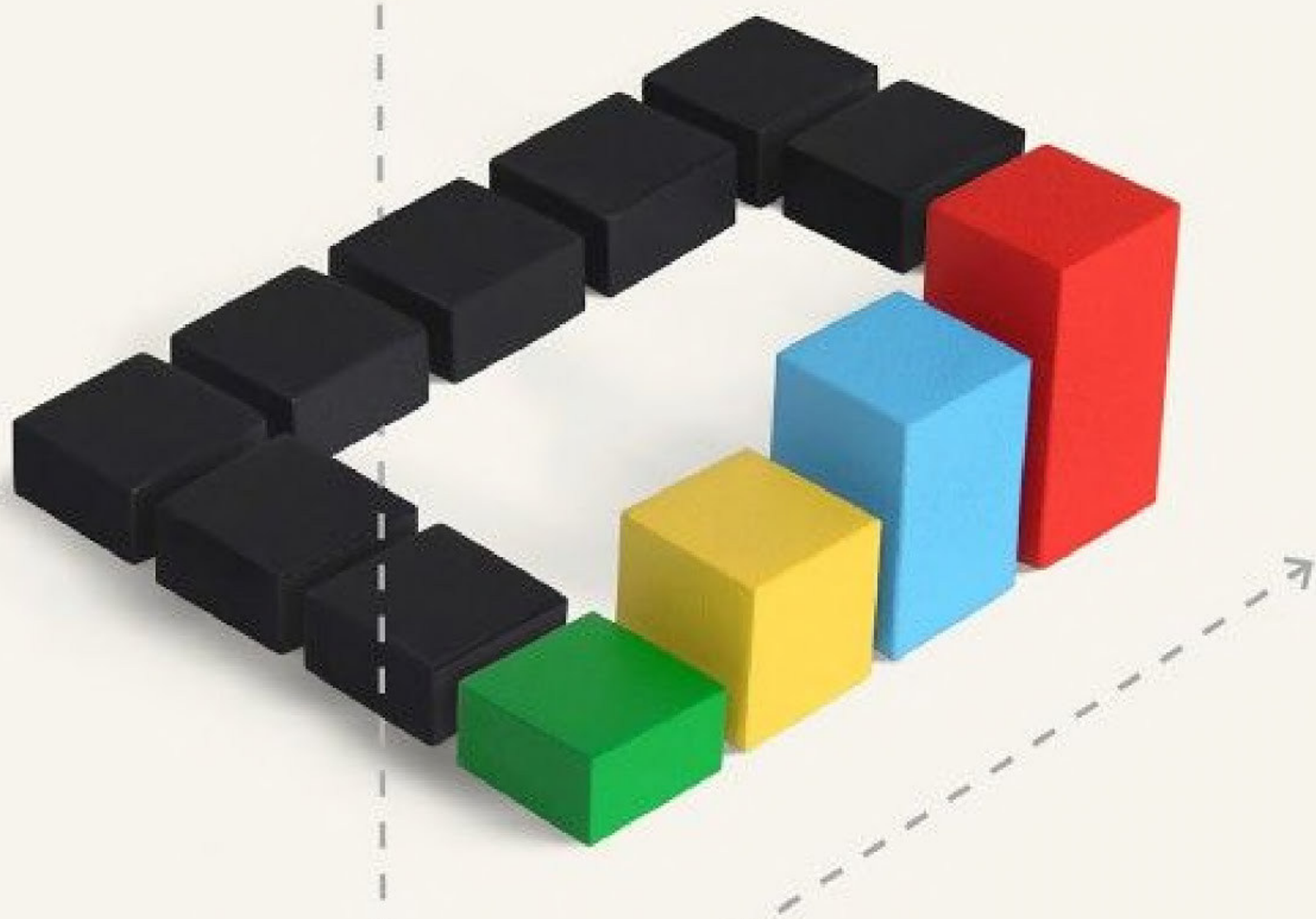
The Efficiency Paradox

What Big Data Can't Do



Edward Tenner

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PREFACE

THE SEVEN DEADLY SINS OF EFFICIENCY

WHY IT IS STILL A WORK IN PROGRESS

This book is a critique of something self-evidently desirable, even wonderful, until it isn't: efficiency. And it's also about an apparent oxymoron that seems absurd until we realize that it's also been essential: inspired inefficiency. Efficiency is mostly good but, like all good things, can be carried too far; even an excess of water can be lethal.

