, too, cannot rest. It must keep upgrading and create complementary products, which help to lock in consumers.

4.2.11.1 Managing the Standards Setting Process

Technical standards and protocols are a mix of industry self-regulation and those encouraged or required by governmental/intergovernmental bodies. There are official and private standards bodies. Additional details are provided in ▶ Chap. 8 Entertainment Law and Media Regulation.

For a firm to join a standard committee may cost between $10,000 and $50,000 in annual membership fees. While official standard bodies are slow and broad in scope, private consortia can be fast and narrow. It is not clear which approach works better for a company, whether to integrate its technology through standards bodies or to create, with allies, its own approach. Practically speaking, a company's standards director must deal with both the international standard bodies as well as private technology development consortia.[87]

The internal organization of how standards function inside media and tech companies varies considerably depending on size, age, and the tech savviness of a company. Some companies have full-time employees devoted to standards, usually at the vice-president level, such as a Director of Standards and Industry Groups. However, it is more common for employees across the company, typically from the R&D department, to devote part of their time toward standards, depending on the technology in question. In addition, sometimes companies bring in late-career senior engineers

84 Standards bodies include the International Telecommunication Union (ITU), the International Standards Organization (ISO), the European Telecommunications Standards Institute (ETSI), the American National Standards Institute (ANSI), as well as, in the USA, the Institute of Electrical and Electronics Engineers (IEEE). There are the CEA (Consumer Electronics Association) and SMPTE (Society of Motion Picture and Television Engineers). The Digital Broadcasting Standards (DVB) set TV and video standards for Europe and elsewhere. Internet standards are set by bodies such as the Internet Engineering Task Force (IETF) as well as the W3C (www consortium).

85 Shapiro, Carl and Hal R. Varian. "The Art of Standards Wars." *California Management Review* 41, no. 2 (Winter 1999): 8–32.

86 Shapiro, Carl and Hal Varian. "Waging a Standards War." *Information Rules* (Boston: Harvard Business School Press, 1999), 228–233, 238–242, 273–276.

87 Dr. Ken Wacks, interview with the author, July 2, 2007.

to monitor standards and participate in the technology, business, and politics of standards game. Many smaller companies pay no attention to standards until they are forced to; and start-ups lack the resources, time, and personnel, but also the awareness of the importance of the issues.

An estimate of the costs of standards activities includes the following. A company might need two engineering employees to devote two months to attend committee meetings and travel, plus two weeks of part-time attention. Based on two salaries at $130,000 and $230,000, respectively, and based on two-and-a-half months of work for each, the personnel cost would be around $100,000 a year.[88]

Larger companies expend several hundred thousand dollars per year on influencing and monitoring standards. A big standards battle, such as Sony Blu-ray versus Matsushita's HD-DVD, costs many millions just in the standards body process. A mid-size tech company with a more modest budget could easily spend $100,000 a year just on monitoring standards process affecting it.

Since the standard-setting process is composed of politics and economics, companies must be selective when picking sides and always consider:

- low cost licensing;
- multiple sourcing;
- giving back patents for improvements;
- assuring future participation on joint tech development on current and future products;
- future deals.

Companies may also attend standards meetings to prevent adverse positions consensus developing against their interest. Determining the optimal level of investment in the standards process may be difficult. Benefits are hard to define, measure, and value. For some companies, failure to have their technology adapted as a standard can be fatal. In other cases, conformance to standards is more of a marketing tool.[89]

A firm should not slow down its R&D while the standard-setting process is going on, otherwise it will fall behind once a standard is set. A firm should also consider building an installed base preemptively. If it can set up a manufacturing base while standards are being set, it can get to the market fastest. But this is a risky strategy if a different standard is picked.

A firm whose technology has become standard should not rest on its laurels. It should offer attractive terms to important complementors, and attend industry meetings to prevent new approaches being developed against the company. It should be developing the next generation of technology, helping in generating complementary products, and developing proprietary improvements.[90]

88 Dr. Ken Wacks, interview with the author, July 2, 2007.
89 Dr. Ken Wacks, interview with the author, July 2, 2007.
90 Shapiro, Carl, Varian, Hall. "Waging a Standards War." *Information Rules* (Boston: Harvard Business School Press, 1999), 228–233, 238–242, 272–279.

4.2.11.2 The Future: Multiple Standards

Digital technology does not require uniformity. Smart TV sets can process multiple standards. Different video providers will choose different standards and compete among themselves. This permits rapid entry of new technologies and innovation. In consequence, it is unlikely that uniform standards will be as important to the future of media as they have been in the past.

4.2.11.3 Case Discussion

Sony's Standards Efforts

Sony had mixed results from its standards efforts. It scored a great success when it developed the CD player technology jointly with Philips of the Netherlands as its European ally, and this then became the worldwide standard. On the other hand, Sony's go-it-alone approach did not work for Betamax at all. Many years later, Sony's Blu-ray DVD standard prevailed after a major struggle, but it took much coalition-building to achieve it, and the process retarded consumer acceptance of HD-DVDs by several years. Partly in consequence, Blu-Ray penetration rates were much lower than those of the previous generation, that of DVD players.

Beyond those specific tasks, one of the CTO's major responsibilities is to help foster a climate of innovation in the organization. This is further discussed in ► Chap. 5 Human Resource Management for Media and Information Firms.

4.3 The Six Stages of Media Tech Convergence: The Six "Cs"

The next and second major section of this chapter is a discussion and overview of the major trends of technology as they affect media and communications. Owing to the breadth of the subject, it can serve only as an introduction, but such an introduction is important for those engaged in or contemplating a career in this sector.

Traditional media were separated by delivery technology—printed paper, film on celluloid, broadcast amplitudes, telephone wires, vinyl discs, computer discs, and so forth. Similar specializations separated the provision of content from conduit. Within these separate markets, a firm could achieve market power. In the 1980s and accelerating in the 1990s, however, a technical convergence of media began to gradually blur the clear lines between segments, thereby creating potentially more rivalry. The major technological trend behind this convergence is well known: the increased use of digital electronics to generate, store, transmit, and display information. The elements of digital electronics use many common hardware elements and similar formats for the coding of information. The various forms of content—text, still pictures, moving images, sound—can be variations of the same basic IT. This fundamentally affects media, the borders between them, and the market structures in which they operate.

The convergence of technology has been a broad and long process. It can be decomposed into several distinct convergences, some sequential, some marching in parallel. This will be the subject of the segments that follows.

4.3.1 Convergence #1: Computers

Several major technologies have come together to make computers possible. In particular, they are calculating devices, electronic components, and control codes.

4.3.1.1 Calculating Devices

Calculators started as mechanical devices such as the abacus, created to assist people in arithmetic. In 1642, Blaise Pascal, a French mathematical genius and entrepreneur, invented a mechanical calculator when he was 19. In 1671, Gottfried Leibniz of Germany, another pioneering mathematician, invented a multiplication machine. In the nineteenth century, Charles Babbage, a British scientist, inventor, traveler, economist, politician, and author, designed a complex "difference engine" and a still more elaborate "analytical engine." His work was supported by Ada Byron (the Countess of Lovelace and the daughter of Lord Byron). Babbage's second machine was an extraordinary mesh of gears, levers, wheels, and other mechanical parts. It was never completed but showed the way when more advanced electronic technology emerged.

4.3.1.2 Components

Babbage's machines and similar calculators that followed had to rely on mechanical wheels, gears, and so on. As soon as calculations became more complex, mechanical devices were not up to the task. To overcome this required the use of electric signals. A major breakthrough was the electric vacuum tube going back to 1906 and the AT&T engineer Lee de Forest, which made it possible to mirror and amplify weak signals, as well as to open and close an electric circuit. These were major advantages. On the negative side, vacuum tubes were bulky, fragile, and energy hogs. They were replaced in the 1950s by solid-state transistors based on silicon.

Transistors were invented in 1947 by William Shockley and his AT&T's Bell Labs team, for which they received a Nobel Prize in 1955. Shockley started his own company. Two of Shockley's best engineers, Robert Noyce and Gordon Moore, in turn left him to start their own firm, Fairchild Semiconductors, which subsequently split off to form Intel, the perennial leader in microprocessors. Intel was founded in 1969 by Noyce, Moore, and Andrew Grove. The company's 4-bit processor, the 4004, was released in 1971; an 8-bit version, the 8008, was released the next year. Ten years later, the company introduced its breakthrough 8080 processor, a variant of which first appeared in the IBM PC microcomputer in 1984.

Transistors are the key element of all microelectronics. They are similar in concept to an electronic tube: a weak signal controls a stronger one and is thus amplified. Transistors consist of three terminals: the source, the drain, and between them the gate (Fig. 4.8).[91] When a positive charge is applied to the gate, the electrons are pulled from the source to the drain, meaning that the transistors are "on". But when the positive charge at the gate is removed, electrons do not flow and the transistor is turned off. The on/off functionality of the transistor is what enables it to code and process information as binary 0s ("off") and 1s ("on").

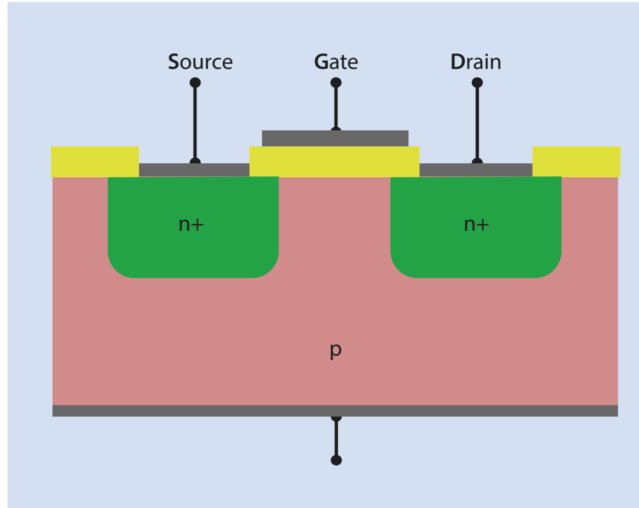

Fig. 4.8 Transistor workings

Transistors proliferated, as did the other solid-state components that are part of electronic circuits, such as resistors and capacitors. In the third generation of components, these elements were put together in a single integrated circuit (IC) on a silicon chip. The first such ICs were produced in 1959 by Texas Instruments and Fairchild Semiconductors. Each IC contained an increasingly large number of transistors on a single semiconductor chip. Such a chip was dedicated to a particular function, such as math calculations or thermostat control. This changed with the fourth generation of components, microprocessors, which were programmable; that is, they could be instructed to do many different things.

The first microprocessor was the Intel 4004 (1971), and it took the IT world by storm. Since then the technological ability to reduce the size of transistors and circuits progressed rapidly, and with it the performance and speed of a chip. Gordon Moore, one of Intel's founders, observed that the computing power of chips doubles every 18–24 months, in other words, at a CAGR of about 40%. Since he came up with this Moore's Law in 1965, the number of transistors on a chip has increased radically, from 2300,[92] to 2.27 billion in 2012.[93] This is an increase by a factor of one million in about 47 years,

91 Nordmann, Arne. "Scheme of metal oxide semiconductor field-effect transistor.svg" *Wikimedia Commons*. ► https://commons.wikimedia.org/wiki/File:Scheme_of_metal_oxide_semiconductor_field-effect_transistor.svg.

92 Scienceray. "Moore's Law Prediction on Computer Chips." July 13, 2011. Last accessed August 9, 2012. ► http://scienceray.com/technology/moores-law-prediction-on-computer-chips/.

93 Angelini, Chris. "Intel Core i7-3960X Review: Sandy Bridge-E And X79 Express." *Tom's Hardware*. November 14, 2011. Last accessed August 9, 2012. ► http://www.tomshardware.com/reviews/core-i7-3960x-x79-sandy-bridge-e,3071.html.

a doubling every two years. In 2017, the Cannondale generation offered a density of 10 nanometers. The next generation, Kaby Lake, had a 3.8 GHz to 4.5 GHz Turbo clock rate, over 7.2 billion transistors, and sold for $350.

More than any technical building block, microprocessors are the heart of the information revolution. A key indicator of their power is the length of the bit strings they process. Microprocessors expanded from 8-bit capability in the 1970s to 16-bits in the 1980s to 32-bits in 1993 to 128-bit processors in 2001.

