leads in discovery and implementation of nanotechnology will have great advantage in the economic and military scene for many decades to come' (Motoyama, Appelbaum and Parker 2011, 113).

In the end, the US government took action. It not only selected nanotechnology as the sector to back most forcefully ('picking it' as a winning sector), but it also proceeded to launch the NNI, review rules and regulations concerning nanotech by studying the various risks involved and become the largest investor, even beyond what it has done for biotech and the life sciences. Although the strongest action was carried out top down by key senior-level officers in the NSF and the White House, the actual activity behind nanotech was, as in the case of the Internet and computers, heavily decentralized through various State agencies (a total of 13, led by the NSF, but also involving the NIH, the Defense Department and the SBIR programme). Across these different agencies, currently the US government spends approximately $1.8 billion annually on the NNI.

Nanotechnology today does not yet create a major economic impact because of the lack of commercialization of new technologies. Motoyama, Appelbaum and Parker (2011) claim that this is due to the excessive investments made in research relative to the lack of investments in commercialization. They call for a more active government investment in commercialization. However, this raises the question: if government has to do the research, fund major infrastructure investments and also undertake the commercialization effort, what exactly is the role of the private sector?

This chapter has highlighted the important role that government has played in leading innovation and economic growth. Far from stifling innovation and being a drag on the economic system, it has fostered innovation and dynamism in many important modern industries, with the private sector often taking a back seat. Ironically the State has often done so in the US, which in policy circles is often discussed as following a more 'market'-oriented (liberal) model than Europe. This has not been the case where innovation is concerned.

CHAPTER 5

THE STATE BEHIND THE iPHONE

Stay hungry, stay foolish.

STEVE JOBS (2005)

In his now well-known Stanford University commencement address, delivered on 12 June 2005, Steve Jobs, then CEO of Apple Computer and Pixar Animation Studios, encouraged the graduating class to be innovative by 'pursuing what you love' and 'staying foolish'. The speech has been cited worldwide as it epitomizes the culture of the 'knowledge' economy, whereby what are deemed important for innovation are not just large R&D labs but also a 'culture' of innovation and the ability of key players to change the 'rules of the game'. By emphasizing the 'foolish' part of innovation, Jobs highlights the fact that underlying the success of a company like Apple—at the heart of the Silicon Valley revolution—is not (just) the experience and technical expertise of its staff, but (also) their ability to be a bit 'crazy', take risks and give 'design' as much importance as hardcore technology. The fact that Jobs dropped out of school, took calligraphy classes and continued to dress all his life like a college student in sneakers is all symbolic of his own style of staying young and 'foolish'.

While the speech is inspiring, and Jobs has rightly been called a 'genius' for the visionary products he conceived and marketed, this story creates a myth about the origin of Apple's success. Individual genius, attention to design, a love for play and foolishness were no doubt important characteristics. But without the massive amount of public investment behind the computer and Internet revolutions, such attributes might have led only to the invention of a new toy—not to cutting-edge revolutionary products like the iPad and iPhone which have changed the way that people work and communicate. As in the discussion of venture capital in Chapter 2, whereby venture capital has entered industries like biotechnology only after the State had done the messy groundwork, the genius and 'foolishness' of Steve Jobs led to massive profits and success, largely because Apple was able to ride the wave of massive State investments in the 'revolutionary' technologies that underpinned the iPhone and iPad: the Internet, GPS, touch-screen displays and communication technologies. Without these publicly funded technologies, there would have been no wave to foolishly surf.

This chapter is dedicated to telling the story of Apple, and in doing so, asks questions that provocatively challenge the ways in which the role of the State and Apple's success are viewed. In Chapter 8, we ask whether the US public benefited, in terms of employment and tax receipts, from these major risks taken by such an investment of US tax dollars. Or were the profits siphoned off and taxes avoided? Why is the State eagerly blamed for failed investments in ventures like the American Supersonic Transport (SST) project (when it 'picks losers'), and not praised for successful early-stage investments in companies like Apple (when it 'picks winners')? And why is the State not rewarded for its direct investments in basic and applied research that lead to successful technologies that underpin revolutionary commercial products such as the iPod, the iPhone and the iPad?

THE 'STATE' OF APPLE INNOVATION

Apple has been at the forefront of introducing the world's most popular electronic products as it continues to navigate the seemingly infinite frontiers of the digital revolution and the consumer electronics industry. The popularity and success of Apple products like the iPod, iPhone and iPad have altered the competitive landscape in mobile computing and communication technologies. In less than a decade the company's consumer electronic products have helped secure its place among the most valuable companies in the world, making record profits of $39.5 billion in 2014 for its owners. Apple's new iOS family of products brought great success to the company, but what remains relatively unknown to the average consumer is that the core technologies embedded in Apple's innovative products are in fact the results of decades of federal support for innovation. While the products owe their beautiful design and slick integration to the genius of Jobs and his large team, nearly every state-of-the-art technology found in the iPod, iPhone and

TABLE 3. Apple's net sales, income and R&D figures between 1999 and 2014 (US$, millions)

Year	Global	Americas	iPod	iPhone	iPad	Net Income	R&D	Sales/ R&D (%)
2014	182,795	65,232	2,286	101,991	30,283	39,510	6,041	3.30
2013	170,910	62,739	4,411	91,279	31,980	37,037	4,475	2.62
2012	156,508	57,512	5,615	78,692	30,495	41,733	3,381	2.16
2011	108,249	38,315	7,453	47,057	19,168	25,922	2,429	2.24
2010	65,225	24,498	8,274	25,179	4,958	14,013	1,782	2.73
2009	36,537	16,142	8,091	6,754	n/a	5,704	1,333	3.65
2008	32,479	14,573	9,153	1,844	n/a	4,834	1,109	3.41
2007	24,006	11,596	8,305	123	n/a	3,495	782	3.26
2006	19,315	9,307	7,676	n/a	n/a	1,989	712	3.69
2005	13,931	6,590	4,540	n/a	n/a	1,335	534	3.83
2004	8,279	4,019	1,306	n/a	n/a	276	489	5.91
2003	6,207	3,181	345	n/a	n/a	69	471	7.59
2002	5,742	3,088	143	n/a	n/a	65	430	7.49
2001	5,363	2,996	n/a	n/a	n/a	(25)	430	8.02
2000	7,983	4,298	n/a	n/a	n/a	786	380	4.76
1999	6,134	3,527	n/a	n/a	n/a	601	314	5.12

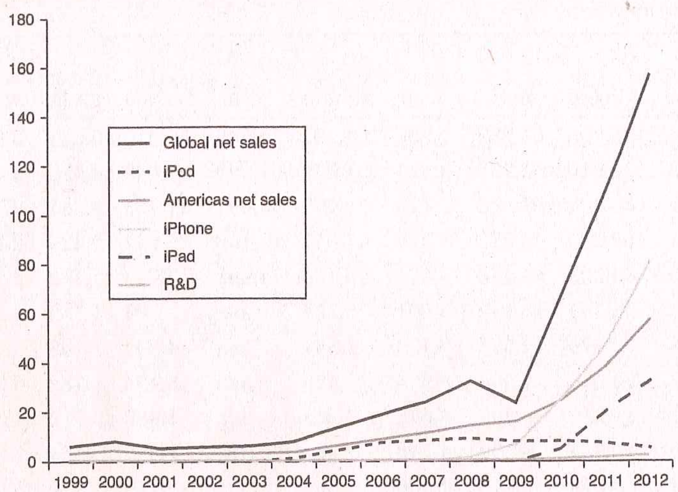
NOTE: Apple's annual net sales, income and R&D figures were obtained from the company's annual SEC 10-K filings.

iPad is an often overlooked and ignored achievement of the research efforts and funding support of the government and military.

