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Business Strategy for the Technology Revolution: Competing at the Edge of Creative Destruction

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Abstract This article presents an overview of the Technology Revolution and how corporations compete in an era of economic transformation. We draw on a state-of-the-art forecasting system to outline strategic technological advances that are likely to enter the mainstream and their expected impacts. To better understand how to navigate this wave of change, we examine three corporate exemplars that have thrived by surfing the leading edge of the technology tsunami—Netflix, Apple, and Toyota. Then we integrate what can be learned from these cases into guidelines for technology strategy. Collectively, the forecasts, exemplars, and guidelines should help improve understanding of the rising wave of creative destruction and advance research on forecasting, technology, and strategy.

Keywords Business strategy · Corporate exemplars · Technology Revolution

Introduction

The strategic impact of technology is seen in the rushing change of everyday products. When digital photography became feasible a few years ago, the entire film industry was overturned by simply moving around digital bits instead. Nikon, Kodak, and other famous names that once dominated photography are still struggling to adjust, laying off thousands of employees and replacing product lines. In place of film, new industries soon sprung up as digital cameras unleashed floods of photos and videos to populate Web 2.0—Facebook, YouTube, blogs, wikis, and more sure to come.

This cycle then repeated as smart phones, in turn, replaced digital cameras. Sales of stand-alone cameras started to decline with the landmark introduction of Apple's

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iPhone with built-in digital cameras and video recorders. The Flip camcorder, for instance, was widely popular because it was simple and easy to use. But the market dried up after a flood of smart phones with good digital cameras and video appeared in 2008, and the Flip was soon sold to a gentle death [1]. Kodak invented the digital camera years ago, but had to abandon the market to smart phones [2].

The same disruptive force of technological change is at work as alternative energy replaces oil, genetic medicine extends lives, artificial intelligence automates jobs, robots serve as helpers, and other innovations reach the take-off point.

These examples highlight the threats managers face if they fail to adapt to strategic technological change, as well as the opportunities available at the leading edge. And shorter technology life cycles require that they act quickly or lose product lines. The only safe haven is to remain at the forefront of change.

The accelerating power of ever more sophisticated information systems is the central force driving this "Technology Revolution" that is destroying old markets and creating new ones. The decoding of the human genome, for instance, was only possible using supercomputers to decipher the three gigabits of information in DNA. For the first time in history, knowledge—the very heart of science—is being harnessed systematically on a massive scale [3].

Think of it as a "virtuous cycle" of continually increasing scientific knowledge driven by the accelerating development of Information Technology (IT). Figure 1 illustrates how IT improves our ability to acquire knowledge → which then encourages more widespread commercial innovation → which in turn improves IT systems again → on and on in a spiral of transformation.

This is not simply a rush of technological advances, but a breakthrough in the way science, product development, and entrepreneurship are conducted. The system of scientific research and commercial innovation is growing in power and speed as the novel ability to amass knowledge drives progress as never before. Some scientists, like Ray Kurzweil, think we are approaching a "singularity" in which the pace of technological change leaps dramatically during the next 20–30 years [4].

A telling indicator is the popular success of the Singularity University sponsored by Ray Kurzweil, Peter Diamandis, Google, and NASA to prepare business leaders for the Technological Revolution. Several classes have completed studies at Ames Research Park in Silicon Valley, and they are developing strategic projects that leverage the power of these accelerating advances [5].

The power of technology can be seen in the fact that the dot-com collapse of 2000 did not faze the Internet, which went on shortly to develop a wave of booming Web

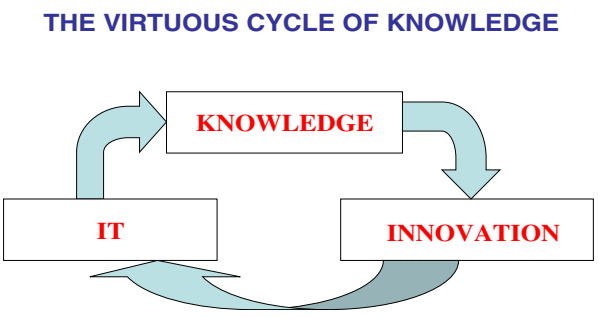

Fig. 1 The virtuous cycle of knowledge. Copyright W. Halal 2003

2.0 sites. Technological progress is insulated from economic cycles because R&D projects often have long-term support from governments, foundations, and universities. Entrepreneurs may delay product launches during recessions, but they also tend to discount downturns in favor of long-term prospects fueled by pent-up demand. In the depths of the Great Recession of 2008, we saw the exploding success of Apple, Facebook, Twitter, Groupon, Netflix, cloud, and mobile everything. Andy Grove, Chairman of Intel, put it best: "Technology always wins in the end."

The challenge of planning for this wave of disruption is not limited to technology companies. All organizations are affected as the forces of creative destruction erode core business sectors and open up new sources of value creation. The Internet continues to transform government, the newspaper industry, book publishing, entertainment, banking, education, health care, and other sectors. As consumption patterns, lifestyles, and even the rules of competition shift, all managers face this common challenge of redefining their goals, cultivating new markets, launching new products and services, and changing how their organizations work.