There are also many types of specialized chips, for example for image processing. General-purpose processor chips are versatile but not super-fast at any one of these capabilities.[94] Microcontrollers (MCUs) are microcomponents that are preprogrammed to perform specific functions in non-computer devices ranging from digital watches to automobiles.

The capability of memory chips has increased exponentially, along the exponential path of Moore's Law of a doubling every one to two years. For dynamic random access memory (DRAM), it grew from 256 bits in 1968 to 1 K in 1970, 16 K chips in 1979, 64 K in 1980, 256 K in 1982, 1 MB in 1986, 1 GB in 2004, 64 GB in 2014, and 128 GB in 2015. In 2017 Samsung's lab created a 256 GB memory stick.

Competition hastened technical advances and decreased the cost per megabyte of memory from $5,242,880 in 1960; $734,003 in 1970; $6,480 in 1980; $100 in 1990; $1 in 2000; $0.20 in 2010; and $0.005 in 2017, a reduction by half every two years. This rate would be higher still if inflation were factored in.

In order to boost performance, semiconductor makers now combine multiple processor cores on a single chip. In 2016, Intel's 6950X Processor had ten cores and operated at a 3.5 GHz clockspeed. The price was $1600. Intel's top high-performance processor Xeon Phi 7290 had 72 cores with two threads per core. It operated at 2.8 GHz clockspeed. The unit price was $6250.

The next generation of chips moves miniaturization and integration to yet another level, that of a "computer-on-a-chip" or a "system-on-a-chip" (SOC). They contain many components of a single chip: a processor (central processing unit, CPU), non-volatile memory (read only memory, ROM, or flash), volatile memory (random access memory, RAM), a clock, an input/output control unit, and more. This is ideal for compact products such as smartphones.

The semiconductor industry tends to follow a boom–bust cycle driven by innovation, high demand, and investment, followed by overcapacity and dropping sales. As the industry grew, it disintegrated vertically. In the 1980s a computer company (often part of a larger electronics firm) would build its own manufacturing equipment, design its own chips, manufacture them, and so forth. By 2000, however, the industry had splintered into sub-industries of increasingly specialized firms.

The deverticalization of the semiconductor industry includes foundries, "fabless" firms, and semiconductor intellectual property (SIP) firms. A foundry is a firm that specializes in producing chips for other firms on a contractual, outsourced basis. Equipment sophistication and manufacturing scale grew, and by 2001, the average cost of a new semiconductor fabrication facility ("fab") was over $2 billion. Some of the big foundries are located in South Asia; for example, TMCS and Winbond (Taiwan). Because of the enormous capital requirements for building a chip fabrication facility, it is uneconomical even for many large firms to build their own facilities.

"Fabless" semiconductor companies are the flipside of the giant foundries. They design, organize, and market. Most new semiconductor companies are fabless, sub-contracting manufacturing to the foundries. Some of these new-style companies became quite large, for example the internet chip firm Broadcom.

The trend toward semiconductor design firms took a further step with the SIP business model, in which a developer company licenses its designs to other designers or manufacturers. The firm MIPS, for instance, helped Nintendo design the processor for its N64 gaming console. The SIP business model is less risky and capital intensive than the fabless model, since a firm does not engage in manufacturing activities—not even through sub-contractors—nor does it have to market any products or maintain inventories.

4.3.1.3 Case Discussion

Should Sony Make its Own Semiconductors?

Developing its own specialized semiconductors has several advantages for Sony. Its semiconductor designs would be closer to its final products, making it easier to design and spot potential problems sooner. It would have a head start for its own consumer products. It would not be dependent upon rival firms for its supplies or have to compete with them for early delivery by suppliers, and it could also sell the chips to other manufacturers as a business. And, indeed, Sony has built many of its own semiconductors ever since the 1950s.

But there are also several drawbacks. Foremost is the cost of such an activity. Companies such as Intel, Texas Instruments, Qualcomm, InterDigital, and Infineon are highly specialized and can devote more resources to designing and/or making chips and can sell them to a wider set of buyers, thus reducing unit cost. Generally speaking, leaving semiconductor development to specialist firms is advantageous to companies whose core competency lies elsewhere. Sony would be required, at the very least, to invest much money to be competitive. Thus, as the complexity of semiconductor technology advanced in the 1970s, it required much larger capital investments for R&D and production lines,[95] and Sony's previous self-reliance

94 Lyon, Daniel. "Holy Chip!" *Forbes*. January 30, 2006. Last accessed August 9, 2012. ► http://www.forbes.com/forbes/2006/0130/076.html.

95 Fransman, Martin (1990) *The Market and Beyond: Cooperation and Competition in Information Technology in the Japanese System*, Cambridge: Cambridge University Press.

became unsustainable. Sony adjusted its business strategy. First, in 1982, it began selling components to rival firms, something which had been a strict taboo before. The purpose was to cover the cost of development and of tooling up over a larger production volume to reach its internal demand.

Second, Sony left the production of commodity semiconductors and focused on specialized chips for media products, such as CAVDs for multimedia products, CCD image sensors, as well as laser diodes.

Third, Sony engaged in collaborations. Its most ambitious semiconductor was created through a co-development deal with other major companies. This was Cell, a super-powerful semiconductor developed together with IBM and Toshiba at total estimated cost of $4.5 billion. Cell ran ten times faster than Intel's most powerful Pentium chip at the time.[96]

The impetus to Cell came when Ken Kutaragi, Sony's chief of video games, went to IBM in 2000 asking for a semiconductor with a processing power of 1 teraflop, which was a significant increase over any chip available at the time, to power what became Sony's PlayStation 3 video game console. Sony, Toshiba, and IBM set up the STI design center at an IBM research lab in Austin, Texas. The center employed 450 engineers, most of them from IBM.

In 2005, the "Cell" chip was unveiled. It was 50 times better at handling graphic-intensive applications, and thus essentially redefined next-generation visual entertainment-immersive games, virtual-reality, real-time video chat, as well as interactive TV shows with multiple endings. Cell's performance was equivalent to a full-fledged supercomputer of the late 1990s. Cell, with the addition of a graphics chip, could run 2 trillion instructions per second for a PS3. The chip was expensive, however, and it raised the PS3 price to the $500–$600 range. By incorporating Cell processors in IBM system Z mainframes, IBM enabled them to be used as servers for massively multiplayer online role-playing games (MMORPGs). Additionally, Toshiba incorporated the chip in its HD television sets. But in 2008, Sony decided to get out of this collaboration and sold its Cell chip part in the venture to Toshiba. For a time, IBM continued to manufacture the Cell processor for Sony's game consoles. Toshiba developed a next-generation processor derived from the multicore technology of Cell.

To conclude: Sony was unable to keep up on its own in semiconductor design and manufacturing. It then moved to consortia with other firms with expertise and deep pockets. But even with shared development, it became increasingly difficult for Sony to remain in the advanced end of semiconductors industry. It therefore seems unlikely that Sony can maintain the design and production of most of its semiconductor components.

4.3.1.4 Control Code and Devices

As machines began to be powerful and fast, it became evident that they required control by human operators and these were often too slow, expensive, and unreliable. Mechanical control devices were therefore developed. In 1805, punch cards were used in France to control a weaving loom. In 1896, Herman Hollerith introduced a tabulating machine for use by the US Census Bureau. This machine became the foundation of a company put together by Thomas J. Watson, Sr., which in 1924 was renamed International Business Machines (IBM).

These devices began to use coding based on a binary system. Central to electronic machines' ability to process and store information is a "binary" coding, in which information is expressed as a string of zeros and ones. These sequences and patterns of zeros and ones can represent decimal numbers, but also letters, numbers, colors, and graphics. They can be manipulated through the mathematics of Boolean algebra, developed by George Boole in the nineteenth century, establishing the mathematical foundation of what became computer science. The mathematics of controlling electronic calculating devices were advanced by Alan Turing of the UK along with John von Neumann, who had left Hungary for the USA. During World War II they conceptualized how a machine could manage computational tasks.

Instructions that controlled the functioning of computer hardware became known as software. Its "programs" or "languages" have progressed from the earlier specialized, expensive science of mathematicians to a craft by skilled programmers and technicians and to a stage where machines write programs for other machines. The software has moved from an arcane and specialized craft product that only specialized engineers could interpret to a thriving, industrialized, and often consumer-oriented industry producing a mass-product, and from products of low volume and high price to those of high volume and low price.[97] Since the ascendancy of microcomputers in the 1980s and the creation of a mass-market for computing, the software industry has become a vibrant sector in the economy. Many creative new companies and products have emerged. In the days of mainframes, much of the software used to be written as custom jobs by manufacturers or by the users themselves. In contrast, packaged applications software is prewritten for numerous users.

Computer software falls into two broad categories: systems software and applications software. Systems software includes operating systems of computers and other devices (such as Microsoft Windows, Apple MacOS, and Google Android), networking software (such as .Net and Novell Netware), and database-management software. In contrast, applications software perform specific functions (e.g. word processing or spreadsheets) and can be either customized for individual users or sold in standardized packages. Another segmentation of the industry is whether it provides client or enterprise software. Client software runs on PCs and usually serves an individual user. Examples are PC operating systems, web browsers, spreadsheets, and personal productivity tools. Enterprise software includes categories for departmental, enterprise, internet, intranet, and extranets.

96 Lyon, Daniel. "Holy Chip!" *Forbes.* January 30, 2006. Last accessed August 9, 2012. ► http://www.forbes.com/forbes/2006/0130/076.html.

97 Noam, Eli. *Media Ownership and Concentration in America.* New York: Oxford University Press, 2009.

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In the late 1990s, there were new developments in software. The first and most potentially challenging development was the growth of the internet. As transmission bandwidth grew cheap and plentiful, many observers expected that users would only need a so-called "thin client" with which to access the internet, with the intensive computing done at a distance by more powerful servers. By reducing the need for a standardized operating system and for most applications programs, software providers would compete based only upon their price and performance criteria, such as speed, reliability, and ease of use. The thin-client network computer concept failed to live up to expectations, but the emergence of cloud-based computing may bring a revival.

4.3.1.5 The Computer

We have briefly explained the emergence of calculating machines, electronic components, and software control languages. By the 1940s, these elements were put together into the first computers.

During World War II, British and Polish decryption of the German secret military "Enigma" codes led to advanced mechanical calculation machines, which soon became electronic-based devices that could quickly go over millions of permutations. The Harvard Mark I (1943) was the first program-controlled calculator. It weighed 5 tons, and had 750,000 parts and 3304 relays. The US Navy utilized it for ballistic tables. The chief programmer was Grace Hopper who later became the first woman US admiral. But it was still a specialized machine for specialized purposes rather than a universal multitask computer. In Germany, similarly, Konrad Zuse developed in 1941 the Z3 as a programmable computing machine. The first general purpose computer was the ENIAC (1946). This was designed by John Mauchly and J. Presper Eckert of the University of Pennsylvania to break codes, calculate artillery flight, and assist in nuclear development. It was 100 feet long, weighed 30 tons, and cost $500,000. The ENIAC's inventors commercialized the technology into the Universal Automatic Computer (Univac) and soon sold their company to Remington Rand. This was the beginning of the computer industry.

IBM, a big office machine supplier of typewriters and desktop calculators, entered the market in 1953. It was able to leverage its dominant position in the tabulator punch card market and it soon dominated the business market. IBM did not sell the equipment but allowed users to open a lease to use. Peripheral hardware and software, even punch cards, had to be supplied by IBM. This prevented secondary resale markets and enabled IBM to engage in price discrimination. When such mainframe computers were not powerful enough to meet specialized demand for high performance, "supercomputers." In 2011, the IBM Sequoia could run at the speed of 20 PetaFLOPs. In 2017, the top performer was the Chinese Sunway Taihulight with 93 petaflops. By 2018, the Oak Ridge National Laboratory in Tennessee took the lead with its 200 PetaFLOP summit computer. Exascale computers were being developed the equivalent of about a trillion regular laptops.

These supercomputers—whose performance rises roughly a thousand-fold each decade—consist of massive, parallel processors and are used for large-scale scientific calculations. Examples of what the sheer operational strength of a supercomputer are weather forecasting, physics simulations, code-breaking algorithms, nuclear engineering, computer-generated animation, airline scheduling, DNA sequencing, and weapons-testing.