More than twenty years ago at the dawn of the web as we know it, when I wrote my first book on the unintended consequences of technology, *Why Things Bite Back*, published in 1996, the idea of efficiency itself as a threat hardly occurred to me. In fact, far from allying with the critics who called themselves neo-Luddites (a term now shared by their friends and foes), I was an early adopter and enthusiast. As a science book editor recruiting authors globally and affiliated with a university offering email, I had already been using it to correspond and set up appointments. As a researcher already using electronic databases, I found the new web browser and graphic interface a welcome improvement. As a writer always

tinkering with my text, I had embraced word processing since the days of the TRS-80 in the early Reagan era. Remembering the tedium of retyping and the mess of carbon paper, I felt (and feel) no nostalgia for my own typewriting, though I do find that the typewritten letter has a distinctive graphic personality through the "bite" of letters in the paper and the varying impressions created by carbon ribbons from saturated to faint.

I saw and wrote about the downside of new technology, the chronic back pain and carpal tunnel ailments resulting from the ever more sedentary office, and the comical fate of the paperless office. But I shared in much of the technological optimism of the later 1990s. The web at first appeared a godsend for newspapers and magazines. Whether or not electronic publication ever replaced print, their publishers reasoned, they held a priceless franchise in high-quality content that attracted an affluent readership coveted by advertisers. Technology itself was a profitable advertising focus into the early twenty-first century. I occasionally find the thick "Circuits" section of *The New York Times* among my clippings, well sponsored by hardware and software publishers and electronics retailers. The efficiency of the electronic newsroom helped make all this possible.

It seemed that society could have its cake and eat it, too. Amazon appeared, but it could coexist with still profitable chains of giant bookstores. It was hard to imagine that Amazon threatened Borders and Barnes & Noble, as these had decimated independent bookstores in the 1980s with crushing scale and an earlier generation of technology. The rise of robotics did not seem to threaten employment levels. Old-line business magazines shared still thriving newsstands with technology-oriented newcomers like *Wired* and *The Industry Standard*. Technological utopian authors spread the gospel of individual empowerment

while corporate elites made more money than ever. If the 1960s were the go-go years, the 1990s were the win-win decade thanks to the efficiency of the web.

Beginning around 2005, the new hyperefficient world entered a different phase. With the introduction of the Apple iPhone in 2007, made possible by the rapid evolution of computer processing speed, electronic devices were gradually ceasing to be tools that people used and put away and becoming extensions of their selves and their personal and professional networks. At the same time, the exceptionally efficient search engine Google and the social networking site Facebook, together with Amazon, were transforming online commerce by adding a new level to the Internet, the platform, between the corporate website and the open web.

Since 2008, the dream of utopia through ever-increasing electronic efficiency has been dimmed. The recession that began that year had many origins, but was due in part to the technical ease with which bankers and securities industry professionals were able to manage risk. Meanwhile, the rate of increase of the number of transistors that can fit on a computer chip has been slowing down. It used to double every eighteen months or so, a rhythm described since 1965 as Moore's Law (after Gordon Moore, a founder of the dominant chip manufacturer Intel), but since 2005 has been stretched to two to three years. Further, the success of new platforms in attracting advertisers and marketers has come at the expense of the revenue of newspapers and magazines. (The all-time peak in advertising revenues did not occur until ten years after the advent of the web, in 2005, when it was $47.4 billion in print and $2 billion in digital; in 2014 these numbers were $16.4 billion and $3.5 billion, respectively.)[1]

There were, of course, many winners as well as losers in

the new hyperefficient web, in which computer techniques—algorithms—were supplanting intuitive judgment. And there were benefits to web-savvy consumers from increased price competition. But for many economists, the hope was dimming that the benefits of more efficient production and distribution would lift the public's standard of living. Two noted economists, Tyler Cowen in *The Great Stagnation* (2011) and Robert J. Gordon in *The Rise and Fall of American Growth* (2016), even advanced the previously heretical idea that the twentieth century had seen the last of an era of "low-hanging fruit," transformative innovations that by today's standards were relatively cheap to develop. This is a sharp turn from the mood even at the beginning of the 2008 recession, when the computer scientist and futurist Ray Kurzweil repeated his prediction from 2000 that a computer with the hardware to emulate a human brain would be available for $1,000 by the year 2020.[2]