Only about a decade ago Apple was best known for its innovative personal computer design and production. Established on 1 April 1976 in Cupertino, California, by Steve Jobs, Steve Wozniak and Ronald Wayne, Apple was incorporated in 1977 by Jobs and Wozniak to sell the Apple I personal computer.[1] The company was originally named

1. In 1977, at the time of incorporation, Ronald Wayne sold his stake in the company to Jobs and Wozniak for $800. When Apple first went public in 1980, its initial public offering generated more capital than any IPO since Ford Motor Company in 1956. This created more instant millionaires (around 300) than any other company in history (Malone 1999).

FIGURE 10. Apple net sales by region and product (US$, billions)

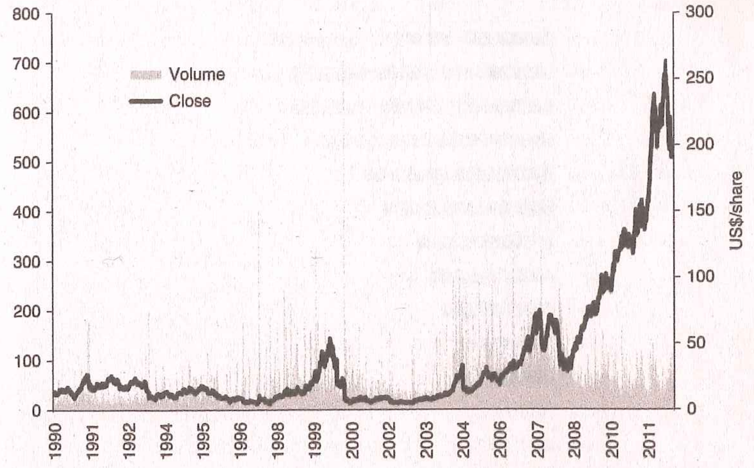


Apple Computer, Inc. and for 30 years focused on the production of personal computers. On 9 January 2007, the company announced it was removing the 'Computer' from its name, reflecting its shift in focus from personal computers to consumer electronics. This same year, Apple launched the iPhone and iPod Touch featuring its new mobile operating system, iOS, which is now used in other Apple products such as the iPad and Apple TV. Drawing on many of the technological capabilities of earlier generations of the iPod, the iPhone (and iPod Touch) featured a revolutionary multi-touch screen with a virtual keyboard as part of its new operating system.

While Apple achieved notable success during its 30-year history by focusing on personal computers, the success and popularity of its new iOS products have far exceeded any of its former achievements in personal computing. In the 5-year period following the launch of the iPhone and iPod Touch in 2007, Apple's global net sales increased nearly 460 per cent. As Table 3 illustrates, the new iOS product line represented on average 72 per cent of the overall net sales of Apple in 2011–2014.

The success and popularity of Apple's new products were quickly reflected in the company's revenues. In 2011, Apple's revenue ($76.4 billion) was so big that it surpassed the US government's operating cash balance ($73.7 billion), according to the latest figures from the US

FIGURE 11. Apple stock prices between 1990 and 2012

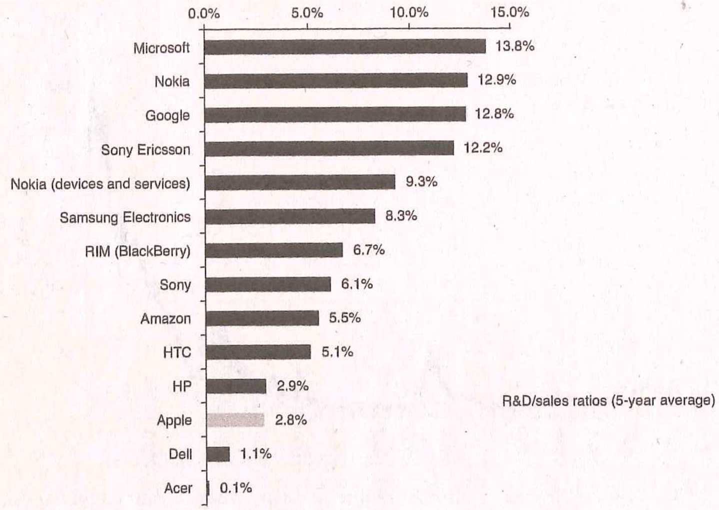


SOURCE: Yahoo! Finance, available online at http://finance.yahoo.com/charts?s=AAPL#symbol=aapl;range=19900102,20121231;compare=;indicator=split+volume;charttype=area;crosshair=on;ohlcvalues=0; logscale=off; source=undefined;Charts/Interactive (from 1 January 1990 to 31 December 2012).

Treasury Department available at that time (BBC News 2011). In 2014, according to figures in Apple's Form 10-K (submitted to the US Securities and Exchange Commission), its revenues reached the impressive figure of $182.8 billion. This surge in Apple's revenues was quickly translated into better market valuations and increased popularity of shares of Apple stock listed on the NASDAQ. As shown in Figure 11, Apple's stock price has increased from $8/share to $700/share since the iPod was first introduced by Steve Jobs on 23 October 2001. The launch of iOS products in 2007 enabled the company to secure a place among the most valuable companies in the US.[2]

2. When Apple stocks were traded at peak levels on 10 April 2012, the surge in the stock prices pushed the company's overall market value to $600 billion. Only a few companies in the US, such as General Electric ($600 billion in August 2000) and Microsoft ($619 billion, on 30 December 1999), have ever seen this incredible level of valuation (Svensson 2012). On 25 November 2014, Apple's market capitalization surpassed $700 billion, a (nominal) level that no other company in American history ever reached (Microsoft still holds the record for market capitalization in real terms).

FIGURE 12. Productive R&D or free lunch?