A different approach to high processing requirements is taken by Google and cloud providers. They run "server farms" of hundreds of servers. These servers are not supercomputers but rather commodity-class PCs running a customized version of Linux operating software. They aim to achieve best performance per dollar instead of being the fastest machines. With upwards of 450,000 servers, each with over 80 GB of hard drive space and 2–4 GB of RAM, Google's processing capacity reached about 40 PetaFLOPs in 2013, with over 1 million servers in operation, mostly of inexpensive commodity type.[98]

Massive computing is used in the film industry for producing special effects and animation. Animated objects such as talking cars or animals are relatively straightforward to generate by computers. It is harder to create the believable animation of regular people, since humans are pretty experienced in the subtle reading of human faces and motions, and computerized re-creations would have to be near flawless in order to be believable rather than seen as cartoons. To do so requires animation computers with a huge combined processing capacity. In 1977, computer processing was still so prohibitively expensive that when George Lucas made the original *Star Wars* film he could afford to use computer graphics for only a single 90-second sequence.[99] The Death Star sequence took several computers three months to complete. The trend in the film industry shifted from a single supercomputer doing animation and special effects, to several mainframes, and eventually to a network of medium-sized workstations known as "render farms." A desktop computer would have about eight cores, making DreamWorks' network one of over 3500 desktop computers. DreamWorks' render farm had about 30,000 "cores." Pixar had 24,000.

DreamWorks Animation produced such blockbusters as *Shark Tale*, *Shrek*, *Shrek 2*, and *Madagascar* using computer-generated animation technology. *Shark Tale* consisted of 300,000 frames, each requiring more than 40 hours of rendering. As processing power and speed grew, so did the ambition of animators and their toolkits. The technology of substituting or enhancing humans by computer-graphic images is referred to as "motion capture," in which humans serve as models for animators. In *The Polar Express* (2004), Tom Hanks was partly replaced by a computer-generated character, leaving the actor with the speaking role, and permitting him to be represented at different ages.

98 Pern, James. "What is Google's Total Computational Capacity" *Google*. ► https://plus.google.com/+JamesPearn/posts/gTFgij36o6u.

99 Epstein, Edward Jay. *The Big Picture, The New Logic of Money and Power in Hollywood.* New York: E.J.E. Publications, Ltd., Inc., 2005.

Once it becomes technically and economically feasible to create believable human characters, the next step will be for studios to create entirely artificial actors by computer technology. They would own the characters, as they own Mickey Mouse, pay them no salaries, subject them to amazing stunts, fine-tune their physical features, and let them live happily forever, with no profit participation or residual rights to royalties. At a foreseeable point in the future, this will become an economically viable proposition.

Thus technology transforms media content. In the old days, live performance technology favored simple and linear plots. Print technology led to a more introspective style of media consumption, in which the users had to supply their imagination to augment the sparse words. Film introduced special effects and action. Broadcast television moved media consumption into the family unit as a shared experience with corresponding content. Cable and satellite enabled highly specialized content. And digital technology leads it to interactivity, immersion, and group social experience.

Consumer Computers

Until the 1980s, computer makers tended to be vertically integrated, that is, involved in most aspects of making and operating computers from basic circuitry, to components, peripheral equipment, operating software applications, software distribution, service, systems integration, and maintenance. Because the manufacturers used proprietary standards, they locked in customers to their entire ecosystem of hardware, software, peripherals, and service contracts.

As computers evolved, product sub-markets evolved, differentiated by operating power. The categories within the general-purpose computer industry, in the order of increasing computing power, are handheld computing devices (personal digital assistants, PDAs, tablets, video game players, and smartphones), PCs, mid-level computers (workstations, minicomputers, home servers), mainframes/rack servers, and supercomputers.

As mentioned, supercomputers are typically customized, state-of-the-art mainframes. Prices range from $200,000 to over $100 million. Supercomputers tend to have special-purpose vector processors. These are often composed of multiple specialized processors that can perform certain calculations at great speed. A different type of supercomputer, the massively parallel computer, uses a far larger number of standard (and thus far cheaper) microprocessors that function in parallel. Massively parallel computers are most effective for solving problems that can be broken down into discrete sections.

Mainframe Computers

Mainframes can handle more tasks and larger jobs than other computers. However, they are expensive and require substantial infrastructure. Networked workstations and PCs present mainframes with substantial competition. In consequence, mainframes' share of aggregate computer hardware sales declined from 100% in 1960 to 44% in 1984, 19% in 1992, and 2.4% in 2016 (about $7.4 billion out of a total $304 billion.)

Although the mainframe market has been shrinking over time, it remains viable. Many large organizations have sunk sizeable investments into proprietary systems and software that cannot be replaced easily. In addition, although mainframe hardware costs are high, the typical total cost of PC and workstation network computer power is higher still, per user or operation, especially if application development and technical support is factored in. There will always be a need for the shared use of sophisticated applications on powerful equipment, as the internet demonstrates with its portals, applications service providers, and e-commerce sites. These internet mainframes are often called servers, though that term also encompasses computers of lesser power.

Mainframes operate as large servers for the internet and corporate intranets. This has breathed new life into the mainframe industry. In media, mainframes can be used in rendering of images for animation and for the distribution of on-demand video by companies such as Netflix. Other applications are for engineering, films, and design, for corporate client server networks, and for general business purposes.

In the 1960s, 1970s, and 1980s, a number of governments around the world supported "national champion" electronic firms in order to keep up with IBM in building computers. In Japan, these companies were Fujitsu, Hitachi, and NEC; in France, Bull; in Britain, ICL; in Italy, Olivetti; and in Germany, Siemens. None was successful in challenging IBM. Yet upstarts in the emerging Silicon Valley of California succeeded without government backing where the big firms had failed. They brought microcomputers to the consumer markets. Intel's 8080 microprocessor chip, introduced in 1974, enabled many computer processes: it could be combined with off-the-shelf components to build small computers, but large firms ignored this potential. Amateur computer builders therefore emerged to take advantage of this new market.

The first microcomputer was developed in 1974 by Micro-Instrumentation and Telemetry Systems (MITS), a tiny company in Albuquerque, New Mexico, building radio transmitters for model airplanes and rocket hobbyists. In 1975, the Altair 8800 from England was the first commercial microcomputer using the Intel 8080 microprocessor. In 1977, Tandy TRS 80 microcomputer was mass marketed through Radio Shack retail chain.

In 1976, Steve Wozniak and Steve Jobs introduced the Apple I computer, which used a Motorola microprocessor and an operating system written in the BASIC computer language.[100] In 1984, they created the Apple Macintosh which used a Graphic User Interface developed by Xerox PARC in 1981.[101]

100 Smith, Roger. "5 Patterns of the Chief Technology Officers." *Research-Technology Management*. Last accessed April 30, 2017. ► http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.158.1721&rep=rep1&type=pdf.

101 Hooper, William. "A Short History of the GUI and the Microsoft vs Apple Debate." *TheOligarch.Com*. April 2008. Last accessed July 11, 2011. ► http://www.theoligarch.com/microsoft_vs_apple_history.htm.

The microcomputers required software development machines. Focusing on the operating software for such small computers, Paul Allen and Bill Gates created Microsoft MS-DOS, which was adopted by IBM when it introduced its highly successful PC and laid the groundwork for Microsoft's and Intel's market dominance.[102]

With the development of computer networks, the PC soon moved from being a standalone processor and storage device to an internetworked device. The internet became the major platform for such interconnection.

By 2014, the market for microcomputers in advanced countries had become, to a large extent, an upgrade market.[103] They became the major access node to the burgeoning internet. Internet and multimedia use increased requirements for processor and memory power. The internetworking encouraged some manufacturers to design simplified computers ("dumb" or "thin" clients) to access the internet, leading eventually to tablets.

Video Game Hardware

Video games have become a new mass media—increasingly sophisticated, interactive, feature rich, and popular. Video game hardware was pioneered in the mid-1970s by Nolan Bushnell, who invented Pong (an early arcade video game machine) and founded Atari.[104] Atari was jointly acquired by Warner Communications and American Express, and became the dominant home video game vendor by developing the first successful programmable video game machine (using a 4-bit Central Processor Unit, CPU). Development of the programmable machine created a new market for video game software. By 1983, Atari had close to 86% of the $2.2 billion global video game hardware and software markets. However, by 1984, consumers had become bored with Atari's products. A new entrant from Japan, Nintendo, became dominant in 1985.

But by 1993, Nintendo had lost its leadership to Sega and its machine that was based on a 16-bit microprocessor. Sega, in turn, lost out to Sony, which enjoyed quick success with its own 32-bit PlayStation machine released in 1995. Sony's PlayStation combined superior hardware with access to content, and a $40 million marketing campaign that focused on celebrities and trendsetters. In 2005, Microsoft ushered in a new generation of consoles with the Xbox 360. In 2012, at the close of the seventh console generation, Nintendo had 42% of consoles sold, Microsoft had 36%, and Sony 22%. Sony's market share almost doubled from 2008 to 2016, by a full 25%, while Microsoft's rose by 10%, and Nintendo dropped by a full 35% from its once dominant 60%.

As can be seen from its history, this market is unforgiving. New technology, expressed in processor complexity, drives console adoption. The first to market with the latest processor technology will sell many consoles in its first year, but sales will quickly fall in succeeding years as the novelty declines and rivals catch up.

Another success factor is the lineup of attractive game titles. Nintendo's early achievements were largely attributed to its innovative game titles such as Mario Bros., Zelda, Metroid, and Pokemon. The Sega Dreamcast console scored disappointing sales because of a shortage of major game titles. This forced Sega out of the hardware market in 2000. Microsoft experienced similar problems. Although its Xbox was technologically superior to Sony's, it lacked Sony's extensive library and backward compatibility to older but popular games.

Video consoles became more than just gaming machines. Machines function as DVD players and enable users to access the internet, especially for online games. The intense competition in gaming consoles and the high demand for the latest game releases led industry participants to adopt a razor and blades business model. Manufacturers are willing to make little or no money on video game hardware sales to quickly build a large installed hardware base, thereby boosting profitable game or cartridge (software) sales.

The video game hardware industry is deeply competitive but sustains only three globally operated firms. Microsoft was one of the few firms globally able to enter the market for gaming consoles and compete with Sony, given the tremendous resources required to be successful and attract developers, coupled with the considerable risk of failure. These tentpole companies are surrounded by small game developers, which jointly create the network effects and scale necessary for success with a very finicky volatile user base. Entry barriers are high for the hardware consoles but much lower for the game applications.

Video Game Software

Video game software is big business. It consists of three segments, each for a different hardware platform: game consoles, PCs, and smartphones. Because each video game device is proprietary it will only run software that is either produced in house, commissioned from a second party, or accepted from an independent third-party publisher (who pays license fees to the game device companies and earns royalties on game sales). The game software industry is fragmented.

The revenue of the video gaming industry in the USA—both hardware and software—was often said to exceed that

102 Ohebsion, Rodney. "A Biography of Bill Gates and History of Microsoft." Last accessed May 9, 2017. ► http://www.rodneyohebsion.com/bill-gates.htm.

103 In 2015, 92% of American adults had a cellphone, 68% a smartphone, 73% a laptop or desktop computer, 45% a tablet computer, and 19% an e-book reader. Anderson, Monica "Technology Device Ownership: 2015" *Pew Research Center Internet & Technology.* ► http://www.pewinternet.org/2015/10/29/technology-device-ownership-2015/

104 Earlier projects were those of Steve Russel and Ralph Baer ("Game Room," "Space War," and "Magnavox Odyssey").

of movie theater ticket sales.[105] However, films are also commercialized far beyond theatrical distribution, such as by home video, video on demand, pay-cable, and so on.[106]

Handheld Computing Devices

Smartphones and tablets are small, handheld, computing devices. A British firm, Psion, offered a product in 1984. Apple introduced the Newton MessagePad in 1993 (this was a $500 million failure). The first Palm Pilot was released in 1996 and became a major success. A critical design feature was its open operating system, which led to grassroots and independent commercial software development. By 2005, personal digital assistants (PDAs) were increasingly being merged into smartphone devices, thus declining as standalone devices.