Technology has usually been considered one of many factors in corporate strategy. The unusual magnitude of these far-reaching changes suggests that decision-makers should elevate technology to the top levels of strategy, a major force to be reckoned with in their strategic planning.

This article draws on a state-of-the-art forecasting system to outline strategic advances that are likely to enter mainstream use soon. To navigate this sea of change, we examine three exemplars that have thrived by surfing the leading edge of the technology tsunami—Netflix, Apple, and Toyota. Then we integrate lessons from these cases into guidelines for technological change.

Forecasting the Technology Revolution

To better understand the Technology Revolution, the TechCast Project at George Washington University (www.TechCast.org) provides authoritative forecasts across the entire technological spectrum. Technology forecasts are essential because society's collective "tools" comprise the economic foundations of the social order, and so sound forecasts are crucial for anticipating product innovations and social changes.

Research Method

TechCast is a data-based website (www.TechCast.org) that pools the knowledge of 100 plus high-tech CEOs, scientists and engineers, academics, consultants, futurists, and other experts worldwide to forecast breakthroughs in all fields. It is possibly the best forecasting system available, covering the entire range of technological innovation, updated constantly, and validated annually. The Project was cited by the US National Academies as one of the three best systems in the world [6], and web searches rank it no. 2 or 3 out of 105 million hits. No forecast can be really accurate, of course, but validation studies confirm this approach provides estimates accurate enough to put decision-makers in the right ballpark—an average error band of about ±3 years for forecasts 10 years distant.

Because this is basically a system for aggregating knowledge, the field of Knowledge Management (KM) offers a useful perspective for understanding the rationale underlying this approach. From the KM view, this is an online "learning system" conducted by a "community of practice" that "continually improves" its knowledge using "collective intelligence" to approach a "scientific consensus." One of the most vivid experiences of this work is seeing how methodically pooling the tacit knowledge of 100 good minds can create forecasts that are remarkably prescient.

The forecasting system is an improved version of the Delphi method [7]. But unlike most Delphi surveys, TechCast uses an empirical foundation. Researchers gather the best background data available and organize it into a succinct analysis of trends driving each technology as well as obstacles opposing it, thereby ensuring balance. Editors constantly scan to define adoption levels, driving trends, opposing forces, and other background information on each technology—a significant improvement in the Delphi method. The TechCast team also conducts strategic studies for corporations and governments, which helps keep the forecasting system at the leading edge.

Experts are taken through these analyses online and instructed to integrate the background data and use their judgment to estimate when each technology is most likely to arrive, the potential size of the economic market, and their confidence in the forecast. The experts are not all world-renowned, but they represent a diverse sample from the leading edge of collective knowledge. Experts self-select areas they know best, so sample sizes average about 50–70 responses. The raw data is automatically aggregated for distribution to clients over the site in real time.

More than snapshots in time, this is a continual tracking process that improves constantly as results, comments from the experts, and new data are used to update the analyses. Annual validation studies find that the average variance of forecasts over time is roughly ±3 years, the major part of which confirms the well-known tendency toward optimism, which we call it "forecast creep [8]." Complex technologies vary widely because they are controversial, while more simple ones that are well understood show little variance. We have also recorded arrivals of several technologies roughly within this same error band of 3 years.

The results are compelling when considering that the expert panel changed over this time, as did the prospects for various technologies and other conditions. "Prediction markets" have demonstrated good accuracy using a similar form of collective intelligence [9]. This work also holds up well in our work for corporations and governments. On one project, we conducted two parallel studies to forecast the maturing of energy technologies, one using a group of the client's energy experts and the other using a group of our general experts. The forecasts compared almost exactly, usually within 1 to 2 years [10].

It is often thought that methods like this are subjective, whereas quantitative methods are precise. However, quantitative methods also involve uncertainty because they require underlying assumptions that often are doubtful, and so they can vary widely. This approach subsumes quantitative forecasts into the background data and allows the judgment of experts to resolve the uncertainty that remains. Experts may have their own bias, naturally, but it is usually distributed normally, washing out in

the aggregate results. If the present level of uncertainty is defined as 100 %, we have found that this process reduces uncertainty to about 20 to 30 %.

The results show that technological advances, their adoption patterns, and social impacts follow well-defined cycles that can be forecast rather accurately. Figure 2 presents highlights of this work for 70 leading technologies organized into seven fields. Some of these technologies are available commercially but they have not yet reached the 30 % adoption level where breakthroughs enter mainstream use. Following is a quick summary of how these advances are likely to affect various business sectors. Please note that these highlights are drawn from the website, and so details and references can be found at www.TechCast.org.