SOURCE: Retrieved from Dediu and Schmidt (2012), 'You Cannot Buy Innovation', *Asymco*, 30 January. Note: The author's calculations are based on the leading smartphone developers' 5-year average R&D figures between 2006 and 2011.

As indicated by Figure 10 and documented in company financial reports, the rampant growth in product sales following the launch of the iOS family of products paved the way for Apple's successful comeback from its wobbly conditions in the late 1980s. Interestingly, as the company continued to launch one new product after the next with increasing success, the company's financial reports reveal a steady decline in the global sales/R&D ratios, which indicate the portion of funds allocated to R&D activities in comparison to global product sales was falling over time (see Table 3). It could be argued that this is simply a testament to how unprecedented and exponential growth in product sales was relative to the annual growth of R&D expenditures. It could also be interpreted as the expected outcome of steady investment in R&D efforts. However, when viewed in the context of just how competitive the product markets are for consumer electronic products, these rather unimpressive R&D figures stand out. Long-time Apple analyst Horace Schmidt approaches this issue from a different angle by comparing Apple's R&D figures against those of the company's rivals. According to the data compiled by Schmidt (2012) and presented in Figure 12, Apple ranks in the bottom three in terms of the portion of sales allocated for supporting R&D activities among 13 of its top rivals.

Schmidt therefore inquires how Apple manages to get away with such a relatively low rate of R&D (as a percentage of sales ratios) in comparison to its competitors while still outpacing them in product sales. Many Apple experts explain this marginal R&D productivity as the company's success in implementing effective R&D programmes in a fashion that can only be seen in small technology start-ups. There is no doubt that Apple's ingenuity in engineering design, combined with Steve Jobs' commitment to simplicity, certainly contributed to its efficiency. But, the most crucial facts have been omitted when explaining this figure, which is that Apple concentrates its ingenuity not on *developing* new technologies and components, but on *integrating* them into an innovative architecture: its great in-house innovative product designs are, like those of many 'smart phone' producers, based on technologies that are mostly invented somewhere else, often backed by tax dollars.[3] The following section will provide historical background on technologies that enabled the future glory of the company.

SURFING THROUGH THE WAVES OF TECHNOLOGICAL ADVANCEMENTS

From its humble beginnings selling personal computer kits to its current place as the leader in the global information and communications industry, Apple has mastered designing and engineering technologies that were first developed and funded by the US government and military. Apple's capabilities are mainly related to their ability to (a) recognize emerging technologies with great potential, (b) apply complex engineering skills that successfully integrate recognized emerging

3. The type of 'architectural innovation' with which Apple engages is not a risk-free enterprise, and in one seminal typology of innovations (Abernathy and Clark 1985) it is considered the most radical type of innovation, for it may disrupt existing markets and competences. Yet the point of this chapter is not to praise Apple for its innovation prowess, which is extensively done by all kinds of publics—from Mac enthusiasts through the media and Hollywood to politicians—but to tell the part of Apple's story that has not been told elsewhere: that its 'architectural innovations' have been enabled by State-led investments in R&D and technological inventions.

technologies and (c) maintain a clear corporate vision prioritizing design-oriented product development for ultimate user satisfaction. It is these capabilities that have enabled Apple to become a global powerhouse in the computer and electronics industry. During this period prior to launching its popular iOS platform products, Apple received enormous direct and/or indirect government support derived from three major areas:

1) Direct equity investment during the early stages of venture creation and growth.
2) Access to technologies that resulted from major government research programmes, military initiatives, public procurement contracts, or that were developed by public research institutions, all backed by state or federal dollars.
3) Creation of tax, trade or technology policies that supported US companies such as Apple that allowed them to sustain their innovation efforts during times when national and/or global challenges hindered US companies from staying ahead, or caused them to fall behind in the race for capturing world markets.

Each of these points is elaborated on in the following section, as the histories of key technological capabilities underlying Apple's success are traced.

From Apple I to the iPad: The State's very visible hand

From the very start, Jobs and Wozniak sought the support of various public and private funding sources in their effort to form and develop Apple. Each believed in the vision in their mind: that enormous value could be captured from the technologies made available mostly as a result of the prior efforts of the State. Venture capital pioneers and Silicon Valley legends such as Don Valentine, founder of Sequoia; Arthur Rock, founder of Arthur Rock & Company; Venrock, the venture capital arm of the Rockefeller Family; and Fairchild and Intel veteran Mike Markkula were among the first angel and equity investors who bought into their vision (Rao and Scaruffi 2011). In addition to the technologies that were going to help Apple revolutionize the computer industry, the company received cash support from the government to implement its visionary business ideas in the computer industry. Prior to its IPO in 1980, Apple additionally secured $500,000 as an

early-stage equity investment from Continental Illinois Venture Corp. (CIVC), a Small Business Investment Company (SBIC) licensed by the Small Business Administration (a federal agency created in 1953) to invest in small firms (Slater 1983; Audretsch 1995).

As briefly discussed in Chapter 4, the emergence of personal computing was made possible by the technological breakthroughs achieved through various public–private partnerships established largely by government and military agencies (Markusen et al. 1991; Lazonick 2008; Block 2008; Breakthrough Institute 2010). When Apple was formed to sell the Apple I personal computer kit in 1976, the product's key technologies were based on public investments made in the computer industry during the 1960s and 1970s. Introduction of silicon during this period revolutionized the semiconductor industry and heralded the start of a new age when access to affordable personal computers for wider consumer markets was made possible. These breakthroughs were the result of research carried out in various public–private partnerships at labs, including those at the Defense Advanced Research Projects Agency (DARPA), AT&T Bell Labs, Xerox PARC, Shockley and Fairchild, to name a few. Silicon Valley quickly became the nation's 'computer innovation hub', and the resulting climate stimulated and nurtured by the government's leading role in funding and research (both basic and applied) was harnessed by innovative entrepreneurs and private industry in what many observers have called the 'Internet California Gold Rush' or the 'Silicon Gold Rush' (Kenney 2003; Southwick 1999).

There are 12 major technologies integrated within the iPod, iPhone and iPad that stand out as features that are either 'enablers' or that differentiate these products from their rivals in the market. These include semiconductor devices such as (1) *microprocessors* or *central processing units* (CPUs); (2) *dynamic random-access memory* (DRAM); as well as (3) *micro hard drive storage* or *hard drive disks* (HDD); (4) *liquid-crystal displays* (LCDs); (5) *lithium-polymer* (Li-pol) and *lithium-ion* (Li-ion) batteries; (6) *digital signal processing* (DSP), based on the advancement in *fast Fourier transform* (FFT) algorithms; (7) the *Internet*; (8) the *Hypertext Transfer Protocol* (HTTP) and *Hypertext Markup Language* (HTML); (9) and *cellular technology and networks*—all of which can be considered as the core enabler technologies for products such as the iPod, iPhone and iPad. On the other hand, (10) the *Global Positioning System* (GPS), (11) *click-wheel* navigation and *multi-touch screens* and (12) *artificial intelligence with a voice-user interface program* (a.k.a. Apple's SIRI) are innovative features that have drastically impacted consumer expectations and user experiences, further enhancing the popularity and success of these products. The following sections take a closer look at the core technologies and features that Apple has managed to ingeniously integrate, initially in the iPod and later in the iPhone and iPad.