After 2010, handheld tablet computers became a major presence. But tablets go back much earlier, and their history is one full of false starts. Typically, tablets use smaller processors than fully fledged computers. This helps save on space and battery power and cuts down on heat generation. A typical tablet includes features not common in PCs, such as an accelerometer, a gyroscope, a touch-screen controller chip, a camera, and sometimes cellular chips and antennas. The Amazon Kindle (2007) was the first successful e-reader. The market exploded after the Apple iPad, leading to numerous rival products. The iPad had a long-lasting battery, a powerful 1 GHz processor, and access to the world's biggest app library (iStore). On the corporate level, tablets have been used in numerous ways, such as for inventory management, asset tracking, or in restaurants to take orders and process payments.[107]

Case Discussion

Should Sony Be in the Computer Business?

Sony has been a major presence in the consumer electronic market. Given the convergence of technologies, should the company also move to PCs? On the one hand, it is a logical market extension. On the other hand, it moves into the territory of experienced computer makers such as Apple, HP, or Dell, as well as into a space covered by low-cost manufacturers such as Acer and Asus. Does it make sense for Sony to be a computer manufacturer?

Already in 1986, Sony entered the computer market with its Network Engineering Workstation (NEWS). It was inexpensive and used mainly as an automated design tool,[108] and was favored by universities and corporate researchers. Fierce competition by Sun, HP, and IBM forced Sony to exit the market. But in 1996, Sony reentered the computer market with its newly launched VAIO (Video Audio Integrated Operation) microcomputer line. The VAIO logo represents an integration of the analog wave and the digital 1–0 binary code.

Sony President Nobuyuki Idei explained: "VAIO is an entrance fee. If you are not making computers, since change is happening so rapidly, you can't keep up. I don't aim to take market share in PCs, but to use the PC as a step to go on to the next step." Sony's strategy for the PC was to utilize it as a platform to insert its content (music, movies) and accessories (cameras, players) into homes. Sony's advantages were physical design and the brand itself. Sony's computers were light and slick with easy-access buttons for web surfing and multimedia controls. Sony also offered consumers perks from its content operations, such as music and movies that are exclusive to VAIO users, and to other Sony hardware. From the beginning, VAIO established itself primarily as a brand for consumers and creators, but had little penetration in the business and office market. Sony identified as target audiences for the VAIO[109]:

- "jetsetters" who required an ultra-portable notebook;
- image-conscious, affluent consumers desiring high-end electronics, regardless of cost.

Can Sony create a technological advantage in the PC business? Can it protect its advantages from lower-price imitators? The answer for both questions has to be no. The parts that make up a VAIO are mostly commodity components—elements supplied by other companies or off-the-shelf products from other vendors. They included microprocessors by Intel, hard drives by Seagate or Fujitsu, RAM by Infineon, optical drives by Hitachi or Matsushita, and graphic processors by Intel. What is the implication? The VAIO performance can be replicated by others who purchase the same components (or cheaper ones). As for Sony's sleek design, it can be substantially imitated.

In consequence, Sony's global PC sales were moderate. Global shipments peaked in 2012 at 8.7 million units, but fell to about 5.8 million in 2013. Market share dropped to 1.9%. This decline ultimately led Sony to sell its PC business, at a loss, to the financial investment firm Japan Industrial Partners (JIP). JIP reintroduced the VAIO line in the USA in 2015. By that time, Vaio had only 250 employees. JIP aimed at returning the VAIO line to profitability by focusing on niche markets such as graphic artists rather than aim at the mass markets, and then spinning the company off in an initial public offering, or selling it to a larger computer maker.

105 The Economist. "Gaming Goes to Hollywood." March 25, 2004. Last accessed May 9, 2017. ► http://www.economist.com/node/2541401.

106 Moreover, the piracy of films is much higher than for video games, where stronger DRM protections exist.

107 Spire Research and Consulting. "The computer tablet industry: Overflowing with opportunities." *SpirE-Journal2012 Q3*. Last accessed May 9, 2017. ► http://www.spireresearch.com/spire-journal/yr2012/q3/the-computer-tablet-industry-overflowing-with-opportunities/.

108 Sony. "Entering a Highly Competitive New Business Area." Last accessed May 9, 2017. ► https://www.sony.net/SonyInfo/CorporateInfo/History/SonyHistory/2-12.html.

109 Ruder Finn. "SONY Consumer Electronics." June 1, 2011. Last accessed July 12, 2011. ► http://www.ruderfinn.com/global-connectivity/consumer-electronics/case-studies/sony-consumer-electronics.html.

4

4.3.2 Convergence #2: Computers with Communications Hardware

4.3.2.1 Telecommunications

The second convergence is that of computers with telecom communications. Electronic communications technology has been around since the mid-nineteenth century. Everybody uses telecommunications—two-way individualized electronic communication—more than ever before: at home, in the office, on the road, at the beach, when web surfing, chatting with friends, emailing, streaming music, watching video, holding a meeting, or running a company.

Traditionally, telecommunications hardware was divided into two categories based on the destination of their products: fairly simple consumer and office-oriented customer premises equipment and carrier-oriented network infrastructure equipment.

Telecom networks used to consist, at their user end, of lines known as twisted pairs of copper wires. For a higher capacity of signals, and for transmission under the oceans, copper coax lines were used. Optical fibers became a hugely powerful alternative means of transmission. They consist of very clear glass strands which can transmit the pulses emitted by light-emitting devices such as lasers. Not only do these fiber strands have a huge capacity, but they can also transmit signals for thousands of miles before they need to be regenerated and amplified. The trend of technological progress in wire-based communications, in terms of transmission rate ("speed") has progressed at a compounded annual growth rate of about 44%, and that rate has been accelerating.[110]

The alternative to wired networks are wireless ones. In the 1840s, the English physicist James Clark Maxwell came up with the theory of electromagnetism. In 1888, Heinrich Hertz (Germany) demonstrated electromagnetic waves. In 1895, Guglielmo Marconi (Italy) applied these waves to transmitting telegraph-type signals to ships. Broadcasting soon followed. Reginald Fessenden (Canada) made the first voice broadcast in 1900 when working for the US weather bureau. Radio amateurs returning from World War I were able to advance technology by leaps and bounds. In 1919, GE, Westinghouse, American Marconi, and AT&T, with US government support, created the Radio Corporation of America (RCA) to compete with the British Marconi Company, and it became the technology leader for a generation. In time, technologists mastered increasingly high frequencies of electromagnetic waves. This made it possible to focus radio beams narrowly, which enabled microwave transmission via one hilltop tower to the next, and later via satellites that seem to be hovering in a stationary orbit.

The second major element of networks are various types of switching devices. These route the signals to their specific destinations. The private firms that had traditionally produced such hardware were doing well when they were the high-priced suppliers of their national monopoly telecom network operator. Two major factors combined to destroy this cozy business. The first was the introduction of government policies around the world that privatized state-owned telecom monopolies and opened telecom network services and hardware markets to competition. The second was the digital revolution. Network switches became, in effect, specialized large computers, and companies such as AT&T became computer makers. But it worked both ways. Companies from the computer and data world entered the huge telecom market, and they tended to be faster moving and lower cost. By 2010, all the traditional major telecom network equipment firms were in trouble. The telecom businesses of Siemens, Alcatel, and Lucent, respectively the traditional communications technology powerhouses of Germany, France, and the USA, were acquired by the Finnish mobile phone-maker Nokia. Nokia, too, was declining rapidly and sold its handset business to Microsoft. Nortel, Canada's leading telecom technology firm, went bankrupt and was liquidated. Instead, high-tech "datacom" manufacturers emerged such as, in the USA, Cisco, 3Com, Aruba (HP), Avaya, Brocade, and Oracle, and in China, Huawei and ZTE. In customer premises equipment, a similar avalanche overtook the traditional telecom industry. Such devices included phone handsets and other devices connected to the networks. For many decades, the telecom network operators controlled access to the consumer market by controlling the connectivity of handsets. Only a few favored suppliers were admitted, such as in Japan the "NTT Family." But when the equipment market was forced open around the world, a flood of new competitors from the CE industry entered. Asian CE manufacturers, in particular, benefited from the opportunity. Sony is one example. But this was just the beginning. Because the rise of mobile communications brought a second and more fundamental wave of new players.

4.3.2.2 Cellular Telephony

The development of cellular wireless increased the utilization of the electromagnetic spectrum by dividing a service area into small sections or "cells." Each cell uses a low-power transmitter. The same frequency can be reused in multiple cells in nearby (through non-adjoining) areas, and this greatly increases system capacity. This is only possible with the use of computer technology that can identify a calling party's location as she is moving, and is able to establish connections. It also benefited from increasing computing power in handsets, leading to "smartphones" which are small handheld computers that are network connected. Although AT&T and Motorola first successfully tested cellular radio in 1962, regulatory struggles in the USA prevented any commercial offering of cellular service for two decades. The world's first consumer-oriented mobile telecom networks were NTT's in Japan (1979) and NMT in Scandinavia (1981). A 150-year-old Finnish company with origins in paper goods manufacturing, Nokia, made the first mobile car phones for the network.

110 Koh, H. and C. L. Magee. "A functional approach for studying technological progress: Application to information technology." *Technological Forecasting and Social Change* 73, no. 9 (2006): 1061–1083.

With several waves of competition, prices dropped. In addition, handset prices also fell rapidly, from thousands of dollars to often a few dozen (frequently bundled into a service contract and therefore invisible), while performance and features skyrocketed. Demand for cellular services grew rapidly in the number of subscribers, minutes of use, and data bits and bytes.

In Europe, a single digital standard (GSM) was mandated for second-generation mobile service. In America, initially four distinct and rival digital standards emerged. CDMA, GSM's major alternative, is a technology developed by Qualcomm that splits each signal into packets with unique identification codes, allocates the packets among multiple channels according to availability, and then reassembles the signal at the receiving end based on their codes. In the so-called "third generation" (3G) of mobile wireless, CDMA became the worldwide approach. In the fourth generation (4G), in the approach known as LTE, Qualcomm collects 3.25% of each device's wholesale price as a licensing fee for its technology contributions, Motorola gets 2.25%, Alcatel-Lucent 2%, Huawei 1.8%, Ericsson 1.5%, and Nokia 1.5%.[111, 112]

Manufacturing cellphones was for a long time a booming business with many vendors, but the average prices for cellular handset declined while the products increased in complexity. Only manufacturers with very deep pockets were able to keep up. Major companies that fell by the wayside were Lucent, Alcatel, Siemens, and RIM. In contrast, successful companies were those with roots in the computer business. Apple, in particular, set the pace with its iPhone, introduced in 2007, where it brought to bear its strength in both computers and in consumer-friendly technology products.

Major players in mobile handsets worldwide based on unit sales in million units in 2017 were: Samsung (403.5 units or 23.4%); Apple (269 and 15.6%); Huawei (203.5 and 11.8%); Xiaomi (144.9 and 8.4%); OPPO (122.4 and 7.1%); and others (581.1 and 33.7%).[113] Of these, none is a traditional established telecom equipment manufacturer.

4.3.2.3 Case Discussion

Should Sony Be in Telecom?

Today, billions of people around the world are walking around connected to each other through telecom networks and small computers in their pockets, made by a variety of manufacturers. Is Sony one of them? Sony was an active supplier of consumer telecom equipment. Initially it focused on well-designed devices such as answering machines and cordless telephones. Sony had a recognizable brand and achieved a strong and profitable market role. However, commodification in the low-end products and low-priced imitators made Sony lose its share. At the same time, Sony as a consumer-oriented firm had no success entering the business telecom market.

For more advanced telecom products such as mobile phones, an increasing resource commitment was required. At first, Sony followed a go-at-it-alone strategy; however, this was unsuccessful even in Japan, mostly because Sony was never a member of the "NTT family" of suppliers to the national telecom incumbent.

By 1999, Sony's wireless condition looked dismal. Its global market share of the handsets market was less than 1% and it was losing money. In 2000, Sony entered into a joint venture with Sweden's Ericsson, the third largest vendor of handsets in the world but facing its own difficulties of plummeting market shares and record losses. The joint venture's headquarters were in the UK, with R&D labs in Sweden, Japan, China, USA, Canada, Netherlands, India, and the UK. The company relied heavily on the West European market, which was Ericsson's main turf.