Not only some economists but many citizens of Western countries have lost faith in the ability of industrial and academic elites to deliver the benefits of technological efficiency to either the middle class or the poor. Unless the trend reverses, politics around the world are likely to remain unsettled for years to come, no matter which parties hold power. So it is time to consider whether too much efficiency is part of the problem. I will suggest that we need not abandon the idea of efficiency but cultivate inefficient behavior that in the long run will make technology not only more effective (getting more done) but more efficient (doing it with fewer resources).

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First we need a definition of efficiency. Economists use the term technically in a way that I could not follow here

without making this a different book. I would define it as producing goods, providing services or information, or processing transactions with a minimum of waste. The word came into wide use in the nineteenth century, when scientists and engineers extended to human labor the physical idea of efficiency as useful work per unit of energy. Social scientists from the 1890s through the 1920s in turn expanded this sense to all inputs and outputs in society, and indeed to an ideal of "social efficiency," the rational optimization of human welfare. Innocent as the phrase sounds today, at the turn of the century it was rooted as much in racism and xenophobia as in technological idealism. Its prophet, the sociologist Edward A. Ross, was forced to leave Stanford University for his anti-Asian pronouncements in 1900. In his book *Social Control*, published the following year, he combined admiration for "the restless, striving, doing Aryan, with his personal ambition, his lust for power, his longing to wreak [*sic*] himself, his willingness to turn the world upside down to get the fame, or the fortune or the woman he wants," with fear that this Faustian individualism would ruin society if left unchecked. As a nativist progressive, Ross looked to the schools to use the methods of industrial work rationalization to indoctrinate a new generation in the ethics of good government. That ideology of efficiency has long vanished, but the goal of achieving more with less effort still thrives. I would apply the word "efficiency" to all technology intended to reduce human time needed for a task, whether buying a product, learning a subject, planning a trip, or making a medical decision. The economist Robert Solow remarked over thirty years ago, in 1987, that computers had become ubiquitous everywhere but in productivity statistics; today we see the benefits of algorithmic efficiency everywhere except in real personal income statistics.[3]

I take no position on the future, whether we are doomed to stasis and growing inequality or whether some new superefficient technology will make today's concerns seem like the pessimism of many economists of the 1930s, when in reality the technological foundations of the postwar boom were laid in antibiotics, detergents, plastics, and ultimately personal computing itself. If any generalization is possible about technological forecasting, it is that many of the projected revolutions are stillborn, while other, often originally more obscure innovations transform society. Science fiction is no exception. Jules Verne's publisher considered his most accurate vision of the future, *Paris in the Twentieth Century*, unbelievable; Verne agreed, and it was not issued until the 1990s.[4]

There are many other caveats regarding efficiency that are not part of this book because others have noted them so ably. One is environmental. Conservative and libertarian economists questioning mandatory energy efficiency targets cite what is called a "rebound effect," in which the savings from a more efficient technology are offset or even completely annulled by increased consumption. This pattern was first noticed in British coal consumption in the 1860s by the economist William Stanley Jevons, and has reappeared with each new energy-saving innovation. Reduced energy costs often have led to purchase of sport utility vehicles and McMansions. More efficient air-conditioning technology has meant that units are installed in more rooms, or replaced by central whole-house air-conditioning systems. This effect is far from an iron law; even one of its leading proponents, Robert J. Michaels, acknowledges that mandatory efficiency standards for refrigerators have created no apparent rebound. But there is no doubt the effect is real. And the efficiency of technology from LED lighting to electric cars is also offset by environmental damage from rare earth

mining to electronic waste.[5]