How State-funded research made possible Apple's 'invention' of the iPod

Shortly after introducing the first generation iPod in 2001, Apple began to create waves of new innovative products (e.g. the iPhone, iPad) that would eventually revolutionize the entire mobile entertainment industry. The iPod, a new portable handheld device, allowed consumers to store thousands of songs without using any cassettes or CDs. In the early 2000s, this new Apple device was gaining popularity among consumers and replacing portable devices such as Sony's Walkman and Discman in the market. This novel application of existing magnetic storage technology therefore enabled Apple to take on an iconic rival such as Sony, and eventually to rise to the top of the music and entertainment market (Adner 2012). The success of iPod in gaining a competitive market position was important in two major aspects: (1) the success was going to set the stage for Apple's comeback from years of stagnant, if not declining, growth; and, (2) the popularity of this new product would constitute precedence to a family of new innovative Apple iOS products. While this much is often known and noted, the fact that much of Apple's success lies in technologies that were developed through government support and -funded research is an often overlooked story to which I now turn.

Giant magnetoresistance (GMR), SPINTRONICS programme and hard disk drives

A rare instance of public recognition of the role played by State-backed technological research in paving the way for Apple products occurred during the 2007 Nobel Prize ceremony. European scientists Albert Fert and Peter Grünberg were awarded the 2007 Nobel Prize in Physics for their work in developing giant magnetoresistance (GMR). The GMR is a quantum mechanical effect observed in thin-film layered structures, for which the main application has been in magnetic field sensors used in hard disk drives (HDD) and other devices. In his ceremony

remarks, Börje Johannson (2007), a member of the Royal Swedish Academy of Sciences, explained what the invention of GMR meant for society by attributing the existence of the iPod to this major scientific breakthrough.

Invention and commercialization of the micro hard drive are especially interesting since the technology development process from its origin to its current form illustrates the role of government not only in establishing the science base for innovation, but also in facilitating the advancement of abstract ideas into manufactured and commercially viable products (McCray 2009). What started as two separate and independent academic, State-funded and -supported research projects in physics in Germany and France culminated into one of the most successful technology breakthroughs in recent years, worthy of the Nobel Prize. Following this scientific breakthrough that Dr Fert and Dr Grünberg achieved, other researchers successfully expanded the size of data storage in conventional hard disk drives during the 1980s and 1990s, breaking new ground for future research and technological advancement (Overbye 2007). While the major scientific breakthrough in GMR was accomplished in Europe, the US government played a critical role in the basic research as well as commercialization of this technology. Dr Peter Grünberg's laboratory was affiliated with Argonne National Laboratory (the US Department of Energy's largest R&D lab, located in Illinois) and received critical support from the Department of Energy (DoE) prior to his discovery (DoE 2007). Based on these developments in hard disk technology, companies such as IBM and Seagate moved quickly to translate the new knowledge into successful commercial products (McCray 2009). Despite the advances taking place in the hard drive industry at the time, they would experience similar competitive challenges faced by the semiconductor industry in the late 1980s, which I discuss in the following section on semiconductor devices.

In his 2009 study, McCray details how DARPA's war-related missions to create and sustain an innovation ecosystem for producing superior defence technologies was transformed during peace time by the new mission of transforming those prior investments into technologies supporting economic competitiveness. McCray (2009) documents that the Department of Defense (DoD) initiated the Technology Reinvestment Program (TRP) and allocated $800 million to upgrade the nation's existing technological capabilities following the Cold War. Through TRP, DARPA targeted dual-use technologies that would benefit the military as well as be commercially viable.[4] McCray (2009) especially documents the increase in scientific research efforts and publications taking place during DARPA's support for SPINTRONICS during the 1990s. McCray (2009, 74) also argues that the role DARPA played in the advancement of this technology was not 'insignificant', simply because the programme was initiated during the time when Japanese competition in computer electronics was pushing computer giants such as IBM and Bell Labs to downsize spending on basic research.

Solid-state chemistry and silicon-based semiconductor devices

Since the launch of the first iPod, the first major new Apple product has evolved many times and also inspired the design of the future iPad and iPhone. Among the factors that have made the iPod, iPhone and iPad possible today are the small microchips that enable handheld smart devices to process large amounts of information and pass it through memory in a virtual instant. Today, central processing units (CPUs) depend on integrated circuits (ICs) that are considerably smaller in size and feature much larger memory capacity in comparison to the integrated circuits once used for processing needs and first designed by Jack Kilby and Robert Noyce in the 1950s. The invention of new silicon-based ICs led to technological developments in various fields in electronics. Personal computers (PCs), cellular technology, the Internet, and most of the electronic devices found on the market today utilize these smart, tiny devices. The journey of ICs from Bell Labs, Fairchild Semiconductor and Intel into devices such as iPhone or iPad was aided by procurement by the US Air Force and NASA. As the sole consumers of the first processing units based on this new circuit design, defence contracts helped fund the development of the infant microprocessor industry and those introducing complementary electronic equipment and devices that were simply unaffordable in regular commercial markets. Large-scale demand for microprocessors by the US Air Force was created by the Minuteman II missile programme. NASA's Apollo mission pushed the technological envelope, requiring significant

4. *SPIN TR*ansport *electrONICS* (SPINTRONICS), initially called the 'Magnetic Materials and Devices' project, was a public–private consortium. It consisted of DARPA and industry leaders but was initiated (and funded) by DARPA in 1995, with the total government investment of $100 million during its existence.

improvements in the production process of microprocessors and also greater memory capacity. In turn, each of the government agencies helped to drive down the costs of integrated circuits significantly within a matter of years.[5]

Although the US was the home for early innovation in semiconductors, throughout the 1980s, Japan was developing advanced manufacturing capabilities and competitive memory products at a faster pace.[6] Given the significant role of semiconductors in defence technologies, the DoD considered the industry vital to its military capabilities and national security. Growing fears that the manufacturing equipment essential for production of these technologies, now vital to national defence, would be imported from countries like Japan spurred the DoD to act. The result was the Strategic Computing Initiative (SCI), which allocated over $1 billion to support research efforts in advanced computer technologies between 1983 and 1993 (Roland and Shiman 2002). Additionally, the manufacturing of highly advanced technologies such as microprocessors had significant economic implications that required collaborative efforts between the government and industry. Recognizing the unique opportunity that semiconductor manufacturing would provide, and fearful of the consequences of lagging behind newly emerging competitors in semiconductor manufacturing such as Japan, the federal government gathered competitive domestic manufacturers and universities together to form a new partnership, the Semiconductor Manufacturing Technology (SEMATECH) consortium.