Sony brought its strength in music to help stimulate its phone sales. The joint venture was at first able to increase its market share by two percentage points to 4.9% in 2009, which was in fourth place worldwide, but far behind market leaders Nokia (37.8%), Samsung (21%), and LG (11%). Worse was to come, Sony Ericsson was soon overtaken by Apple and its innovative smartphone. Sales shrank from 103 million units in 2007 to 57 million in 2009, leading to the layoff of 2000 jobs, nearly 25% of the total.

In 2008, Sony Ericsson came out with its smartphone Xperia. It outsourced the manufacturing of half of its Xperia line to the low-cost Taiwanese contract manufacturer Foxconn, many of whose operations are in mainland China. Xperia moved its operating system from Windows to Android (earlier, it had used a third operating system, Symbian). Xperia was nicely designed and had useful features such as water resistance, but it did not make a big dent in the market. In 2011, Ericsson was bought out of its partnership by Sony for $1.47 billion. By 2013, Sony's world market share was about 2.1%.

Sony's initial role in the first and second generations of mobile dure to the company's reputation as a CE giant and owing to its marketing prowess. But Sony did not succeed in entering the next level of mobile handsets on its own. The R&D here required a major commitment and investment. Instead Sony had to rely heavily on Ericsson's abilities. When Sony and Ericsson parted company again, Sony could not stay technologically in the leading group, in contrast to its Korean rivals Samsung and LG.

111 Armstrong, Ann K., Joseph J. Mueller, and Timothy Syrett. "The Smartphone Royalty Stack: Surveying Royalty Demands for the Components Within Modern Smartphones." *WilmerHale*. May 29, 2014. Last accessed May 9, 2017. ► https://www.wilmerhale.com/uploadedFiles/Shared_Content/Editorial/Publications/Documents/The-Smartphone-Royalty-Stack-Armstrong-Mueller-Syrett.pdf.

112 Stasik, Eric. "Royalty Rates and Licensing Strategies for Essential Patents on LTE (4G) Telecommunication Standards." *Les Nouvelles* (September 2010): 114–119.

113 IDC. "Global market share held by leading smartphone vendors from 4th quarter 2009 to 1st quarter 2018." *Statista*. 2018. Last accessed June 19, 2018. ► http://www.statista.com/statistics/271496/global-market-share-held-by-smartphone-vendors-since-4th-quarter-2009/.

4.3.2.4 The Internet

The internet was initiated by the United States Department of Defense as a system of linking smaller networks. In the 1960s, the RAND Corporation presented the concept of its researcher Paul Baran for communications following a hypothetical nuclear attack on the USA. Text messages would be divided into small "packets," with each packet separately winding its way through the network and thus being able to bypass section damages by attack. The Pentagon's Defense Advanced Research Projects Agency (DARPA) funded a project based on this concept, linking several defense technology R&D centers in government, private industry, and academia. It could interconnect local computer networks provided the individual machine could speak a common digital language known as Transmission Control Protocol/Internet Protocol. The resultant ARPANET grew rapidly after 1969. With the proliferation of microcomputers in the 1980s, an increasing number of research users linked themselves to ARPANET and then to its civilian successor, NSFNET.

NSFNET was replaced in 1995 by a collection of commercial internet backbones and internet service providers (ISPs). The number of host networks and domains increased exponentially. In 1995, 50 million people were online, primarily in the USA, Canada, and Europe. By 2006, that number had increased to 694 million, in 2013 to 2.71 billion, including by mobile devices, and to 3.58 billion including mobile devices in 2017.

In the 1990s, everything related to "the net" seemed certain of success. The financial markets were welcoming almost every internet-related firm with open arms. Applications such as internet telephony and webcasting began to attract the attention and funds of telecommunications companies and venture capitalists alike. Plummeting computer and internet access prices coupled with increased transmission, and faster processing speeds drove internet usage. Applications such as email portals, interactive gaming, online banking, e-auctions, e-tailing, online advertising, social networking, and streaming music and video, made the internet increasingly popular.

ISPs link computer users to the internet, and may provide additional services such as email. Small users typically connect to an ISP by using always-on high-throughput connectivity ("broadband") through various forms of transmission, such as a digital subscriber phone line (DSL), a fiber line, cable co-ax connection, mobile wireless network, or satellite. The ISP connects to the rest of the internet by high-capacity links as directed by "routers," and reach the main backbones, which in turn connect directly or over still other backbones to other internet nodes or ISPs.

The original internet grew by leaps and bounds, but was initially confined to relatively sophisticated users. It was complex to use and its content was essentially geeky text. This changed dramatically with the introduction of the world wide web. The web's key ease of use feature is hypertext, developed at Geneva's CERN laboratory in 1989 to allow researchers to reference other documents available on the internet. This means that data needs only be stored on one server to be accessible by any computer connected to the web.

Because of the intuitive nature of hypertext, even those with little computer experience were able to quickly make use of the web. The low computing power required to run a web server and the simplicity of creating web pages made it possible for individuals and small organizations to become web information providers, and to do so on an international scale. Thus the web gave large segments of society the ability to access and distribute information.

For a period, the internet was celebrated as open, free, and competitive. Entrepreneurialism was high, financing easy, and entry barriers were low. But in time it became more dominated by large firms with market power, whether ISPs or large application providers. The common elements were high economies of scale (scalability), based on high fixed costs and low marginal costs, and often complemented by network effects (positive externalities) on the demand side.

Thus, by the 2010s computers and telecommunications were firmly intertwined. Around the world, billions of people carried small computers whose value derived from the interconnection to each other. The drivers of such interconnection were, first, data communications in the form of the internet which vastly enhanced the value of computing devices and telecom networks. The second driver was the explosion in mobile and ubiquitous wireless networks that made handheld computers particularly useful. The networks themselves were operating with a dense inclusion of computer-type devices that enabled mobile cellular communications in the first place, by routing calls and managing frequencies. The result was a rapid technology acceleration in both sectors. The telecom network environment, in particular, moved from the previous slow and carefully planned public utility model to the much more rapid and competitive pace of the computer and IT world.

4.3.3 Convergence #3: Integration with Consumer Electronics

4.3.3.1 Consumer Electronics

The convergence of consumer electronics (CE) with computing and telecom devices has two dimensions:

1. integrated multipurpose devices;
2. communications capabilities.

Devices combine a platform (typically a CE device such as a music player or game console) with processing (calculators, computers, etc.), data storage, and software for operating systems and applications, and communications capabilities through connectivity technologies such as telecom, cable, Ethernet, mobile wireless, wi-fi, or Bluetooth and the like.

Some such integration goes back a long time. Originally, CE devices were not connected to each other or to a central node. Examples are phonographs (1870s) and cameras.[114] However, key CE devices became connected by communications networks, though initially of the one-way variety.

Milestones were:

- radio sets (1920s);
- television sets (1940s);
- cable TV and satellite TV connected TV sets (1960s);
- MP3 players (1990s);
- smartphones (2000s);
- tablets (2010s).

Although the consumer media electronics sector is novelty driven, it is not new. Thomas Edison's contributions (1870s–1890s) included the phonograph, the motion picture system, a microphone for the telephone, and in particular electric power distribution, which enabled many subsequent applications.

After World War I, American CE firms became world leaders. General Electric (GE), Westinghouse, AT&T, and American Marconi, with U.S. government prodding, created the Radio Corporation of America (RCA) to compete with the British Marconi Company. By 1922, there were over 200 smaller US radio set manufacturers. RCA, however, drove many of these firms out of business. In Europe, the major CE firms included Philips, Siemens, AEG, Thomson, and GEC.

In the second half of the twentieth century, the consumer electronics sector became dominated by Japanese firms.[115] Their government, through the MITI trade ministry, supported and subsidized the electronics industry. Japan also de facto closed its markets to imports. Partly as a result of these policies, and partly owing to an emerging extraordinary strength in R&D, manufacturing, and marketing, a vibrant industry emerged in Japan based on several large and diversified firms. In time, similar initiatives were undertaken by the government and industries of South Korea, Taiwan, and China. American-owned firms were either put out of business or bought out by foreign firms, often mostly for the value of their brand names. The main Japanese firms were Sony, Matsushita/Panasonic, Sanyo/JVC, Toshiba, Sharp/Pioneer, Hitachi, Mitsubishi, and Funai. In South Korea, they were Samsung and LG. In China, they were Hisense, TCL, Goertek, Huawei, and Lenovo. In Taiwan, major CE manufacturing was done by Foxconn, Pegatron, and Quanta.

The Dutch firm Philips remains among the largest CE companies. American firms survive in the areas where there is much convergence with computer technology and the internet (exemplified by Apple's products), in high-end segments (such as Bose speakers), in specialized products, or in business-to-business product markets such as set-top boxes (Motorola/General Instruments). Although the rate of major business upheaval in the CE industry is more gradual than it is in the computer sector, there is always a flurry of innovation and countless new products are released annually.

For CE companies, the best business model has been to build up scale and experience behind early protectionist walls, then move into exports on a value-pricing basis, build a strong, global brand with a few impressive products, and then expand into multiple products while commanding a premium price. The emergence of contract outsourcing manufacturers (OEMs) such as Flextronics and Solectron lowers entry barriers on the design stage by giving smaller CE firms access to large, flexible manufacturing facilities with economies of scale. For example, an entrepreneurial upstart in TV sets, Vizio, entered successfully with a low pricing model and offshore manufacturing. In time, even established CE giants such as Sony, Philips, and Motorola outsourced the manufacturing of products to the OEM firms.

4.3.3.2 Television Sets

The first public demonstration of television occurred in 1926 in London, by John Logie Baird, using mechanical scanning of images. The first large-scale television service was offered in Berlin, Germany, for the 1936 Olympics, and by the BBC in the same year. Regular television service in the USA began in 1939, using electronic scanning invented by Philo Farnsworth. World War II halted the advancement of television. Between 1948 and 1958, the number of American households with televisions grew from less than 1 million to 42 million.

In time, most household in rich (and many poor) countries had a TV set, and markets became saturated. It has therefore been the challenge for CE manufacturers to persuade consumers to upgrade from perfectly well-functioning devices that they had been told, just a few years previously, were performing miracles. For example, color television sets were slow to catch on—*Time* magazine declared them the "greatest industrial flop of 1956." It was a classic instance of the slow penetration of a gradual improvement, far behind the expectation of the experts.

Sales of digital flat and large screen liquid crystal display (LCD) and plasma monitors raised sales again as consumers upgraded. These screens require complex and costly manufacture, and even some of the largest Japanese manufacturers ended up using screens made by the Korean firms Samsung and LG, or those of the Japanese Sharp.

The key to the success to radio and TV sets was their connection to communications networks that provided content and information. Thus these devices were no longer self-contained, but derived their value from the linkage to information sources. These were mostly one-way connections.[116]

114 Originally, cameras were based on optical and chemical processes rather than electronics. They gradually incorporated electronics in light sensors and other control functions, and then became fully electronic by way of digital recording. We therefore include camera devices under consumer electronics.

115 Curtis, Philip J. *The Fall of the U.S. Consumer Electronics Industry: An American Trade Tragedy*. (Westport: Quorum, 1994), 194.

116 "Addressable" cable TV had rudimentary return channels.

More recently, TV sets have also become "connected" by two-way access to the internet, and have supported links to content providers such as Netflix as well as to each other. They have incorporated electronic storage, switching, modems, and home networking, and have thus became, in effect, display and control terminals of home-based computer-style networks.

4.3.3.3 Home Video Equipment

Because of the limited state of storage technology, recording on the consumer level was for many decades limited to audio records. In the 1950s, tape recorders emerged which made possible self-recording. In the 1970s, optical discs (CDs) emerged. The recording of video on magnetic tape was not feasible technically until 1959, when Ampex increased the relative speed of tape to recording head by mounting the tape heads on a rapidly spinning cylinder. Ampex and Sony marketed the first videotape recorders using this technology in 1961.[117] Because of their high price, such recorders were mostly used as professional devices until 1975, when Sony introduced an affordable VCR, the Betamax. In 1977, Matsushita introduced a non-compatible format, VHS, which had a longer recording time but lower picture quality and ultimately emerged as the industry's consumer standard. The market volume, however, soon fell victim to a new technology. The DVD optical disc player format, an upgrade of CD optical storage technology, rapidly replaced VCR players. But standard DVD players, too, were soon challenged by HD optical discs using blue-light lasers with still higher storage density. Two standards battled for supremacy, greatly delaying introduction: eventually, Sony's Blu-ray won.