Next after energy are critiques of agricultural efficiency, usually from the left. In output per farmer and farm employer, mechanized conventional agriculture has been outstanding. Yet Swedish agricultural scientists, painstakingly adding up energy inputs and outputs, recently were able to show that a tractor needs 67 percent more energy than the feed required for a draft horse tilling the same field. The tractor is far more *effective* than the horse; it will produce almost two and a half times the food from the same area that the animal's ancestor did in the 1920s, but it needs thirteen times as much energy. And there are other objections to our conventional agriculture. Efficiency of breeding plants and animals for rapid harvesting and slaughter, respectively, has often damaged nutritional value and taste. Only recently has the heirloom tomato begun to make a comeback. Pigs and chickens raised for efficient production may suffer health problems; bovine growth hormone, while "natural" and safe for human consumption, induces a level of milk production that can be painful to cows. And the quest for efficiency can encourage a potentially disastrous monoculture, such as the lumper potato that dominated pre-Famine Irish agriculture. Since almost all potatoes in Ireland and much of the rest of Europe were genetically identical, a blight originating in the New World devastated the 1845 harvest. "Monoculture," as the writer Michael Pollan put it in *The Botany of Desire*, "is where the logic of nature collides with the logic of economics; which logic will ultimately prevail can never be in doubt."[6]

On a global level, true efficiency has always been difficult to calculate, especially since some means to efficiency (fertilizers and pesticides) can reduce the earth's overall productivity (by harming fish in runoff, and by endangering pollinators, respectively). In fact, our entire

industrial civilization has been threatening its own efficiency through carbon emissions. If "efficiency" is defined broadly, a book on its paradoxes would become a study of everything. It would be returning to ecological economics of the Romanian American scholar Nicholas Georgescu-Roegen, who saw the decline of order in the world—the increase of entropy—as the inevitable consequence of human attempts to defy it. Climate change has helped to revive interest in Georgescu's ideas, but I leave assessments of their validity to others.

Even Silicon Valley culture, which rejects such theoretical limits and tends to regard space exploration as the solution to all earthly resource constraints, recognizes the environmental, health, cultural, and ethical costs of too much efficiency. For all their smart houses, web-connected appliances, and self-monitoring devices, the acolytes of efficiency know how to draw the line. From organic heirloom produce to (as we will see in Chapter Three) technology-free Rudolf Steiner elementary schools, the fruits of artisanal values attract many otherwise high-tech families. Inefficiency in the form of labor-intensive goods and services has a place in their society, as a signifier of authenticity and privilege. This new upper stratum seems to have little in common with the robber baron society described by Thorstein Veblen in his 1899 tract, *The Theory of the Leisure Class*. The patriarchal and often racist values of the Gilded Age plutocracy may not have vanished entirely, but they are considered worse than immoral now; they are unfashionable. So is the old ideal of cultivated ease as embodied in palaces like the Frick Collection and the Morgan Library, a pose already obsolete as early as 1970, when the economist Staffan Linder published his pathbreaking *The Harried Leisure Class*. Today's technology multimillionaires are more likely to be scouting for the next start-up than to be enjoying the cash

from their last venture in early retirement. Yet as in Veblen's day, ostentatious inefficiency has its privileges. As the technology journalist Dave Rosenberg noted in 2013 on the *San Francisco Chronicle* website: "Luxury goods, especially watches…are part of a subtle push in Silicon Valley toward 'quality crafted' tools, clothing and accessories….While the general population looks forward to the latest in futuristic status symbols, tech's futurists are going retro." The same can be said of other labor-intensive tools such as hand-forged chef's knives.[7]

The private traditionalism of technologists may be seen as admirable pragmatism and open-mindedness, and a force for more employment amid growing automation. It can also be seen as a cynical endorsement of a two-tier society: mediocrity for the masses, luxurious heritage for creative innovators. (There have always been extremes, but the market for good middle-range products has declined. There is room for Bloomingdale's and Walmart, but the classic middle-class department store, Gimbel's, closed its doors in 1986 and its former rivals are struggling.) This points up yet another criticism of technological efficiency, a tendency (according to some economists) to amplify inequality and thus to endanger civic life and even democracy itself. Arthur M. Okun's *Equality and Efficiency: The Big Tradeoff* is still debated among economists forty years after its publication and was reissued by the Brookings Institution in 2015. It's possible to imagine a society that is both highly efficient and unstable. The Silicon Valley cult of disruption may have originally suggested turning power from oligarchs to the people. But now it can also mean the creation of a new oligarchy that appears even harder to dislodge. In Silicon Valley itself, the increase in house prices and apartment rent has borne out the analysis of the economist Fred Hirsch, who in the 1970s foresaw that even if efficiency

and productivity continued to rise, there was a "positional economy" of goods that could never, like information technology products, become affordable to the masses, like good tickets to a hit play, or apartments in global economic hubs, both of which are what Hirsch called "positional goods."[8]