The Energy and Environment Crisis is an Opportunity in Disguise

Globalization is expected to almost double the number of people living at industrial levels over the next decade [11], producing commensurate increases in energy demands, pollution levels, global warming, and other aspects of the energy and environment crisis. Our forecasts show that green business is likely to take off in 3 to 5 years and governments are likely to take serious steps on global warming about that time. Alternative energy sources—solar cells, wind turbines, biofuels, etc.—are growing 30–40 % per year, almost like Moore's Law. The global market for green technologies is expected to reach about $10 trillion in two to three decades, larger than autos, health care, or defense. In short, the energy and environment mess actually offers a great opportunity in disguise.

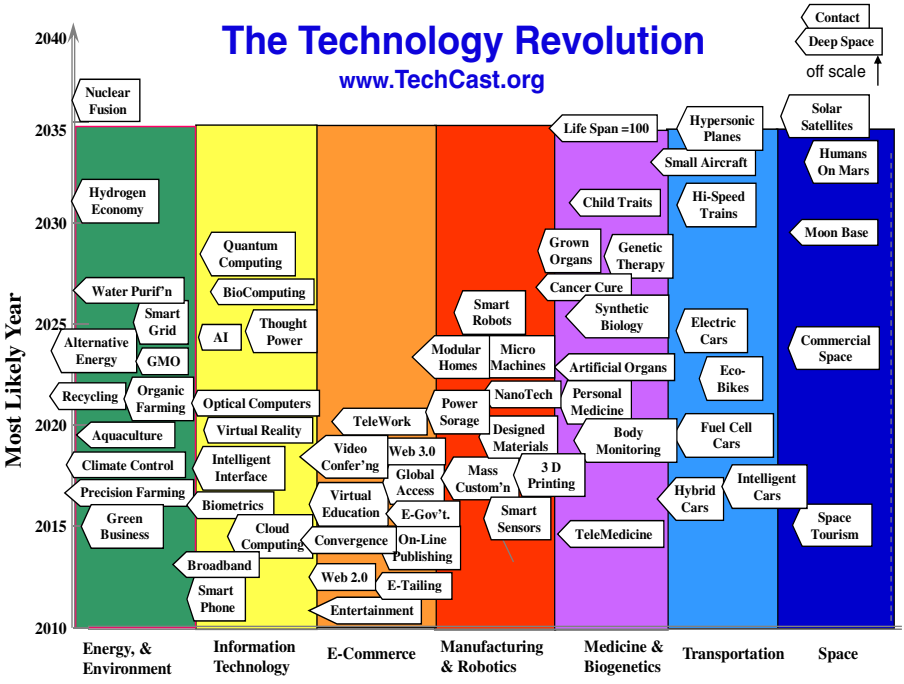

Fig. 2 The technology revolution (www.TechCast.org). Copyright W. Halal

Information Technology Changes Everything

Computer power should continue to double every 2 years; a second generation of optical, biological, and quantum computers is poised to take over; and artificial intelligence is automating routine tasks. The Web is the same age that TV was when it became the dominant force of the twentieth century. Over the coming decade, working, shopping, learning, and most other social functions are likely to move online into a virtual world that is ever-present and intelligent. You might buy something by simply talking with a virtual robot that greets you by name, knows all the merchandise and displays it on demand, answers questions, and has infinite patience—the perfect salesperson [12].

e-Commerce is Exploding Around the Globe

Most e-commerce today operates at 10–15 % adoption levels, but online shopping, publishing, education, entertainment, and other services are likely to reach the critical 30 % adoption level soon where new markets usually take off. And the huge populations of China, India, Brazil, and other developing countries are moving in droves to PCs, the Internet, and smart phones. We anticipate that five to six billion people will soon create online markets of several trillion dollars. The late C.K. Prahalad, a leading business professor, put it best: "The world's four billion poor should be considered the biggest source of growth left [13]."

Manufacturing Goes High-Tech

The factories of the Industrial Age are yielding to intelligent manufacturing systems operating worldwide to produce goods cheaply and quickly. Research in materials and nanotechnology is making it possible to create almost any type of product, and mass customization can deliver sophisticated goods designed for individuals easily. Attracted by cheap labor and new markets, industrialization is likely to raise living standards dramatically in most poor nations over the next few decades—along with mounting demands for energy, ecological damage, and clashes between diverse cultures. An industrialized world will be a boon to business, but making it sustainable is an enormous challenge that will test us severely.

Medical Advances Confer Mastery Over Life

Artificial organs are being developed to replace almost all bodily functions, including parts of the brain, and stem cell research is increasingly able to repair and grow organs. Electronic medical records, online doctor's visits, computerized diagnostics, and other forms of telemedicine should curtail rising costs and improve quality of care. Nanotech is being used to develop tiny devices that are intelligent enough to seek out cancer cells and destroy them. Just as the Industrial Age mastered most aspects of the physical world, these advances are now making it possible to master the biological world. Yes, it sounds too good to be true, but so did the notion that men could fly, much less to the Moon.

Transportation is Moving Faster and Farther

Our forecasts show that a new wave of green autos powered by hybrid, electric, and fuel cell engines should become mainstream about 2013–2018, and we are likely to see intelligent cars that drive themselves. It may seem that information systems could replace travel, but information forms a virtual world that parallels the physical world. People will always want to visit each other, handle the merchandise, and hammer out tough decisions together.