This move, to advance US-based semiconductor manufacturing technology and capability above and beyond those of the nation's competitors, was part of an overall effort to promote US economic and technological competitiveness globally. The process of organizing collaborative effort among semiconductor companies through SEMATECH was a challenge for the government. In order to make this partnership more appealing, the US government subsidized SEMATECH R&D with $100 million annually. Over time, the members of the consortium came to recognize the benefits of the R&D partnership fostered by SEMATECH.

5. Lower costs became visible when the price of a microchip for the Apollo program fell from $1,000 per unit to anywhere between $20 and $30 per unit within just a few years (Breakthrough 2010).

6. Roland and Shiman (2002, 153) document Japan's significant progress in the global chip market as having 0 per cent market share as opposed to the US's 100 per cent share in 1970s, to 80 per cent global market share in 1986.

The extensive knowledge-sharing efforts that took place among members of SEMATECH helped them avoid duplicating research efforts and translated into less R&D spending. The advanced performance and affordability of microprocessors and memory chips today are to a great extent the result of years of government intervention and supervision (Irwin and Klenow 1996).

From capacitive sensing to click-wheels

As the pioneer of personal computers, Steve Jobs was on his second mission for re-revolutionizing them. His vision for Apple was to prepare the company for the post-computer era, in what he envisioned and often acknowledged in his interviews and media appearances as the new era of the consumer–computer relationship. During an interview at the 2010 D8 conference, Steve Jobs explained his vision of the future for computing by using the analogy of rapid urbanization and its effects on changing consumer views and the need for transportation (Jobs 2010). During his talk, Jobs redefined Apple's overall strategy as building a family of products around the concept of fragmented computing needs by different uses. Jobs often acknowledged his trust in the data-processing technologies that had enabled Apple to come up with compact portable devices. It was these processing technologies leading to the portable iOS products that eventually replaced desktop computers. To do this, Apple had begun to work on building a periphery of portable iOS devices, with the Mac becoming the 'digital hub' that would integrate the entire product family together (Walker 2003).

Despite his strong opposition to tablet computers in the 1980s and 1990s, upon his return to Apple in the late 1990s, Jobs had decided that the time was right to focus once again on tablets. Underlying this shift in perspective was the fact that technology in semiconductor devices, batteries and displays had progressed significantly. However, a challenge still remained given the absence of sophisticated technology to successfully replace the *stylus pen*, a feature that Jobs had long despised and considered an inconvenience (Isaacson 2011, 490). The emergence of more sophisticated applications such as inertia scrolling, finger tracking and gesture-recognition systems for touch-screen-enabled displays presented Jobs and his team with the possibility of moving forward (and far beyond the stylus pen). Jobs and his team thus gathered experts together that could integrate these new technologies. The end results included replacing buttons and roll-balls on devices, developing a new navigation system, and enhancing input techniques on touch screens.[7]

The iPod's click-wheel component that allowed users to navigate quickly through their music library was part of Apple's earlier attempts to implement touch-based features with finger scrolling. In addition to the micro hard disk drive for the storage of memory-intensive digital records, the finger scrolling click-wheel feature differentiated the iPod from the majority of other available portable music players. Although the application of finger scrolling was something novel at the time, the technology behind this feature had been around for decades. The click-wheel significantly benefitted from the *capacitive sensing* technology widely applied in the design of various other products.[8] In fact, the click-wheel feature was not the only feature of Apple products that benefitted from capacitive sensing. The iPod Touch, iPhone and iPad's *multi-touch screen* also embodies the same principles of finger(s)-operated scrolling on a glass screen.

E. A. Johnson, considered the inventor of capacitive touch screens, published his first studies in the 1960s while working at Royal Radar Establishment (RRE), a British government agency established for R&D of defence-related technologies (Buxton 2012). One of the first notable developments of the touch screen was at the European Organisation for Nuclear Research (CERN) by Bent Stumpe and his colleague Frank Beck in 1973 (CERN 2010). Samuel Hurst's invention of resistive touch screens was another notable breakthrough. Hurst's invention came right after leaving Oak Ridge National Laboratory (a national research laboratory in Tennessee established in 1943 and the site of the Manhattan Project and first functional nuclear reactor) for two years to teach at the University of Kentucky (Brown et al., n.d.). While at the University of Kentucky, Hurst and his colleagues developed the first resistive touch screens. Upon his return to Oak Ridge, they started a new company in 1971 to commercialize the new technology and produced the first

7. During his TV interview on 30 April 2012, Tony Fadell, who was on the original iPod design team, revealed the challenges Apple was facing with finding ways to replace buttons on the new gadget. Available at: http://www.theverge.com/2012/4/30/2988484/on-the-verge-005-tony-fadell-interview (accessed 12 April 2013).

8. *Capacitive sensing* is a technology that draws on the human body's ability to act as a capacitor and store electric charge.

functioning version in 1983 (Brown et al., n.d.). Earlier work on touch screens in the 1970s and 1980s, such as that conducted by Johnson, Stumpe, Hurst and others, continued in different public and private research labs, creating the foundations for today's important multi-touch applications (Buxton 2012). Among various other factors, moving from touchpads with limited functionality to multi-touch screens was a major leap forward for Apple in the smartphone race. Along with the other technological advancements they exploited, Apple has not only helped redefine the markets it competes from within but has also defined a different path for growth.

THE BIRTH OF THE iPOD'S SIBLINGS: THE iPHONE AND iPAD

Apple's new vision included radical redefinitions of conventional consumer products and was a great success. The introduction of the iPod generated over $22 billion in revenues for Apple. It was the company's most important global product until the iPhone was introduced in 2007. The cohesion of aesthetic design, system engineering and user experience combined with great marketing helped Apple rapidly penetrate and capture market share in different consumer electronics markets. Apple's new generation of iPods, iPhones and iPads have been built under the assumption that new consumer needs and preferences can be invented by hybridizing existing technologies developed after decades of government support. As a pioneer of the 'smartphone' revolution, Apple led the way in successfully integrating cellular communication, mobile computing and digital entertainment technologies within a single device. The iconic iPhone dramatically altered consumer expectations of what a cellular phone was and can do. With the introduction of the iPad, Apple transformed the portable computer industry that had been dominated for decades by laptops, netbooks and other devices. By offering a slimmer handheld device equipped with a large touch screen and virtual keyboard, with solid Internet browsing and multimedia capabilities, along with broad compatibility across other Apple products and applications, the iPad virtually created a new niche and captured it at the same time. In less than a decade, Apple singlehandedly came to dominate the consumer electronics industry, a testament to Apple's ingenuity in consumer-oriented device product design and marketing, as well as their organizational capabilities in managing complex 'systems integration' (Lazonick 2011).