Even so, the rising importance of and frustration engendered by positional goods is not, I believe, the best argument against efficiency. Technological enthusiasts have countered that even if the gap grows and billionaires capture more of the world's output, the planet's people are still better off, and might not be if there were no incentive to take risks and fail, as most ventures do. Silicon Valley depends on an inefficient and wasteful start-up culture to create a more efficient society in the end, in this view.

Electronic efficiency has more serious problems. On a technical level, there is still no answer to the challenge of security and the threat of hacking. If fear of electronic transactions reaches a critical level, there may yet be a backlash against web commerce, but so far it has been so profitable for banks and credit card companies that they have been able to absorb at least some varieties of fraud as a cost of doing business. Likewise, the 1990s dream of participatory democracy has at least been stalled by fringe groups' ability to use websites and social media, but defenders of electronic democracy can always point to promising new initiatives. The technology critic Evgeny Morozov rightly observes that inefficiency can be good if it results from "deliberative commitment by a democratically run community" taking a stand against "the inhumanity of Taylorism [regimentation of work methods] and market fundamentalism." But that does not prevent market fundamentalists from securing *democratic* consent for hyperefficiency. Likewise, algorithms can both intentionally and unintentionally discriminate against

individuals by gender, race, geography, or socioeconomic status—but defenders can reply that offending programs can be made fairer and thus even more efficient. Algorithms and the staggering data they gather on our spending, travel, investments, credit, and political views (or at least those of our friends) threaten the privacy of Americans every day, and some people have begun opting out of online life, but so far there has not been enough damage from either identity theft or intrusive marketing to change Americans' behavior radically.[9]

Yet another critique of the efficiency of mobile technology aims at its damage to human relationships, whether commercial or personal. But Americans at least have always been unsentimental about the first, forsaking local merchants for big box retailers even before the rise of electronic commerce. And while many people, especially parents of young children and teenagers, have reservations about the effects of social media on concentration and human relationships, abrasiveness remains a feature rather than a bug in much of Silicon Valley culture.[10]

To the enthusiasts of efficiency, in and out of Silicon Valley, such objections are only temporary issues for technical resolution in the next round of algorithms. Mass unemployment from robotics is still only a disputed hypothesis, and robotics advocates can point to the failure of previous doomsaying. Efficiency remains a core American value, and while Silicon Valley billionaires now face more skeptical scrutiny, they have not lost their mantle of being successors of Thomas Edison, John D. Rockefeller, and Henry Ford as builders of American culture. Steve Jobs, ruthless like all of them at times, still was widely mourned by millions who believed he had enhanced their lives.

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This book offers a different critique of technological efficiency, one that accepts the goal of reducing waste in the use of human time and natural resources, but recognizes that a single-minded drive for a "friction-free" world, as Bill Gates and his coauthors put it in 1995, can actually reduce efficiency. Instead of examining all the social, political, and ethical challenges of information technology, it focuses on its long-term self-subversion. We know that the obsession with childhood hygiene, so popular since the early twentieth century, can weaken the immune system. We know that overprescription of antibiotics can foster superbugs, that liberal use of opioids can reduce their effectiveness and encourage addiction, and that habitual reliance on sleeping pills can worsen insomnia. Few of us renounce medicine or pharmaceuticals, but we have a new respect for natural equilibria.

Questioning efficiency must now go beyond the familiar distinction between efficiency and effectiveness. War is extremely inefficient when the number of bullets or shells needed to defeat the enemy is considered, but since defeat can be catastrophic, all that inefficiency can be effective. Conversely, "clean diesel" automotive engines are highly efficient in fuel consumption, but because their emissions are difficult to control, they can no longer be considered effective. Algorithms—the programming techniques that multiply the power of computer hardware—present a different set of problems. Most of the time they are highly effective as well as efficient. For example, public key cryptography takes advantage of the difficulty of factoring very large numbers to make electronic financial transactions secure and Internet communications generally secure, despite many successful attacks. But other algorithms may risk not only effectiveness but efficiency itself in the long run. That is, they can lead not

just to undesirable consequences but to wasted efforts and missed opportunities. They fall into seven groups:

COUNTERSERENDIPITY. Most chance events are adverse or neutral. Efficiency makes the world more predictable. But if everything is as direct as possible, we are also deprived of the benefits of occasional randomization and of productive mistakes. Conventional algorithms reduce negative surprises at the high price of threatening positive ones. The two are inseparable.