Variations of magnetic and optical disc storage were similarly used for consumer computers, such as floppy discs, hard drives, and CD-ROMs. Because they were spinning mechanical devices they consumed much battery power. In time, the progress in semiconductor "solid-state" memory became cheap enough to replace in part or totally magnetic and optical storage. The technology also spilled over into CE. In 2001, a new type of home video equipment emerged—the personal digital video recorder (PVR or DVR). A DVR is essentially a hard-disk drive connected to the television set that enables users to record, store, and time-shift favorite television shows. Soon, DVRs were integrated into cable and satellite set-top boxes. The next step was for the storage element to become network based. This will be discussed further below.

As CE firms moved into networked devices, IT companies moved in the opposite direction, eyed the large consumer market, and entered it. Most successful was Apple, which did well with its iPod, a music device based on computer-based data compression (MP3) and laptop-style memory (at first a magnetic hard drive, later solid-state semiconductor). This was followed by the iPad, a light, handheld, and wi-fi-networked consumer computer in the tablet format, which became a successful device for media consumption. Other computer and IT makers also took that route, such as Cisco and Dell, but with less success. There were also small innovator start-ups from the internet and IT sector. TiVo, Roku, and Sling are examples, with products that extended the range of video options that are open to the user in terms of time and location. Virtual and augmented reality devices and apps emerged, with products by Samsung, Sony, Facebook, HTC, and Google, as well as several Microsoft Windows-based vendors.

Some of the CE companies were also able to move consumer-oriented electronics into other parts of a user's life, such as into home systems (temperature control and security, for example), appliances such as refrigerators, and into automobiles. With the Internet of Things emerging, it is only a matter of time before billions of devices are interconnected and communicating.

Thus, by the early twenty-first century, CE had transitioned from standalone devices lacking logical processing and produced by sprawling multiproduct firms to one of internetworked and "smart" products produced by a wider set of companies hailing also from other industries and from the start-up sector. In the aggregate, this trend accelerated the pace of innovation in the CE industry and changed in some cases the scale economies. CE markets became global, manufacturing split off from product design and marketing, and the market power of large retail intermediaries rose. The industry destabilized. Some CE firms weathered this challenge better than others.

4.3.3.4 Case Discussion

Sony's Convergence of Consumer Electronics with Communications and Computers

For several decades, Sony used to be the leader in CE, based on superior technology, design, and marketing. But by 2009, Samsung's TV manufacturing business had surpassed Sony's, which had been the latter's special source of pride and profits.[118] Sony was humiliated when in 2010 it had to rely on Samsung to supply key components, such as large LCD flat screens.

Sony's strategy for the convergence of CE with computing was to upgrade TV with its other product lines, by turning existing analog products into digital and "smart" ones. This enabled new products that combine audio, video, mobile, and internet capabilities.[119]

117 Mungwun, A.F. *Video Recording Technology: Its Impact on Media and Home Entertainment*. (Hillsdale, N.J.: Erlbaum, 1989), 144–145.

118 Dvorak, Phred and Evan Ramstad. "Behind Sony-Samsung Rivalry, An Unlikely Alliance Develops." *The Wall Street Journal.* January 3, 2006. Last accessed May 9, 2017. ► https://www.wsj.com/articles/SB113625623819236122.

119 The Economist. "Boot up the television set." June 26, 1997. Last accessed May 9, 2017. ► http://www.economist.com/node/92139.

Sony's early attempt in such devices was the Magic Link Personal Communicator, released in 1994. Such devices were known as personal digital assistants (PDAs). The project was a joint venture with AT&T which provided the telecom network. Sony hoped to use this device as an entry point into the telecommunications market, with sights on signing further agreements with telecom companies in Japan and Europe. But the device failed miserably in the marketplace. Its price was high for consumers at $1195; it was heavy (1.2 lbs); and while the target was businesspeople, the design made it look like a game console. Finally, its technological capabilities were premature, ahead of the market. Later, Sony introduced the Clie as its entry product in the PDA market. Even though the product had nice styling, its market acceptance was low. Sony ended up selling Clie in 2004.

Another Sony product was its Location-Free TV in 2004. It was a wireless broadband connected TV set, the first in the industry. In addition to watching TV, it could be used to browse the web, access email, photos, and remote access personal and business files. However, owing to its difficult set-up process and bulky looks, it was in a consistent second place behind start-up company Slingbox and its elegant solution. Sony's product line was discontinued.

Another Sony attempt was Qualia, a line of several audio and video peripherals that could be linked to each other. The line was launched in Japan in 2003. The Qualia line was targeted to the upscale market with a combination of cutting edge technology, design, and functionality with a high-end digital camera (introduction price about $3000), a MiniDisc player described as "an object d'art carved from a block of pure brass," and a headphone set, which established a new standard in audio reproduction. However, the product line did not sell well and was discontinued in 2005.

4.3.4 Convergence #4: Integration with Content

4.3.4.1 Connected Content

The fourth type of convergence is that of media hardware with media content—with text, music, pictures, videos, and games. This goes beyond one hardware device connecting to others. Such connectivity enables links to content, but it is not the content integration itself. An example is an interactive game console. These consoles have built-in modems which can provide access to internet content such as software, web browsing, social media, and email, but in particular they offer content: games. Electronic books are another type of device, as are audio players. Apple's iPod and iPad were successful because Apple was able to integrate hardware and content through the creation of its iStore.[120] By 2017, the Apple iTunes store had sold over 50 billion songs. It offered 45 million songs, 90,000 movies, 2.5 million iBooks, and 2 million apps. Its annual revenue was almost $10 billion, with an average spending of $40 per user per year. This made Apple the leading music retailer in the world.

4.3.4.2 Case Discussion

How Sony Achieved Content–Hardware Convergence

Sony's content–hardware strategy is probably stronger than that of any other company in the world. This strategy goes back to its Betamax defeat by the technologically inferior Matsushita's (Panasonic) VHS. The debacle led Sony's CEO Morita to conclude that hardware superiority was not enough and had to be supported by control over some content software to assure a format's success. Morita's content strategist was Norio Ohga. As mentioned at the beginning of this chapter, Ohga had a career as an opera singer and symphony orchestra conductor, and in 1986 he convinced Sony to buy the music division of CBS for $2 billion. This acquisition helped the success of the CD launch.[121]

In 1983, Sony and Philips jointly introduced the CD as high-fidelity, noise-free digital audio storage. It revitalized the recorded music and audio electronics industries. Sony also pioneered the portable audio tape player with the release of its popular Walkman in 1979. But the market as a whole declined with the advent of portable alternatives with better sound quality. New products emerged, most notably the portable MP3 player, introduced by the tiny computer equipment company Rio. Sony and Thomson followed with their own products. Sony, however, was hampered by the demands of its own music division for strong security against piracy. This held the company back from taking the lead in this market, which should have been its stronghold given the dominance of its Walkman and Discman player generations. Yet Sony's MP3 player was a distant runner up. In 2001, Apple entered the market with the iPod, coupled with the music store iTunes, and quickly became the dominant force in the market with a share of 73.8% in 2005. Through innovations such as the iPod Mini and Nano, Apple was able to keep charging a premium price. In contrast, Sony's market presence in portable music declined.

In 2004, Sony added to its music content strength by joining up with Bertelsmann, another of the five music majors, and merging their music operations to create Sony BMG, the world's second largest music group. In 2008, Sony raised the stakes further and bought out Bertelsmann's half-share of the company.

Sony Music Entertainment includes several subsidiaries, such as Columbia Records, Epic, Legacy, RCA, Jive, Kinetic, Arista, Sony Music Japan, Sony Music UK, and Sony Music Germany.[122] Sony also distributes many independent labels.

Sony tried to integrate this content into its mobile phone venture Sony Ericsson. In

120 MacNN Staff. "Apple calls iPod nano demand 'staggering.'" *MacNN*. October 11, 2005 Last accessed May 9, 2017. ► http://www.macnn.com/articlesloaddetails/05/10/11/aapl.q4.conference.call/.

121 Epstein, Edward Jay. *The Big Picture, The New Logic of Money and Power in Hollywood*. New York: E.J.E. Publications, Ltd., Inc., 2005.

122 Wikipedia. "Sony Music Entertainment." May 29, 2011. Last accessed June 1, 2011. ► http://en.wikipedia.org/wiki/Sony_Music.

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order to compete with Apple's iTunes and Nokia's Comes With Music services, Sony Ericsson launched its own mobile phone service, PlayNow Plus.[123] But this did not make much of a dent.

Music was only the first step for Sony's entry into the content business. Film followed. In 1989, Morita bought the film studio United Artists Columbia for $3.4 billion from Coca-Cola. Sony Pictures was able to produce big hits at the box office such as *The Da Vinci Code*, *Casino Royale*, and *Spider-Man 3*.

Sony used its content strategy to drive the transition to HDTV and HD-DVD film format. By owning film content, Sony strengthened its hand in the battle over the standards. For example, Sony collaborated with the Discovery Network and with IMAX to launch a 3D network called 3Net, with Sony being the primary sponsor for the ESPN network. Sony used its game console PSP and PS3 to drive consumers to its Blu-ray video disc standard, and prevailed over its rival Panasonic. The success of the PSP console was partly driven by publishing games such as EverQuest, Star Wars Galaxies, The Matrix Online, Gran Turismo, Warhawk, and Formula One. They created a large user base with access to Blu-Ray content, which in the end tipped the scale against rival Panasonic.

Thus there have been several examples of success for Sony's content integration strategy. On the other hand, the Sony Reader shows the downside. The Sony Reader was the first tablet to use an e-paper screen, but it had no wi-fi or wireless connections. It failed to make a splash while Amazon's Kindle took 85% of the market share. Kindle had the advantage of Amazon's bookstore, while Apple's iPad had the advantage of its iStore when it took off in 2010. Sony's online content story which offers a broad selection of fiction and non-fiction, manga comics and graphic novels, did not take off, just as its music store had also failed. It 2014, Sony closed the North America operations of its Sony Reader store owing to a lack of success against Amazon and others.

Other Sony efforts included a wireless broadband TV, enabling the first dual-band wireless audiovisual transmission, with web browsing, email photos, and access to personal contents while traveling. Sony's Cocoon (released 2003) was a Linux-based set-top box with broadband internet connectivity. Cocoon aimed to become an alternative to the PC for accessing internet content. It could also analyze previous choices and items stored to identify a user's preferences and automatically record programs that fitted that profile.

So the question is, has content strategy benefited Sony, or has it slowed it down? Has Sony gained an advantage from its content, or should it simply concentrate on offering a better hardware device platform? Sony's PS3 had the Blu-ray player, and with it and its Hollywood studio position Sony was able to win against HD-DVD. On the other hand, Sony's music division opposed aggressive moves in MP3 players owing to fears of piracy. And Sony's TV set business? Its film *Hancock* was made available via internet download only for its Bravia premium brand TVs for just $9.99 prior to the DVD release.[124] Did that measurably increase Sony's sales? Probably not, but it generated some buzz. Despite these efforts, Sony's TV set sales were in serious trouble.

Symmetrically, one should also ask: has Sony's *content* benefited from Sony's hardware connection? Has Sony created new convergence types of content, or promoted its content better through its hardware? So far there have been no examples.

4.3.5 Convergence #5: The Media Cloud

Today, the next generation of technology integration is emerging, that of connecting consumer hardware devices with computing services. The world wide web with its numerous websites for information and transactions was a major step. Today we are moving to date processing itself, by way of "clouds," which is the current term for server-based services to end users. The basic idea has been around for decades, to move data and operations to big central servers, and to leave the periphery of end user "clients" to be relatively slim terminals. In that way, the device can be small, relatively simple, and parsimonious of battery power.

Some clouds are mostly storage service providers or backup services such as Dropbox, or the music "lockers" of content owned by users, such as Apple iCloud, Google Music, or Amazon Cloud Player. But other clouds go much further and provide software applications, middleware, social apps—software as a service—rather than conduct such operation directly on user devices such as tablets, or smartphones. Some companies have created huge facilities for these services. Apple spent about $1 billion on a new data center in Maiden, North Carolina.