From click-wheels to multi-touch screens

Development of touch-screen displays recognizing multi-touch gestures was one of the most important technologies integrated into Apple's devices and for their successful introduction of pocket-sized portable devices such as the iPod. The technology allowed human–machine interaction through a new interface that allowed fingers to navigate the glass surface of LCD displays included with handheld devices. As with the *click-wheel* feature, the technology behind this ground-breaking new way to interface with electronic devices relied on earlier basic and applied research that had been supported by the State. During the 1990s, touch-screen technology was incorporated into a variety of products by numerous computer developers, including Apple, but the majority of the touch-screen technologies available during these earlier days were only capable of handling single-touch manipulation.[9] The introduction of multi-touch scrolling and gestures was developed by Wayne Westerman and John Elias at the University of Delaware (Westerman 1999).

Wayne Westerman was a doctoral candidate under the supervision of Professor John Elias studying neuromorphic systems at the (publicly funded) University of Delaware, as part of the National Science Foundation (NSF) and Central Intelligence Agency/Director of Central Intelligence (CIA/DCI) Post-Doctoral Fellowship programme (Westerman 1999). Following the completion of Westerman's PhD, he and Elias commercialized this new technology after founding the FingerWorks company. Their new product, called 'iGesture Numpad', enabled many computer users to enter input by applying 'zero-force' pressure on an electronic screen with no need of additional devices such as a keyboard or a mouse. The underlying scientific base and patent application for the new finger-tracking and gesture-identification system was built on the earlier studies on *capacitive sensing* and *touch-screen* technologies. FingerWorks' successful attempt to translate prior touch-screen research into a commercial product was quickly recognized by Apple, which was interested in developing a multi-touch navigation capability on a fully glass LCD display for the new-generation iOS products.

9. As a world-renowned expert on touch-screen technology, Bill Buxton provides an extensive archive of electronic devices with touch-screen applications. The list of Apple products with the touchpad feature can be seen online at http://research.microsoft.com/en-us/um/people/bibuxton/buxtoncollection/ (accessed 12 April 2013).

FingerWorks was acquired by Apple in 2005 prior to the launch of Apple's first-generation iPhone in 2007, and today this new technology lies at the heart of the coveted multi-touch screen featured on Apple's iOS products. As a result, Westerman and Elias, with funding from government agencies, produced a technology that has revolutionized the multi-billion-dollar mobile electronic devices industry. Apple's highly comprehensive intellectual property portfolio had benefitted, once again, from technology that was originally underwritten by the State.

Internet and HTTP/HTML

Although the iPhone appears to be a 'cool' gadget with its cutting-edge technology features and hardware components, what makes a phone 'smart' is its ability to connect phone users to the virtual world at any point in time. With the artificial intelligence application named SIRI on board, the iPhone appears to be attempting to outsmart its users. After replacing the handset-industry-standard keypads with touch screens, SIRI is Apple's attempt to transform input entry and navigation interfaces. As Apple's 'smartphone' continues to evolve into an even smarter device, it is important to recognize and value the underlying and necessary intelligence and technological capabilities that have smart-wired, if you will, this smart device. If hardware, software, memory and the processor were to be the body, soul and brain of a computer, what does the Internet, Hypertext Transfer Protocol (HTTP) or Hypertext Markup Language (HTML) mean to any computer or smart device? Or, what would a computer or smart device be worth in the absence of Internet or without cellular communication capability? Answers to these questions can help us understand the value of the networking capabilities of smart devices. But more importantly, they can help us understand the value of support efforts that the government made in the process of inventing and developing cellular technology, the Internet and satellites.

During the Cold War era, US authorities were concerned about possible nuclear attacks and the state of communication networks in the aftermath of possible attacks. Paul Baran, a researcher at RAND—an organization with its origins in the US Air Force's project for 'Research and Development', or RAND for short—recommended a solution that envisioned a distributed network of communication stations as opposed to centralized switching facilities. With a decentralized communication system in place, the command and network system would survive during and after nuclear attacks (Research and Development 2011).[10] The technological challenges of devising such a network were overcome thanks to the various teams assembled by DARPA to work on networking stations and the transmission of information. Although DARPA approached AT&T and IBM to build such a network, both companies declined the request, believing that such a network was a threat to their business; with the help of the State-owned British Post Office, DARPA successfully networked various stations from the west to east coast (Abbate 1999). From the 1970s through the 1990s, DARPA funded the necessary communication protocol (TCP/IP), operating system (UNIX) and email programs needed for the communication system, while the NSF initiated the development of the first high-speed digital networks in the US (Kenney 2003).

Meanwhile, in the late 1980s, British scientist Tim Berners-Lee was developing the HTML, uniform resource locators (URLs) and uniform HTTP (Wright 1997). Berners-Lee, with the help of another computer scientist named Robert Cailliau, implemented the first successful HTTP for the computers installed at CERN. Berners-Lee and Cailliau's 1989 manifesto describing the construction of the World Wide Web eventually became the international standard for computers all over the world to connect. Public funding has played a significant role for the Internet, from its conception to its worldwide application. The Internet is now in many ways a foundational technology that has affected the course of world history by allowing users all over the globe to engage in knowledge sharing and commerce using computers and popular smart gadgets such as the iPhone, iPod or iPad.

GPS and SIRI

Another great feature that an iPod, iPhone or iPad offers is GPS integration. GPS was an attempt by the DoD to digitize worldwide

10. Other goals of the new network project were (a) to save computing costs, as government contractors across the US would be able to share computer resources; and (b) to advance the 'state of the art' in data communications to enable transfer of information between machines over long distances. An additional goal (c) was to foster collaboration among contracted researchers in different locations.

geographic positioning to enhance the coordination and accuracy of deployed military assets (Breakthrough Institute 2010). What initially began in the 1970s as a strictly military-use-only technology is now widely available to civilians for various uses. In fact, civilian use of GPS quickly outnumbered military utilization following the release of GPS for public applications in the mid-1990s. Yet, even today, the US Air Force has been at the forefront of developing and maintaining the system, which costs the government an average of $705 million annually.[11] An iPhone user can search for a nearby restaurant or an address, based on the NAVSTAR GPS system, which consists of a 24-satellite constellation providing global navigation and timing data for its users. This technology, as well as the infrastructure of the system, would have been impossible without the government taking the initiative and making the necessary financial commitment for such a highly complex system.