HYPERFOCUS. Efficiency is often expressed as focus, which up to a point is excellent and necessary. But evolution has given us and other animals a second kind of sight, peripheral vision, which is less sensitive to details but allows us to see large patterns and motion. Early in the history of astronomy it was understood that faint objects could be seen better by looking slightly away, "averted vision." As Edgar Allan Poe wrote in "The Murders in the Rue Morgue": "To look at a star by glances—to view it in a side-long way, by turning toward it the exterior portions of the retina (more susceptible of feeble impressions of light than the interior), is to behold the star distinctly." Efficiency, indispensable in everyday operations, makes it harder to pull back for the big picture.

SELF-AMPLIFYING CASCADES. Intentionally or not, algorithms may fail to select the most optimal choice by amplifying initially small effects. Their early decisions can become self-fulfilling prophecies. This is a special risk in automated processes, from financial trading to self-driving vehicles, in which multiple algorithms, none of which can be flawless, are turned loose to interact, sometimes without the possibility of quick human intervention.

SKILL EROSION. Automated systems perform most tasks better than most people, most of the time. They are nearly always more efficient and consistent, which is why they have been so popular. And rightly so. The partnership of a

skilled person and an electronic system in principle delivers better performance than either alone. But there can be severe problems when the robotic partner fails. If the human—whether physician, airline pilot, or everyday motorist—has not maintained skills, the result can be catastrophic for the efficiency of the whole system.

PERVERSE FEEDBACK. The interaction of automated systems becomes even more problematic when they are called upon not only to execute human goals but to provide incentives. It's possible to satisfy a criterion (like a test score) through means that frustrate the real desired outcome (actual understanding). In social science this is known as Campbell's Law.

DATA DELUGE. Huge data sets, when used by skilled people with a deep understanding of underlying processes, may increase efficiency. But their use can also threaten efficiency itself. The volume of automatically acquired data in many fields is increasing more rapidly than the per-terabyte cost of storage, increasing expenses. Big data can also suggest false positives and erroneous hypotheses that take expensive person-hours to evaluate and rule out, leading (especially in health care) to alarm and alert fatigue. The net result may be less real efficiency.

MONOCULTURE. Without careful design, an algorithm can multiply a successful formula to the point that a system becomes less responsive to changing circumstances. Social psychologists acknowledge, for example, that some of their experiments cannot be replicated, not because of any error in the original design, analysis, or data collection but because societies and their values change. Life scientists' mice are genetically standardized, but people live in a constantly evolving technological environment and adjust their behavior constantly and often unconsciously.

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To write about information technology is to shoot at a target that appears to be not only moving but accelerating. And one of the greatest challenges is that there are so many other books addressing the same issues. As I'll suggest in Chapter Two, far from killing the publication of printed books, network technology has helped strengthen them. One of the favorite topics on the web is the web itself; in May 2017, a Wikipedia category article listed forty-nine pages of books about the Internet, and a number of major new works had not yet been included. Amazon.com listed over 24,000 books on "Internet & Social Media" alone. It is a striking illustration of the information abundance that will be discussed in that chapter.[11]

While many of these books are technical monographs or college texts, and others are reports on primary research on economic and social statistics, databases, or experiments with human subjects, others (like this one) are interpretations. There are so many that overlapping studies citing similar evidence may appear in the same season; parallel ideas and mutual influence are inevitable. This crowding is hardly new. Literary theorists have long expounded on intertextuality, while as early as 1898 the fiction writer Arnold Bennett, in his autobiographical novel *A Man from the North*, more vividly portrayed the majestic British Museum round reading room as a "cannibal feast of the living upon the dead" served by attendants off rolling book trucks.[12]