Space is Going Private

CEO Richard Branson's Virgin Galactic is likely to launch its first suborbital flight of tourists in a year or two, commercial rockets will soon service the International Space Station, and other competitors are planning visits to the Moon and space hotels. Just a few years ago the idea seemed laughable, but it now looks like space commercialization will soon open the final frontier to private ventures [14]. As access to space becomes widely available, it is easy to imagine how this watershed from government control to private enterprise could unleash a rush of space pioneering.

Macroforecasts of the Next Economic Upcycle

Our collective forecasts are aggregated to "macro-forecast" the larger economy over the next decade or two. The bubble chart in Fig. 3 presents all three dimensions of all

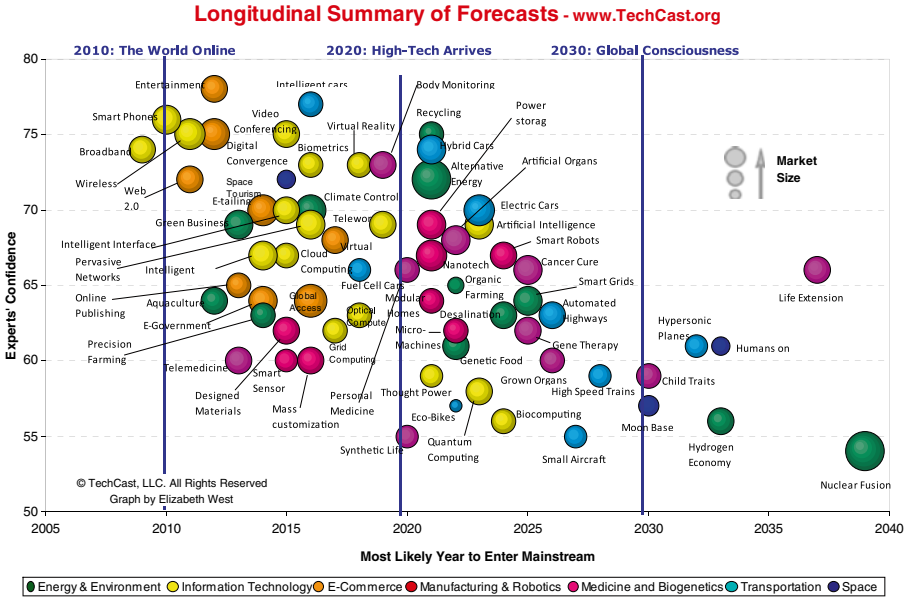

Fig. 3 Longitudinal summary of forecasts—www.TechCast.org

forecast data: Most Likely Year, Experts' Confidence, and the potential Market Size. This analysis suggests that the Great Recession may linger for a few years, but a new wave of economic growth is likely to take off about 2015.

The period around 2015 is significant because the cluster of green technologies, information systems, e-commerce, and advanced auto designs in Fig. 3 suggests a resurgence of economic growth is likely about that time. This also coincides with the pattern of 35-year cycles that roughly govern US stock markets. Look at a 100-year graph of the Dow Jones Industrial Average on a log scale and you will find three 35-year cycles. The Roaring Twenties was the peak of a 35-year cycle that ended with the Great Crash of 1929. The Eisenhower boom of the 1960s started about 1945 and was followed by the Reagan boom that began with his election in 1980. The 2008 economic crisis marked the end of the Reagan 35-year cycle, and it is likely be followed by a new worldwide boom starting about 2015 based on the technologies noted above.

As the Technology Revolution picks up speed about 2020, we are likely to see personal medicine, intelligent cars, alternative energy, and the other advanced technologies shown. This period is also likely to enjoy near-infinite computing power with second-generation architectures (optical, bio, nano, and quantum). Smart robots are likely to enter homes and offices, and good AI is likely to automate routine tasks, in the same way GPS navigation solved the problem of travelling from point A to point B.

Netflix, Apple, and Toyota: Exemplars of Technology Strategy

To better understand how companies implement technological change, we now shift attention to the following three case studies of Netflix, Apple, and Toyota. These exemplars demonstrate how leading companies use technology planning to develop successful strategies.

How Netflix Beat Blockbuster

Just a decade ago, Blockbuster ruled the movie rental business with 25,500 employees at 8,000 outlets and a parallel distribution system of 6,000 DVD vending machines [15]. Meanwhile, Netflix was using the postal service to distribute DVDs, and it did not seem to have a chance. Founded in 1997 by Reed Hastings, its prospects of surviving battles with Blockbuster, Wal-Mart, Amazon, and other competitors looked so poor that a Wall Street analyst labeled its stock "a worthless piece of crap."

Yet Blockbuster soon filed for bankruptcy, while Netflix gained leadership of the industry. Blockbuster lost $518 million in 2010, running $1 billion in debt, and closed most outlets. Meanwhile, Netflix gained 23 million subscribers, more than 60 % market share, by running a well-executed system for streaming movies online. The company's stock soared from $11 in 2005 to above $200 in 2011 [16].