Apple's latest iPhone feature is a virtual personal assistant known as SIRI. And, like most of the other key technological features in Apple's iOS products, SIRI has its roots in federal funding and research. SIRI is an artificial intelligence program consisting of machine learning, natural language processing and a Web search algorithm (Roush 2010). In 2000, DARPA asked the Stanford Research Institute (SRI) to take the lead on a project to develop a sort of 'virtual office assistant' to assist military personnel. SRI was put in charge of coordinating the 'Cognitive Assistant that Learns and Organizes' (CALO) project, which included 20 universities all over the US collaborating to develop the necessary technology base. When the iPhone was launched in 2007, SRI recognized the opportunity for CALO as a smartphone application and then commercialized the technology by forming 'SIRI' as a venture-backed start-up in the same year. In 2010, SIRI was acquired by Apple for an amount that is undisclosed by both parties.

Changing industry standards from keypad to touchpad input and adding GPS navigation were a significant achievement when iPhone was first introduced. A second game-changer for cell phone, media player and tablet computer developers was the introduction of multi-touch screens and gesture recognition. With SIRI, Apple introduced another radical idea for a device input mechanism that has been

11. The DoD estimates that, in 2000 dollars, the development and procedure of the system cost the Air Force $5.6 billion between 1973 and 2000 (DoD 2011). The figure does not include military user equipment.

integrated within various iOS features and applications. The introduction of SIRI has launched a new round of redefining standards of human–machine interaction and creates a new means of interaction between the user and the machine. Steve Jobs often acknowledged the potential of artificial intelligence and his interest in the future of the technology. During his 2010 interview with Walt Mossberg and Kara Swisher (2010) at the California D8 conference, Jobs had shared his excitement about the recent acquisition of SIRI by Apple, and talked about the great potential the technology offered. Once again, Apple is on the verge of building the future for information and communication industry based on the radically complex ideas and technologies conceived and patiently fostered by the government.

Battery, display and other technologies

The story of the LCD shares great similarities with the hard disk drive, microprocessor and memory chip (among other major technologies) that emerged during the Cold War era: it is rooted in the US military's need to strengthen its technological capabilities as a matter of national security. Rising competition from the Japanese flat panel display (FPD) industry was a concern for the DoD because the US military's future demand for the technology could not be met solely by the Japanese suppliers. Given this determination, the DoD began implementing a variety of programmes geared towards strengthening the industry's competitiveness, including the formation of an industry consortium and deployment of new resources for the improvement of manufacturing capabilities and commercial products.

The major breakthrough in LCD technology came about during the 1970s, when the thin-film transistor (TFT) was being developed at the laboratory of Westinghouse under the direction of Peter Brody. The research carried out at Westinghouse was almost entirely funded by the US Army (Hart and Borrus 1992). However, when management at Westinghouse decided to shut down the research, Brody sought out possible funding opportunities elsewhere in the hopes of commercialising this technology independently. In the process of appealing for contracts to ramp up the production of TFT displays, Brody contacted a number of top computer and electronic companies, including Apple and others such as Xerox, 3M, IBM, DEC and Compaq. All these major private companies refused to sign on with Brody largely because they doubted his ability to build the manufacturing capability necessary to provide the product at a competitive price compared to his Japanese counterparts (Florida and Browdy 1991, 51). In 1988, after receiving a $7.8 million contract from DARPA, Brody established Magnascreen to develop the TFT-LCD. This advancement in the LCD technology became the basis for the new-generation displays for the portable electronic devices such as microcomputers, phones, etc.

Florida and Browdy argued that this pattern of the inability of private actors to build or sustain manufacturing capabilities in various high-technology fields presented a broader problem with the nation's innovation system:

> The loss of this [TFT-LCD] display technology reveals fundamental weaknesses of the U.S. high-technology system. Not only did our large corporations lack the vision and the persistence to turn this invention into a marketable product, but the venture capital financiers, who made possible such high-technology industries as semiconductors and personal computers, failed too. Neither large nor small firms were able to match a dazzling innovation with the manufacturing muscle needed for commercial production. (1991, 43)

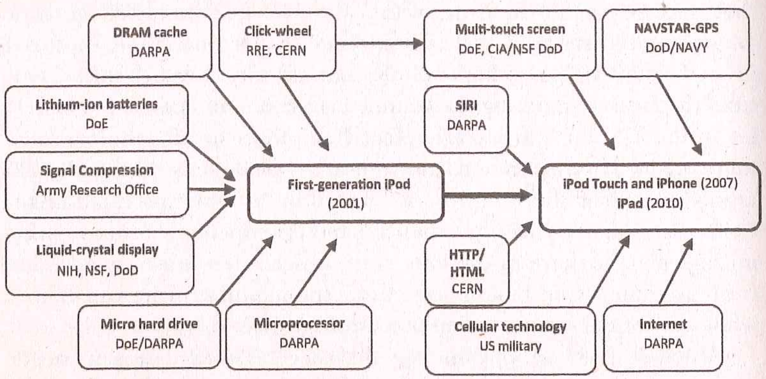
In an attempt to retain the manufacturing of TFT-LCDs in the US, the Advanced Display Manufacturers of America Research Consortium (ADMARC) was established by the major display manufacturers with initial funding appearing from the National Institute of Standards and Technology's (NIST) Advanced Technology Program (ATP) (Florida and Browdy 1991). The industry also received additional assistance from the US government in the form of antidumping tariffs (while at the same time touting the 'free competition' line), as well as funds and contracts provided by various military or civilian agencies that supported many start-ups in the US as part of an effort to develop manufacturing capabilities of TFT-LCDs in the 1990s (OTA 1995).

The lithium-ion battery is another example of a US-invented but Japanese-perfected and manufactured-in-volume technology. John B. Goodenough, who pioneered the early research on lithium-ion battery technology, received his main funding support from the DoE and NSF in the late 1980s (Henderson 2004; OSTI 2009). Major scientific breakthroughs accomplished at the University of Texas at Austin were quickly commercialized and launched in 1991 by the Japanese electronics giant Sony. In a 2005 working paper for the NIST, Ralph J. Brodd (2005) identified issues with the advanced battery industry innovation model that were similar to the issues within the TFT-LCD industry. Another major scientific success faded away without greater value being captured in the form of US-based high-volume manufacture. Brodd's study identifies the factors hindering the volume production of lithium-ion batteries in the US, but particularly placed emphasis on the short-termist approach of US corporations and venture capitalists. Brodd (2005, 22) argued that their short-termism was based upon achieving rapid financial returns (in comparison to their Japanese competitors' focus on maximizing market share in the long run), which often discouraged them from any interest in building the domestic manufacturing capabilities while encouraging outsourcing of manufacture as an option.