So it seems to be almost 125 years later. I thus should situate this book. It is obviously not in the cornucopian genre of Kevin Kelly's *What Technology Wants* or Ray Kurzweil's *The Singularity Is Near*. But technological optimism is, on balance, a blessing. Given the dismal

failure rate of innovation, even unrealistic hopes help raise money for potentially beneficial inventions. Hype can be good for society if not always for the average individual investor or consumer. At the other extreme are the works of technological Cassandras such as *Superintelligence*, by the Oxford philosopher Nick Bostrom. Joyful and fearful prophecies actually have much in common. They both foresee a transformed humanity and disagree only as to whether it will be paradise or inferno.[13]

The Efficiency Paradox is part of a great middle range by authors skeptical of technological utopianism but not necessarily alarmed by the likelihood of meltdown. A half dozen are especially worth discussing.

The most thoroughgoing nemesis of Silicon Valley is Evgeny Morozov, who combines polemical verve with impressive documentation. Morozov's early years in Soviet-era Belarus inform his rejection of planners' arrogance. Having grown up in an ideology-saturated society he has a keen eye for the cant of the Western information technology industry and its admirers as well. His book *To Save Everything, Click Here* is a critique of what he calls (adopting a concept from architecture critics) solutionism, the idea that human problems have purely technological remedies, a pursuit of efficiency that ignores serious social, political, and ethical consequences, and unjustifiably equates innovation with improvement. He might equally have called it neo-efficiency. "Inefficiency, ambiguity, and opacity—whether in politics or in everyday life—that the newly empowered geeks and solutionists are rallying against are not in any sense problematic," Morozov observes. "Quite the opposite: these vices are often virtues in disguise." In fact, he argues against the very existence of "the Internet" as opposed to the agendas of powerful organizations exploiting networked resources. At the same time, he scoffs at what he considers futile

attempts by web critics like Eli Pariser (*The Filter Bubble*) and Ethan Zuckerman (*Rewire*) to promote their own progressive solutions. More efficient communication has not and will not resolve social, political, and ethical questions.[14]

In Morozov's terms I am probably a "technostructuralist," one less interested in the "direct, anticipated, and desirable consequences of innovation" and more interested in the "indirect, unanticipated, and undesirable ones." Yet I part ways with Morozov's "post-Internet" viewpoint and cite what sociologists call the Thomas Theorem, proposed by William Isaac and Dorothy Swaine Thomas. If people believe something is real, it becomes so in its consequences. To take a mundane example, false news about gasoline shortages sometimes creates real gasoline shortages as panicking drivers top up their fuel tanks more often. "The Internet," as opposed to the maneuverings of those who control influential websites, may be a myth, but if enough people accept (for example) the neutrality of Google and Facebook algorithms, it is a reality. Since web-based commerce and publishing won't go away, and since they have had positive as well as negative results, I believe in accepting this situation as a fact and finding new ways to blend the intuitive and algorithmic, the analog and the digital. That is obvious. To his credit, Morozov is not afraid of negativity, just as I am not afraid of obviousness. I recall the lecture-hall remark of one of my undergraduate teachers, the historian of science Charles C. Gillispie: "There is nothing more embarrassing to the educated mind than a true cliché."[15]

Like *To Save Everything*, Nicholas Carr's *The Glass Cage: How Our Computers Are Changing Us* identifies efficiency as the core of both its values and its strategy —"dogged, almost monomaniacal" in the case of Google. It

also correctly highlights the dangers of allowing overreliance on algorithms to erode human skills, a theme that Carr presented forcefully in his earlier book *The Shallows*. From similar facts and studies, this book draws different conclusions. Carr is a disillusioned information technologist; I am a historian by background. In the late 1970s and 1980s I found that first word processing and then electronic library resources helped me to return to a writing career that had been interrupted. Because I already had an excellent education in research, information technology turned out to be a multiplier. Pessimism about the effects of technology is a distraction from the real need for education and self-education on the best way to combine algorithms and intuition, digital and analog.[16]