How did an upstart like Netflix succeed in beating an entrenched opponent like Blockbuster? NetFlix executives understood that information technology

was rapidly changing the delivery of movie rentals, and they developed a strategy of Internet streaming, convenient customer service, and a virtual organization to deliver it cheaply and flawlessly. John Doerr, a partner at the venture capital firm Kleiner Perkins, said "Reed was ahead of the technology curve, and completely changed the industry [17]."

When faster broadband and better video compression allowed YouTube and other Web 2.0 sites to erupt on the scene about 2005, Hastings realized that the time has come to cannibalize his DVD rental business in favor of streaming video. He also knew that developing a TV box was too limiting, and that an open-source approach would allow Netflix to distribute movies on TVs, DVD players, desk-top computers, mobile phones, or almost any device [18].

The second part of Netflix's strategy was to avoid the burden of retail outlets by operating online. With only a few warehouses and offices, the company became a virtual organization with no retail stores and no sales employees. A small staff operates on what Hastings calls their "Freedom and Responsibility Culture." Instead of authorized vacations, sick days, and fixed work hours, people work when they choose as long as their job gets done. Titles and even compensation are up to the individual.

Finally, Netflix went well beyond Blockbuster's lackluster service and outmoded pricing. Blockbuster charged $5 for a movie, and people especially hated the fees for late returns. So Hastings used a monthly subscription service that allows unlimited rentals and no late fees. To make it inviting to order movies online, Netflix developed what is possibly the best software in the industry. Their website is a model of efficient, clean design, and intuitive clarity.

In short, Netflix beat Blockbuster by setting a new standard for the exploding market in movies and video—much the way Microsoft set the standard for desktops, the way Amazon gained dominance of book sales, and Google gets the majority of search. This stunning success propelled Hastings to the top of Fortune's "2010 Businessperson of the Year" award.

But success is fleeting at the leading edge of innovation. Netflix's decision to raise subscription fees and split the DVD and streaming markets disappointed many, and it lost 1 million subscribers. Meanwhile, a rejuvenated Blockbuster introduced "Movie Pass," which streams movies to TVs and PCs, and offers 20 movie channels, DVD's, Blue-rays, and games for only $10 a month. The race goes on.

What are the Keys to Apple's Success?

Apple did not come by its present success easily. Before the iPod, iPhone, and iPad became profitable icons of high-tech fashion, the company suffered a long series of failures. Apple's Pippin game player, the Next computer, Apple TV, the Lisa computer, the Newton PDA, and the Apple mouse are among the many products that are barely known because they were dismal flops. For many years, there were serious doubts if Apple could survive the battles it was losing to competitors like Microsoft.

In contrast, Apple sold 40 million iPads in 2011—two-thirds of all tablet computers sold globally. Although the iPhone is fighting off 90 different smart

phones, Apple's sales are growing 60 % annually and reached 146 million iPhones sold in 2011. The source of this staying power is seen in the fact that the iPhone has the highest consumer satisfaction scores ever recorded. Apple is considered one of the most innovative and valuable companies in the world [19–22].

Such stunning success always raises questions over its origins. How did a struggling company run by a charismatic but somewhat erratic CEO learn to excel? Can the factors of this success be identified and used to guide others?

The most striking conclusion about Apple's rise is that Steve Jobs learned crucial lessons from failure. After years of his autocratic leadership, dismal sales, and temperamental behavior demoralized the company, John Sculley became CEO in 1985 and Jobs was sent into the computing wilderness. Jobs failed again with the Next computer, which was overpriced and sold only 50,000 units. When he returned to head Apple after 12 years, Tim Bahrain, who heads a consulting firm, said "Steve would not have been successful if he had not gone through his wilderness experience [23, 24]."

The main lesson from Apple's success, however, is the central importance of applying leading technologies to create strong new products that are well-designed for the market. Jobs was a genius at minimalist designs that integrate technology breakthroughs to fill a newly emerging need with unusual style. Here's how he described the iPad—"It's like holding the Internet in your hands; It's so much more intimate than a laptop and more capable than an iPhone. It's truly magical [21, 25]."

This keen sense of anticipating where the technology is leading comprises the central talent that allowed Apple to create revolutionary breakthroughs that transformed computers, music, telephones, tablets, and even retail stores. There was the first personal computer (Apple 1), the first graphical interface (Mac), the first Unix PC (Next), the first successor to Sony's Walkman (iPod), the first online music store (iTunes), the first widely used smart phone (iPhone), the first successful tablet (iPad), and the first useful personal assistant (Siri) [26]. Apple's 371 stores are wildly popular and the most profitable in retail. The Apple music store—iTunes—has expanded into a powerful market for videos, movies, and other information products [24, 27].