What are the implications? First, the consumer electronic (CE) business is being changed. The home is at the center of our private life, but it is also a technology nightmare because of an obsolete consumer infrastructure and unqualified system operators (i.e. consumers themselves). Because of this discrepancy, there is often a clash between the vision conveyed by advertising and the reality of the actual user experience.

To overcome these consumer problems "home networks" emerged. The aim is to interconnect the increasingly complex set of home electronic devices, such as TV monitors, audio equipment, computers, storage printers, fax, phones, cable and satellite TV set-tops, cars, refrigerators, heat and air conditioning, and alarm systems.

Various industry groups have tried to establish control over home networking, including the CE industry, cable TV, telecom and wireless networks, computer makers, and operating software firms. The computer industry's "wifi" (the IEEE 802.11 standard, building on Australian innovations) prevailed.

123 Sandoval, Greg. "Sony Ericsson announces PlayNow music service." *Cnet*. September 24, 2008. Last accessed May 9, 2017. ► https://www.cnet.com/news/sony-ericsson-announces-playnow-music-service/.

124 Nakashima, Ryan. "Sony free to mix music, electronics." *Los Angeles Times*. October 14, 2008. Last accessed June 1, 2011. ► http://articles.latimes.com/2008/oct/14/business/fi-sony14.

There are consequences. If all devices in the home are interconnected, then there is no reason to have, for example, numerous separate storage subsystems, multiple separate power supplies, multiple antennas, signal processors, tuners, input devices, displays, codes, and software. Instead, there are incentives for more powerful specialized devices for storage, antennas, processors, sensors, and to internetwork them at home.

But why stop at the home? Shared facilities will move further away from the consumer to the facilities of remote applications providers who will have still more powerful functional boxes, software, and expertise. This means that we move from CE as hardware devices to CE as services. A familiar example is the voicemail service that is now being provided by a phone company to replace an answering machine, a hardware device. Services are paid according to usage, or by subscription, or by sponsorship.

The necessary hardware will mostly be bought by service providers rather than consumers. In this market, IT companies have more credibility than CE companies. More powerful but fewer hardware boxes will be sold. This is even worse news for retailers. Standardization will be less important, as long as the cloud providers use the various systems and bridge them. So instead of following the standard developed by one particular company or industry, the cloud providers can use different technology solutions from different companies, bridge them, and make them interoperate as a whole.

Thus the future of the CE industry seems to be that consumer electronic devices will disintegrate, and instead often become services, bringing CE companies under severe pressure.

4.3.6 Convergence #6: Bio-Electronics and Human Cognition

The next convergence (C6), clearly ahead of us, is that of IT technology with bio-technology, into bio-electronics. Already, cochlear implants, which directly stimulate the auditory nerve, have enabled thousands of deaf people to hear sound. Similarly, a retinal implantable chip for prosthetic vision may restore vision to the blind.[125] Another type of technology, aimed to create a touch and feel sensation, is the TactaPad, where a pad is touched directly with the hands, providing dynamic "force feedback." The pad has a unique feel that corresponds to the object being touched.

But the applications will go deeper rather than overcome sensory handicaps. We may be able to integrate a computer's speed and accuracy, as well as its ability to transfer knowledge easily, into our own sensory systems. Similarly, sensory signals picked up by humans may be processed by technical devices rather than the human brain, and human responses or emotions could be detected and interpreted directly in a kind of "brain-modem."

An early device is Emotiv Systems (EPOC), which was introduced in the video gaming market. It is a wireless headset that can detect conscious thoughts, facial expressions, and non-conscious emotions. It also contains a gyroscope to register movement.[126] Emotiv's "brain computer interface" reportedly allows users a new generation of gaming experience. When users play a game using the Emotiv interface, 15 sensors detect their brain activity and emotions such as fear and excitement.[127]

Similarly, NeuroSky's MindSet has an electrode connected to the user's forehead and is capable of reading the player's brainwave information. The headset can register users' current state of relaxation or concentration.[128] A third example is OCZ Neural Impulse Actuator. This, too, captures several types of signals, including facial muscle movements, eye movements, and brain waves and converts them into commands for the computer. Another company, Guger Technologies, has an interface that allows users, by only using their brains, to compose messages on their PCs and play simple games.

Futurist Ray Kurzweil, extrapolating current exponential trends in computation power, predicts that the capability of a human brain will be available electronically in around 2023 for a price of $1000 and for only 1 cent in 2037. Eventually, the capability of the entire human race will be reached in 2049 for $1000 and in 2059 for 1 single cent.[129] While such extrapolations often reflect a technologist's narrow perspective of human capability, the broader point is valid: a good number of our mental processes could be done more powerfully by machines. This includes the control of media-created sensory experiences.

Such technologies emerge first for medical and military use. They have a great potential for good, but also implications for altering or controlling behavior. They are fraught with perilous implications and will lead to much societal debate. And they create enormous challenges for the next generation of technologists and media managers.

125 McGee, Ellen M. and G.Q. Maguire, Jr. "20th WCP: Ethical Assessment of Implantable Brain Chips." Proceedings of the Twentieth World Congress of Philosophy, August 1998. Last accessed August 10, 2012. ► http://www.bu.edu/wcp/Papers/Bioe/BioeMcGe.htm.

126 Hanlon, Mike. "The first commercial Brain Computer Interface." *Gizmag*. February 21, 2008. Last accessed June 1, 2011. ► http://www.gizmag.com/the-first-commercial-brain-computer-interface/8860/.

127 Dasey, Daniel. "Aussies develop brain-driven computer game." *The Sydney Morning Herald*. March 18, 2007. Last accessed May 11, 2017. ► http://www.smh.com.au/news/technology/aussies-develop-braindriven-computer-game/2007/03/17/1174080226488.html.

128 Quick, Darren. "Brainwave controlled video game concept unveiled." *Gizmag*. October 8, 2008 . Last accessed June 1, 2011. ► http://www.gizmag.com/brainwave-controlled-video-game-concept-unveiled/10154/.

129 Kurzweil, Ray. "The Law of Accelerating Returns." *KurzweilAI.net*. March 7, 2001. Last accessed August 10, 2012. ► http://www.kurzweilai.net/the-law-of-accelerating-returns.

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4.4 Case Conclusion

The Next Act for Sony

Sony is a brilliant technology and marketing firm but has difficulties in keeping up with specialized firms. Increasingly, it leaves R&D in those areas to partners or vendors. Sony's strengths are its integrator role, its strengths in design, and its prowess in global marketing. The aim is a streamlined Sony. As Sony's past CEO Howard Stringer stated, "in terms of the variety of products, Sony is still unbeatable. The question is how much variety is too much variety."[130] Specialization is not just a matter of technology. Sony is spread thin not only in R&D but also in the marketing of its products.

Aware that it might be too diversified, Sony gradually and reluctantly abandoned its "scatter-gun" approach to customer electronics in favor of focusing on the "champion products."[131] But internal stakeholder constituencies of product fiefdoms make such a prioritization difficult.

Internal communications in the sprawling company were often flawed. In one instance, Sony's marketing people did not alert the R&D managers of the impending demand for large flat screen TV, leaving the company to fall behind Samsung and Sharp and requiring it, embarrassingly, to buy those screens from its competitors.

In the computer field, PCs became a commodity, with Intel and Microsoft taking most of the profit. Sony's Vaio did not create a strong multiplier for the company's overall products.

Being pummeled financially, in 2009 Sony announced layoffs of 8000 permanent and 8000 contract workers, most of them in America. In 2010, there were 450 layoffs at Sony Pictures. In 2010, it reduced its capital investments in electronics by 30% and reduced manufacturing prices by 10%. It continued to shift R&D and manufacturing to outside the firm. Even so, it lost $5.5 billion in 2011. In 2013, sales declined, and the loss was over $1 billion. TV shipment declined from 40 million to 20 million. According to its then CEO Howard Stringer, every TV set built by Sony created a loss for the company.[132] Outside analysts recommended that Sony abandon product categories where it could not compete anymore, such as television sets, and focus on its strengths, such as entertainment and video games.

Appointed as the new CEO was Kazuo Hirai, a lifelong Sony technologist who was credited with making the PlayStation business profitable.[133] Hirai aimed to turn the business around with cost cutting, layoffs, new products, and a breakdown of internal barriers. His priorities were five initiatives:

- focus on the core businesses: digital imaging, games and mobile;
- turn around the TV business;
- expand business in emerging markets;
- create new businesses and accelerate innovation;
- "realign the business portfolio and optimize resources," in other words more closely co-ordinating its content units with its technology devices.

These were broad goals, hardly focused targets, and action strategies. Concrete actions taken were a new top management structure ("One Sony, One Management"), which means a unification of all electronics business units, but at the same time the divisions would have more independence to accelerate decision-making; and cost cutting in the TV set business, with the aim to reduce fixed cost by 60% and operating cost by 30%. In 2014 and again in 2015, CEO Hirai took several steps: Sony spun off the audio and TV set manufacturing operations into a wholly owned subsidiary to speed up decision-making processes, and its computer division Vaio was sold to an investment consortium, Japan Industrial Partners, for about $500 million plus a 5% stake in the new company. Another 5000 jobs (approx. 3% of global staff) were cut.

Within the constraints of legacy, Sony's strategy was to focus on its most profitable and high-margin businesses. It aimed to increase operating profit 25-fold within three years by growing its camera and game divisions and to give up on raising its sales in smartphones or computers. It then proceeded to cut 2000 jobs out of 7000 in its smartphone division.

The major building block for Sony was its strength as one of the largest camera makers in the world. Sony is number one in 4K-quality video, production cameras, and projectors. The entire market, however, has greatly declined owing to a migration to smartphone cameras. The emerging Sony strategy has been "From the Lens to the Living Room," meaning the value chain from professional content production hardware to consumer media devices. Profitability of Sony's camera business rose 73% in 2015/2016.

Another strategy was to differentiate Sony by connecting its entertainment properties, such as the music, movie, and video game sections, more closely with its electronic devices. This concept, of course, had been promoted for over two decades, and it was not clear why it would be more successful now.

Sony also aimed to increase capital investments by generating significantly funds—$3.6 billion—in its first outside capital raising in 25 years. Partly based on these measures, operating profit rose in 2015/2016 by 330% (from $655 million to $2.81 billion). Losses in its mobile communications business dropped 72%, to $590 million from $2.08 billion. Its gaming division's profits rose 84% to $850 million, with PS4 sales rising significantly to 35 million. On the other hand, it lost $270 million in its semiconductor and component division. That segment had recorded a $850 million profit in the preceding year.

But the trends are still running strongly against it. Does this mean that within the next years Sony will continue to break itself up? It will remain a strong brand, but with most of the R&D and manufacturing done outside, and with major product lines being spun off. Rather than a technology R&D developer, in most of its product lines, Sony will be a technology aggregator and a technology/content integrator.

130 Schlender, Brent. "If you don't act, you will kill the company." *Fortune Magazine*. April 4, 2005. Last accessed May 11, 2017. ► http://archive.fortune.com/magazines/fortune/fortune_archive/2005/04/04/8255922/index.htm.

131 Nakamoto, Michiyo and Paul Taylor. "From push to pull – Sony's digital vision." *Financial Times*. January 6, 2006. Last accessed June 1, 2011. ► http://www.ft.com/cms/s/2/381891be-7f09-11da-a6a2-0000779e2340.html#axzz1O3C6NQw3.

132 What Hi-Fi? "Sony Admits Losing Money On Every Kind of TV It Makes; plans "different kind of TV." November 11, 2011. Last accessed June 14, 2012. ► http://www.whathifi.com/news/sony-admits-losing-money-on-every-tv-it-makes-plans-different-kind-of-tv.

133 Yasu, Mariko. "Sony's Hirai Stakes Reputation on Restoring TVs to Profit." March 27, 2012. ► http://www.bloomberg.com/news/2012-03-27/sony-s-incoming-president-hirai-to-run-home-entertainment-unit.html.