Absence of a battery technology that met the storage capacity needs of increasingly powerful electronic devices posed one of the greatest challenges that the electronics industry faced following the revolution in semiconductor devices. The invention of lithium-ion technology enabled portable devices to become much slimmer and lighter as battery capacity increased relative to size. Once again, the federal government stepped in to assist smaller-battery companies through a variety of agencies and programmes that invested in the industry in an effort to develop the necessary manufacturing capabilities (Brodd 2005)—not only for electronic devices but, equally or even more importantly, for 'zero-emission' electric vehicles. The US government has been actively involved with the energy industry for decades as part of a broader effort to address economic and social needs, which is extensively discussed in Chapters 6 and 7.

State-of-the-art iOS products are highly complex electronic devices. Despite the fundamental differences in use, each device embodies numerous technologies that are often present in all the devices. Cellular technology is available for most of Apple's devices with the exception of its iPod media players. Cellular communication technology received enormous government support in its early days. The Breakthrough Report (2010, 5) examines the role of the US military in advancing the radiotelephony technology in the twentieth century. The Office of Science and Technology Policy (2006, 8) also documented the role of State support in the digital signal processing (DSP) technology that came about following scientific advancements in the application of the fast Fourier transform (FFT) algorithm during the 1980s. This new signal-processing approach enabled real-time processing of sound

FIGURE 13. Origins of popular Apple products



SOURCE: Author's drawing (with Oner Tulum's research assistance) based on the Office of Science and Technology Policy (OSTP) diagram 'Impact on Basic Research on Innovation' (2006, 8).

(such as during a two-way phone call) as well as real-time processing of large audio or multimedia files that can improve the quality of their playback. DSP is considered to be a core feature of iOS products with a media player function (Devlin 2002).

DID THE US GOVERNMENT 'PICK' THE iPOD?

In a 2006 policy document where former US president George W. Bush laid out the nation's innovation strategy, the various component technologies that were featured in the first-generation iPod were linked to their origins as part of the basic and applied research funded by US tax dollars (OSTP 2006). Although lacking substantial context and/or literal figures, the report does include a diagram illustrating the origins of iPod's component technologies, such as its hard disk drive, Li-ion battery, LCD, DRAM cache, signal processing, etc. Figure 13 expands on the OSTP diagram by further mapping out the tech components featured in later Apple products like the iPod Touch, iPhone and iPad.

FOSTERING AN INDIGENOUS SECTOR

In addition to government efforts nurturing the science base and fostering innovation in the US, the US government has played a critical role in protecting the intellectual 'property' of companies like Apple,

and ensuring that it is protected against other trade right violations. The federal government has actively fought on behalf of companies like Apple to allow it secure access to the global consumer market, and it is a crucial partner in establishing and maintaining global competitive advantage for these companies (Prestowitz 2012). Although US-based corporations define themselves as transnational entities whose existence transcends political borders, Washington is the first place they usually turn to when conflicts in the global market arise. Accessing foreign markets protected by trade restrictions was only possible with the US government acting as a backer and vanguard. For example, in the 1980s Apple had difficulties entering the Japanese market. The company called on the US government for assistance, arguing that it was the government's obligation to assist the company in opening the Japanese market to US products by appealing to the Japanese government (Lyons 2012). When unfettered global competition hit home, companies such as Apple were backed by the government to ensure that intellectual property laws were carefully enforced all over the world. The added protection created for Apple by local and federal authorities continues to provide this form of subsidy, which allows the company to continue innovating.

Additionally, the US government has been providing various other types of tax and procurement support that greatly benefits American companies such as Apple. According to a Treasury Department document, companies (including Apple) overall claimed \$8.3 billion in research and experiment (R&E) tax credits in 2008 (Office of Tax Policy 2011). Additionally, California provides generous R&D tax packages for which computer and electronics companies are the largest applicants (Ibele 2003).[12] Since 1996, Apple has reportedly claimed \$412 million in R&D tax credits of all kinds (Duhigg and Kocieniewski 2012).

Government procurement policies have supported Apple through various critical stages, which made it possible for the company to survive in the midst of ferocious competition against its competitors. Public schools in the US have been loyal Apple customers, purchasing their

12. According to a 2003 state of California legislative report assessing the results of California's research and development tax credit (RDC) programme, SMEs are the largest applicants in terms of number of claims (over 60 per cent of the applicants), while larger companies have the largest share of claims in total value (over 60 per cent of the total value of RDC claims).

computers and software each year since the 1990s.[13] Klooster (2009) argues that public schools were a critical market for Apple as it reeled from its Apple III and Lisa product flops in the late 1980s. Provisions in the (post–financial crisis) 2009 American Recovery and Reinvestment Act (ARRA) provided incentives to benefit computer and electronics companies in the US. For instance, among various other incentives, through a small change in the scope of IRS 529 plans, 'computer technology and equipment' purchases were defined as a qualified education expense, which is expected to boost up Apple's computer, tablet and software sales.[14]

In sum, 'finding what you love' and doing it while also being 'foolish' is much easier in a country in which the State plays the pivotal serious role of taking on the development of high-risk technologies, making the early, large and high-risk investments, and then sustaining them until such time that the later-stage private actors can appear to 'play around and have fun'. Thus, while 'free market' pundits continue to warn of the danger of government 'picking winners', it can be said that various US government policies laid the foundation that provided Apple with the tools to become a major industry player in one of the most dynamic high-tech industries of the twenty-first century so far. Without the frequent targeted investment and intervention of the US government it is likely that most would-be 'Apples' would be losers in the global race to dominate the computing and communications age. The company's organizational success in integrating complex technologies into user-friendly and attractive devices supplemented with powerful software mediums should not be marginalized; however, it is indisputable that most of Apple's best technologies exist because of the prior collective and cumulative efforts driven by the State, which were

13. Apple's share of the total educational computer purchases of US elementary and high schools reached 58 per cent in 1994 (Flynn 1995). Educators have also welcomed Apple's new 'textbook initiative', which is expected to reduce textbook prices significantly by increasing school use of virtual textbooks. These virtual textbooks would require iPad use and would be expected to increase Apple's iPad sales in the coming years.

14. Section 529 of the Internal Revenue Code (US tax code) includes certain tax advantages, also known as 'qualified tuition programs' or 'college savings plans'. A legislative amendment in 2011 allowed parents and students to use the funds in their college savings accounts for purchasing computers, computer equipment and accessories (including iPads). None of these purchases were considered eligible school expenses for account withdrawals before (Ebeling 2011).

made in the face of uncertainty and often in the name of, if not national security, then economic competitiveness.

In Chapter 8, I will return to Apple, to ask what the State received back in return for the entrepreneurial, risky investments it made in both Apple the company and all the 'revolutionary' technologies that make the iPhone so 'smart'. As we will see, this is perhaps the most crucial question policymakers must ask themselves in the twenty-first century; when on the one hand we want an 'active' State with the courage to lead the next technological 'green revolution'; while on the other hand the State has to create a revolution with constrained budgets and pressure to pursue austerity measures. Finding a solution to this 'risk–reward nexus' will be key to this dilemma.