Even with these stunning achievements, Apple faces enormous new challenges as competition among other smart phones and tablets heats up. There are at least 20 versions of Android phones alone, slowly taking Apple's market share. In 2011, Americans bought more Androids than iPhones [28]. And what will happen now that Steve Jobs is gone? Despite claims that Apple has institutionalized practices that foster creativity, innovation, good design, and other Jobs' legacies, it is really impossible to replace true genius.

Toyota's Model of Technology Strategy

Toyota offers a model of strategic planning that succeeded in using a disruptive technology to gain leadership of the global auto industry. Two to three decades ago, Japanese carmakers struggled to compete with the Big Three US carmakers, who

ruled the industry with cars and trucks averaging 12 miles per gallon (MPG). GM alone held almost half of the US market at one time.

By anticipating the rise of environmental threats, the end of cheap oil, and the development of hybrid technology, Toyota led the way to an era of energy-efficient, green car design. It surpassed GM as the world's biggest carmaker in 2010, and Consumer Reports acknowledged "Toyota is the most recognizable car brand in the US [29]." How did they pull this upset off?

Toyota began planning their game-changing hybrid, the Prius, in 1970 because forecasts indicated a decline in oil supplies and growing public concern over the environment. The obstacles were considerable because battery designs were not adequate, hybrid technology would take many years to develop, and product costs would remain high. But their technology forecasts showed the obstacles could be overcome, and the demand for green autos looked promising. They decided to press ahead, investing $1 billion in R&D. Toyota's executive vice president, Masatami Takimoto, handled the uncertainty of such radical innovation by pursuing competing hybrid technologies and then choosing the one that works best—the Prius [30].

In 2008, gas prices in the US hit $4 and the Great Recession stalled the economy, causing the car market to collapse and leaving GM, Ford, and Chrysler with sales declines of almost 50 %. Toyota withstood a modest loss [31] and went on to sell one million Prius cars. The Prius is the top selling auto in Japan and Toyota expects it to lead the American market by the end of this decade [32].

Other carmakers are catching up, of course. After the government reorganization of GM and Chrysler, the Big Three are profitable again, making vehicles that now average 30 MPG, which will be boosted by regulations to 36 MPG by 2016. GM regained the lead in world car sales in 2011, while Toyota suffered from the Japanese earthquake and floods in Thailand.

Toyota is adopting a "real options" strategy to contain these threats. It is hedging on the rise of electric cars by developing plug-in hybrids, working on advanced batteries, and invested in the electric car start-up, Tesla. The Toyota research team is also developing its own all-electric. The company plans to have hybrid versions of all 20 or so models in its product line by 2020. A Toyota spokesperson put the strategy succinctly: "Customers are going to ultimately decide what kind of car they want. Whatever they choose, we will be there [32]."

Guides to Managing Breakthroughs

These are only a few examples, but collectively they offer useful guides to planning and implementing technology breakthroughs. Forming a good strategy is inherently an uncertain process and all organizations do it somewhat differently, of course. Box 2 integrates insights from the NetFlix, Apple, and Toyota cases, as well as other prominent companies, our consulting work, and sound management to identify four general principles that effectively guide technology strategy.

Box 2. **Guides to Technology-Based Strategy**

1. Track Strategic Technologies Online research systems now offer big advantages in the need to track critical emerging technologies and social trends, and to anticipate their likely corporate impact. (see box 1)

2. Develop Creative Opportunities Trends should be explored carefully to discover creative opportunities for converting disruptive breakthroughs into successful ventures.

3. Involve Stakeholders Critical knowledge, good ideas, and commitment are gained by working with employees, partners, clients, and other stakeholders.

4. Plan on Both Failures and Success Failure can offer valuable lesions, and good management can hedge against risk.

Track Strategic Technologies

Organizations are affected by different technologies, so it is essential to identify those that are strategic for a specific organization and monitor their progress.

For Reed Hastings, the crucial technologies affecting Netflix involved the widespread adoption of broadband and compression techniques that enable streaming video. A critical threshold occurred in 2005 when 30 % of American homes first gained broadband. YouTube was launched and its instant success dramatically signaled to Hastings that the take-off point in streaming video had arrived. Today, video comprises roughly 90 % of all Internet traffic, and is expected to reach 3.5 billion viewers around the globe by 2015—a huge new market hungry for movies, TV, and other digital entertainment. By monitoring the rise of these crucial enabling technologies, Netflix was able to time its move to deliver movies online and transform the industry.

Apple had to anticipate a wave of creative new technologies to make the iPod, iPhone, and iPad possible—more computer power and memory, good wireless systems, and the intuitive feel of those lovely touch interfaces. Toyota had to track the development of high-performance lithium-ion batteries and hybrid technology, as well as the coming of "Peak Oil" and public concerns over the environment. Now the company is monitoring advances in competing technologies: plug-in hybrids, electric cars, ultracapacitors that may replace batteries, and fuel cell cars.

Although most carmakers are focusing on electric cars, for instance, batteries are limited by low power and short driving ranges, and likely to remain so for years. J.D. Power forecasts slightly more than 1 million all-electrics to be sold by 2020, about 2 % of the market. Atsushi Niimi, Toyota's EVP said, "We predict the spread of electric vehicles will be extremely slow [32]."