4.5 Outlook

We have discussed in this chapter a dozen tools and tasks for media and digital companies to manage their technology functions. They include:

- technology assessment and forecasting;
- selection of R&D projects for funding;
- integration of R&D with firm strategy;
- in-house versus outsourcing?;
- organizational Structure of R&D activities;
- managing the globalization of corporate R&D;
- organizing the R&D lab Itself;
- implementing R&D alliances;
- KM;
- participation in standards strategy;
- internal adoption of technology;
- working with developers and with "open innovation";
- budgeting R&D.

We have also discussed six technology convergences:

- computers;
- communications;
- consumer electronics;
- content;
- connectivity cloud;
- cognition.

And we have discussed one quintessential media technology convergence company, Sony.

Even all of the enormous changes in media technology, we are most likely only at the early stages of the evolution. Coming down the road are many technologies with a media impact, some of them listed below:

- Intelligent interfaces that make human–machine interaction more convenient.
- Bio-electronics that directly link physiological sensations with machines.
- Machine-to-machine intelligent communication.
- Semantic networks which can interpret and understand meaning.
- Intelligent screeners of information.
- Cognitive radio that can roam and use bits and pieces of spectrum.
- Large, thin, and flexible screens that are integrated into walls and various products.
- Ubiquitous non-stop connectivity.
- Gigabit-rate networks in the home.
- Megabit mobile wireless.
- Smartphones with visual projection.
- Miniaturization and systems on a chip.
- Sensor networks that can provide feedback, monitoring, and controls.
- Holographic and glasses-free 3D.
- Real-time rendering that enables true customization and interactivity of content.

This raises the question: for media and communications, is technology destiny? On the stormy seas and currents of technology change, are they tossed about like little boats, or are they able to navigate and make their own way? People tend to overestimate the short term, but to underestimate the long term. In technology devices, it is quite common to encounter a "hype cycle," in which new or anticipated products raise expectations that are far out of line with reality. Eventually inflated expectations reach their peak, and disillusionment sets in, a gloomy counter-reaction to the previous rosy scenario. But, in time, reality returns and a cooler assessment emerges.

But within those oscillations there are general trends. A Moore's Law pace of advance in semiconductors is one of them. What then are the implications? For example, if the trend of technology is increased convergence of devices and software, should one also expect a convergence of companies from the various segments of hardware, software, and connectivity? But, as we have seen, technological *convergence* is one trend, but so is specialization. Specialization seems to be winning. Though here, too, there are cycles. Specialization helps companies to achieve economy of scale and build a barrier to protect their market share from competitors and potential newcomers. It also can deal with the presence of disparate industry cultures, which is often a retardant for innovation. Therefore, technology innovation is mostly a specialty endeavor in terms of the focus of activity and in terms of culture.[134] It is difficult for a Sony-style firm to have tech-development success across multiple media and products.

Does a "technological determinism" exist in which the technological developments set the direction of a media firm or industry?

- Yes, for the broad directions—such as toward interconnected computer-based communication
- No, for an organizational structure of platform arrangements—such as the internet system that has evolved.
- No, for a specific company or industry performance—such as Google versus Amazon
- Yes, for broad content genres and applications types that become possible.
- Yes, for the dispersion of information and for interpersonal and intergroup communication

The preceding discussion has shown the many dimensions and tasks of technology management faced by a media or digital company or organization. Whether they are handled by a CTO or by others in the organization, they are issues

134 In contrast, convergence leads to a firm that must operate across several sectoral cultures. Even where top management embraces such cultural integration, the sectoral culture is much slower to change than organizational structure, top leadership, or strategy. Some units empower individuals, while others control them firmly. Some take a short-term orientation; others look for the long term. Some stress an environment of rapid change, while others offer job security. It is doubtful that homogenizing them will raise their individual or aggregate effectiveness.

that require an understanding of the underlying trends, of competitors' initiatives, production planning, market forces, fostering of innovation, and government actions. They require savvy in tech, strategy, marketing, operations, HR, and public policy. This is not an easy set of skills to combine, but it is an essential one for a media company. The aggregate impact is fundamental. Media technology affects media content and societal interaction. In that sense, R&D technologists are also the engineers of our culture and of our politics.[135]

4.6 Review Materials

Issues Covered

We have covered in this chapter the following issues:

- Which technological trends drive the media industry.
- What the functions and responsibilities of the CTO are.
- How to select R&D projects for funding.
- Whether to specialize or diversify in R&D.
- What tech company's R&D horizons for short-term and long-term projects are.
- How to position and organize R&D within the firm.
- When to outplace R&D.
- How to involve developers and users in the R&D process.
- How to determine R&D budgets.
- How companies (and universities) benefit from R&D alliances.
- How companies manage their internal knowledge.
- How to play the standards setting game well.
- How semiconductors transformed IT and CE.
- How PCs and smartphones evolved.
- How the internet emerged and evolved.
- What the future of the CE industry is.
- How the integration of media hardware and content generated new media types.
- What the implications of the convergence of consumer hardware and computing devices are.
- What the potential of a convergence of bio-electronics and bio-technology might be.

Tools Covered

We used these tools to discuss technology management issues:

- Moore's Law.
- R&D project selectivity and success rate.
- Scoring method for projects.
- Economic–financial analysis of project prioritization.
- A tech company's R&D categories for short-term and long-term projects.
- Dimensions of consumer acceptance.
- Risk–reward diagram.
- Network effects.
- Innovation platforms.
- R&D effectiveness index.
- Standards process participation.
- KM.
- Media cloud.
- NPV approach.
- R&D alliances.

4.6.1 Questions for Discussion

1. What are the key technology innovations from the 1990s that will affect media by 2020? Explain. And what are technology innovations of the 2000s that will affect media 20 years later?
2. A consumer electronics manufacturer has hired your consulting services to forecast trends in CE. What do you foresee and how should this CE manufacturer adapt to the future?
3. When it comes to patents, is R&D management moving in an identifiable direction? If so, what is it, and does it make sense?
4. Is there a relationship between market volatility and technological progress in a field? How do these relationships play out in major media sectors?
5. You are the CTO for a network equipment firm. Researchers from the University of Wallalia have just reported discovering a new principle of particle physics that could lead to hyper-broadband that leaves all current transmission technology in the dust. How should R&D management address this opportunity and threat?
6. Does the current patent system retard technology innovation? Explain why or why not.

135 Example: a study shows that over time, films have shifted toward movie types that are most amenable to special effects, such action films and sci-fi, while romance and drama have declined. "Movie characters can now be transported, transfigured, or killed in an incredible number of ways, but what can digital effects do for a kiss?" Ji, Sung Wook and David Waterman. "Production Technology and Trends in Movie Content: An Empirical Study." Working Paper, Indiana University, December 2010. Last accessed May 11, 2017. ► https://www.researchgate.net/profile/Sung_Wook_Ji/publication/228448250_Production_Technology_and_Trends_in_Movie_Content_An_Empirical_Study/links/55196ea60cf23c470a5c7a23.pdf.

7. Contrast the responsibilities of the CIO and the CTO at a typical media company.

8. How does the CTO evaluate the viability of R&D projects? What advance information from the R&D department would s/he require?

9. How does Moore's Law affect R&D planning?

10. How can a media company take advantage of user communities that would like to converge with the company and provide innovation? What are the possible disadvantages?

4.6.2 Quiz

1. Which of the following products is a part of the convergence of devices and content?
   A. Sony's multimedia platform Vaio computer;
   B. Amazon's e-book reader Kindle;
   C. Sony's mobile media player LocationFree TV;
   D. None of the above.

2. Which is not likely to be an impact of the ultra-broadband networks?
   A. Higher prices for devices as they become more powerful;
   B. More subsystems (software and hardware) are built in the devices;
   C. Transitions from device-based features to online-based services.

3. Which of the following best represents the organizational structure of R&D activities?
   A. In the centrally supported model, most research is done at the division level, while most development is done at the corporate level;
   B. As R&D becomes more complex, the R&D organizational structure becomes more decentralized;
   C. Companies can be successful in R&D even without any corporate level R&D.

4. Which of the following will ensure a standardization war victory over a rival?
   A. Control over a large part of installed base;
   B. Perfect compatibility with the former standards;
   C. Exceptional quality of new standard;
   D. None of the above.

5. Which of the following is the worst reason to join a R&D alliance?
   A. Members can share the cost for developing new technology;
   B. Members have highly complementary technology skills and experiences;
   C. The culture and structure of the alliance will reduce the development time significantly.

6. Which of the following is correct about the impact of home networks?
   A. Shifting actual functions to remote locations is not practical, because it overloads bandwidth requirements;
   B. It will become even more complex for the users to handle the functions of devices, because of the complexity of the network;
   C. Standardization will become more important because of various systems provided by various service providers;
   D. None of the above.

7. Which of the following is not a necessary criterion of good balance between centralization and decentralization of R&D activities?
   A. The corporate level has the ability to conduct research and acquire knowledge to enable future profitable innovations;
   B. The company has the ability to synthesize the knowledge of different divisions;
   C. The responsibilities of R&D are split clearly between the corporate and division levels;
   D. None of the above.

8. The first general purpose electronic computer was/were:
   A. The Electronic Numerical Integrator and Computer (ENIAC), invented in 1946;
   B. The "difference engine," invented in 1839 by Charles Babbage and Ada Countess Lovelace;
   C. The Atanasoff-Berry computer, developed by Iowa State College professor John Atanasoff and Clifford Berry in 1941.

9. The impetus for the development of the ENIAC was the need to:
   A. Compute enormous amounts of statistical data for meteorological research;
   B. Perform ballistics computations for firing tables during World War II;
   C. Calculate studies of thermonuclear chain reactions, that is, the hydrogen bomb;
   D. All the above.

10. In 1975, Intel CEO Gordon Moore predicted that the power of a computer chip would:
   A. Progress arithmetically;
   B. Progress exponentially, doubling every 18–24 months;
   C. Double every four years due to exhaustion of early gains.

4

11. The future trend in computing is:
    A. Mainframes becoming insignificant;
    B. Computer devices accelerating performance at Moore's Law rate;
    C. Computer devices for every person on the planet;
    D. All of the above.

12. With client-server computing, corporate growth is expensive because:
    A. PCs take up a great deal of footprint;
    B. The complexity of PCs makes maintenance difficult;
    C. If companies decide to upgrade software, they must do so on every PC;
    D. All of the above.

13. During what phase of tech product development should a company more effectively analyze market potential?
    A. Testing;
    B. Product selection;
    C. Prototype construction;
    D. None of the above.

14. What is the trend of the video game market?
    A. Reaching out to younger consumers;
    B. Increased video game console sales;
    C. Increased competition in portable consoles;
    D. Online gaming sales are increasing mainly owing to the popularity of high-tech games.

15. Which sales have decreased?
    A. Gaming hardware sales;
    B. Electronic game sales;
    C. Electronic gaming software sales.

16. Which type of R&D model gives research the least importance?
    A. Technology-driven;
    B. National treasure;
    C. Market-driven;
    D. Global.

17. Which officer of a company is most responsible for the corporate R&D organizational structure?
    A. Chief Information Officer;
    B. Chief Technology Officer;
    C. Chief Executive Officer;
    D. All of the above.

18. What has the convergence of CE with telecom devices led to?
    A. Integrated multipurpose devices with communications capabilities;
    B. Faster mobile internet speed;
    C. Telecom law regulation extended to CE devices;
    D. Data caps.

19. What is not a key task or function of a CTO?
    A. The CTO identifies present and future technology options;
    B. The CTO contributes to published scientific research;
    C. The CTO has to deal with scenarios and opportunities that are composed of building blocks that already exist;
    D. The CTO shapes part of the overall corporate strategy along the dimensions of technology.

20. Which statement about the purchasing behavior of consumers is incorrect with regards to innovative products?
    A. Consumers fear losses much more than gains of the same magnitude;
    B. Behavioral change is not easy for consumers;
    C. People tend to overvalue the benefits of new goods over the goods they own;
    D. There is a mismatch between what innovators think consumers want and what consumers truly desire.

21. What is especially important for the innovation stage "Horizon 1: Improvements"?
    A. Mostly money and people;
    B. Corporate culture of creativity;
    C. Making bets;
    D. Exploration into new markets.

Quiz Answers

1. B
2. A
3. C
4. D
5. A
6. D
7. C
8. A
9. D
10. B
11. C
12. D
13. B
14. C
15. A
16. C
17. B
18. A
19. B
20. C
21. A