Not only did Netflix, Apple, and Toyota focus on technology advances to form strategy, their implementation plans had to be timed quite precisely. Taking such a big

risk a few years too early would invite bleeding-edge failures, while a few years later the field would be left to competitors.

These cases highlight the central need to track technologies for planning corporate strategy. As another example, decades ago we forecast growing business opportunities in aquaculture because it was clear that rising demand for the health benefits of eating fish was outstripping supply. The world's catch of wild fish topped out in 1985, and many species could become extinct soon. The rise of aquaculture parallels the rise of chicken farming, and is now growing three times the rate of meat production. The proportion of farm-raised seafood grew from 8 % in 1984, to 15 % in 1995, to 30 % level in 2003, and 50 % by 2012.

Many corporations have systems for technology tracking and planning. Johnson & Johnson developed a scanning system called FrameworkS to track advances in health care, changing government regulations, and competitive products and services. MasterCard uses a "dynamic strategy" process that tracks trends in technology and consumer spending to identify disruptive changes and develop strategic responses [33]. The variations are endless, but organizations need to scan for trends, forecast breakthroughs, and plan for technological and social change.

Develop Creative Opportunities

Disruptive technologies that could change an industry are especially important and require creative thought to develop viable new business ventures.

Netflix illustrates the central role that a technology-inspired vision plays in transforming a field. Because Hastings is a Stanford computer scientist and a Silicon Valley entrepreneur, he could see that it would soon be feasible to stream movies, and he understood that this shift in technology would change the rules of the game. He also knew that having employees run shops, charging for rentals, and imposing late fees were outmoded relics of the past, while online service delivered by a virtual organization offered unbeatable value.

Possibly the best example is Apple's brilliant use of technology to create a long line of stunning products that were revolutionary. The genius of Steve Jobs was his unique talent for finding exciting possibilities in a long series of technological breakthroughs. Jobs did not focus on market research because he was planning transformative products that few yet understood. He thinks success requires "listening to the technology" in order to "discover" the potential products waiting to be invented [25]. Here is how Jobs described his approach:

> If I had asked someone who only used a calculator what a Mac should be like, they couldn't have told me. There's no way to do consumer research so I had to go and create it, and then show it to them… It's not the customer's job to know what they want [23].

Toyota's Prius hybrid was inspired by powerful trends toward environmental sustainability, rising energy prices, and advances in car batteries. While GM, Ford, and other car companies procrastinated, Toyota executives had the foresight to envision a new generation of hybrid cars that were energy-efficient and non-polluting.

Involve Stakeholders

The knowledge and support of external constituencies are essential for success, so stakeholders should be involved. Cooperation is crucial in today's knowledge economy because knowledge increases when shared. That is why progressive managers have longed practiced "coopetition"—cooperating even with competitors to produce better results for all. Social responsibility and ethics are commendable, but it takes active collaboration to actually resolve tough challenges and create value [34].

Steve Jobs created a political breakthrough in entertainment by convincing the record companies that the future lay in online music sold for $.99 per song [35]. Hastings had to create a collaborative ecosystem of talented staff, media companies, Internet firms, and viewers to make streaming video a reality.

Toyota offers an instructive negative example because insular management was largely responsible for the damage caused by runaway cars that required millions of recalls and shredded the company's reputation. A study by the US Department of Transportation found that Toyota management "gave too little weight to feedback from customers, regulators, and rating agencies, and centered too much control in Japanese headquarters… Toyota's culture left it unusually vulnerable to a fast-moving crisis [36]."

The power of cooperation is clear in our consulting work. A project for the Federal Drug Administration to assess the prospects for medical advances used a panel of experts drawn from the National Institutes of Health, the National Science Foundation, Department of Commerce, and pharmaceutical and biotech companies. Results were presented for discussion at a conference that included all these stakeholders, offering one of the first serious opportunities to coordinate strategies for health care development across the nation.

Today, the US Agency for Health Research and Quality (AHRQ) and similar government programs in the UK, Spain, Austria, Canada, Australia, and New Zealand are all forecasting medical technologies because the Technology Revolution is transforming medicine, and health care providers are struggling to adapt. They are now pooling their knowledge in an online repository to avoid redundant work, making better results available around the world far more quickly and cheaply.

Other corporate examples abound. Lee Scott, CEO of Wal-Mart, implemented an environmental sustainability program by having employees, suppliers, government officials, and outside experts work together; Scott said the strategy boosted employee morale and saved customers money while protecting the environment [37]. Cisco has "democratized" management by setting up "councils" that bring together executives, groups of employees, and customers to resolve tough issues. Cisco's CEO, John Chambers, says "The future is about collaboration and teamwork [38]."

Plan on Both Failure and Success

Disruptive technologies involve great uncertainty, so failures should be anticipated and planned for. Netflix and Apple show how successful companies use failures to learn, and Toyota exemplifies hedging against risk.

At Netflix, Hastings work developing a TV set-top box for streaming movies flopped because 16 h of download time was unworkable. But this failure led to the

realization that an open-source approach offers far greater advantages. By distributing movies via a variety of platforms, Netflix was freed of the responsibility for producing hardware and able to focus on its core competence of managing an online movie library in a superior way.

Apple's long list of failures prepared Steve Jobs to create great products when he returned from exile. John Sculley acknowledged "I'm convinced that if Steve hadn't come back when he did… Apple would have been history [23, 39]." In fact, Jobs' approach to developing strong new products is based on failure. Here's how he selected the best concepts: "Killing bad ideas is not hard—what is really hard is killing good ideas [40]."

Toyota offers a good example of hedging against failure. As noted earlier, the company ran parallel development programs for hybrid technologies, bought an option for plug-ins, formed a partnership with the leading electric maker, and is developing electric models as a cushion against threats from competitors.

Hedging can also be managed by distributing risk across many ventures. We assisted a major organization in planning a high-tech industrial park that included ventures in more than 30 different areas. Using portfolio management methods, the ventures that prove disappointing are offset by those that succeed to realize sound overall return rates for the project as a whole.

Google does much the same using teams of three to ten people to manage each new project. The teams operate like internal ventures and the company acts as a venture capital firm, placing bets on different projects [41]. After their Wave Internet messaging system showed poor results, the company did not hesitate to pull the plug [42].

Discussion and Conclusions

This paper has presented a collective intelligence, or Delphi, forecasting method and results outlining the entire Technology Revolution. It also analyzed case studies of three corporate exemplars, and illustrated how they develop strategy for technological change. We have not discussed specific methods of innovation, macro-economic policies, or other practices, but focused on how companies adapt to the coming wave of disruptive technology.

A special aspect of this work is that results are analyzed annually to estimate errors over the 20 years this data has been collected. The recent annual validation studies in 2011 show little change in forecast dates generally, which is good because accurate forecasts remain valid and constant over time. We notice a continuation of the same ±3 years average error band at about 10 years out. A full analysis is underway, which we hope to publish soon [43]. Good longitudinal forecast data series are rare [44], so the TechCast data offers interesting research opportunities.

Some of the original forecasts are uncanny in their accuracy, with many arriving quite close to the forecast dates. The arrival of "Broadband" was estimated at 2009 in 1993, and actually entered mainstream use about 2008. "Electronic Banking" was expected to become common by 2009 and arrived at that exact year. We forecast most

seafood would be produced using "Aquaculture" in 2014 and data confirms 50 % adoption in 2012.

Another interesting finding is what could be called "forecast creep"—the much discussed tendency of experts to be overly optimistic in estimates of when technologies mature. The early forecasts in 1993, for instance, estimated that TeleMedicine would be common by 2001, "Virtual Education" about 2003, and "Optical Computing" by 2007—all now seen as demonstrably over-optimistic. Some technologies involving great uncertainty seem to lose a year or two every so often in their life cycle, and our forecasts reflect that by creeping slowly into the future. How much is due to inherent uncertainty and unexpected obstacles versus poor knowledge and judgment of experts is a good question.

Errors are partially the result of poorly defined targets, and so the editors are constantly rethinking the event being forecast into a sharp and salient focus. But it is also true that some experts do not pay attention to the background data. Experts are instructed to use their knowledge and judgment to integrate trends, current results, and any other sound knowledge into best possible estimates of where the technology is heading. This takes time to read and digest, of course, and some experts do not bother. Errors are the exception, however, as validation results confirm.

These simple examples highlight the strengths and weaknesses of using the Delphi technique [45]. TechCast deals with error by improving transparency. Accuracy results are made widely available and experts encouraged to incorporate them into their estimates. To create a sound system of collective intelligence, it is necessary to learn and improve with mistakes. All systems fail at times, and good systems learn from their failures.

Using an empirical base of background data grounds the forecast by reducing uncertainty, and conducting a validation process opens up new areas for discovery and improvement. Going through an annual update and validation typically redefines forecast targets and expert practices to reduce error, producing a big improvement in the method.

University faculty and students are invited to use the TechCast data for theses and dissertations. The system has been under development for 20 years, and the collected data from annual validation studies now comprises a large and unique time-series knowledge base recording actual forecasting processes over time. This data repository offers rare opportunities for further research on critical questions—which experts prove to be more accurate and why? Can we predict expert profiles that produce more accurate forecasts? How accurate are forecasts at various time horizons—10 years out? Twenty years out? What causes the tendency toward optimism, or forecast creep?

Because the Technology Revolution presents bold prospects over the next 5 to 10 years, it is essential to prepare for massive technological, economic, and social change. Whatever the method and whatever the purpose, organizations need to develop some type of well-thought system to forecast and adapt to this wave of disruption. There may be uncertainty about specific breakthroughs, but there is very little uncertainty that we are going to see plenty of creative destruction over the planning horizon.

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