The Glass Cage elaborates a point that I believe was first made by the technology curator James Blackaby, that we lose something when we shift from tool use (the premodern woodworker's shaving bench) to tool management (the workbench, a nineteenth-century innovation). Blackaby showed how the slide rule required engineers to be more directly involved in their calculations than did the electronic devices that replaced it decades ago —a point also made more recently by the engineer and historian of technology Henry Petroski. Without calling for a return to eighteenth-century agriculture, Carr praises the unity of body and tool in the operation of the scythe, citing a sonnet of Robert Frost. Carr is not alone. Hand mowing is a flourishing niche hobby. Thanks to modern search engines the would-be mower can choose scythes from Austria, Italy, Denmark, and Australia. He or she can also find other literary evocations of hand tools, like the Tolstoy-quoting *New York Times* op-ed piece "The Russian Peasant's Workout," which makes one want to find a meadow and swing away. Inspired by this style of human-tool relationship, Carr scorns Morozov's allegedly

simplistic idea of technology as a mere means to liberate us from toil. (Is that payback for Morozov's remark about Carr's "McLuhanesque medium-centrism"?) But I suspect it must have been much less satisfying to premodern peasants to be swinging (and sharpening) those blades for their livelihoods from dawn to dusk during harvest season than it was to more recent poets and novelists. Pieter Bruegel the Elder's paintings and prints, with their images of muscular prowess, fatigue, and thirst, are stylized but may also be more historically accurate. So I cannot agree that our age necessarily has more "aimlessness and gloom" than previous decades or centuries—or conversely find it one of joy and fulfillment just because it is easier to join a hand-mowing club. Instead, I agree with Norbert Wiener in believing that if properly used, information technology can spare us mind-numbing routine and free our time for more creative activity. There was an intimate relationship between tool, hand, and mind in the quill pen, and it may have enforced deliberate writing of so many literary classics, but I am glad I never needed to sharpen one.[17]

Cathy O'Neil's *Weapons of Math Destruction: How Big Data Increases Inequality and Threatens Democracy* offers another important caveat from an information technology professional; unlike most technology critics, O'Neil has been on the forefront of the systems that alarm her, the use of algorithms to target vulnerable people, whether in workplace "wellness" programs, in for-profit higher education sales, or in the justice system. The cynicism that she reveals makes her book the work on the ethics of big data and algorithms most widely reviewed online to date. But as in medicine, therapy is more challenging than diagnosis. Her proposal for audits of artificial intelligence systems raises questions. First, many other theorists and technical experts now believe that with machine learning, artificial intelligence can no longer be

understood in the way that the source code of conventional programs can be studied. It is not clear that even if the initial code is freely available online, the ultimate behavior of the program after assimilating vast quantities of new data is humanly understandable. If these specialists are right, rationality carried far enough creates a black box machine impenetrable to human reason and thus to auditing. Second, even if the software and its implicit biases are understandable, financial auditing is a discouraging precedent. Who can forget the collapse of Arthur Andersen following the Enron scandal, and the failure of other giant accounting and bond rating firms to question the practices leading to the 2008 recession? Seeking objectivity, judges protect forensic science and sentencing software from disclosure and effective challenge. In such cases, potentially biased algorithms may annul the right to confront witnesses and rebut government evidence.[18]

The legal scholar Frank Pasquale's *The Black Box Society* preceded *Weapons of Math Destruction* and remains the best account of the challenges facing legislators and regulators from the power of secret algorithms. Pasquale recommends the European approach to regulating big data, and I agree that we can learn from it. But well-intentioned privacy laws are a two-edged sword. The "right to be forgotten" enshrined in European Union legislation may have been motivated by a desire to remove the shadow of youthful indiscretions from search engine results. But laws protecting the powerless may also shield the privileged. The London *Daily Telegraph* published summaries of stories deleted after objections brought by their subjects, including a physician, a military officer, and a cleric involved in sexual abuse cases. Of course, press reports may be unfair or inaccurate, but erasing published information is an alarming precedent.

Pasquale's book and O'Neil's complement each other in demystifying Silicon Valley's claims. Their concern is with effects on society; O'Neil in particular is impressed with how well today's algorithms work, which makes them all the more dangerous. My own emphasis is on why the short-run efficiency of algorithms can impede rather than stimulate innovation.[19]

David Sax's *The Revenge of Analog* documents persuasively that older media and experiences, from chemical film to mechanical watches and retail stores, have been remarkably resilient, meeting human needs that digital life cannot fulfill. It's a vivid account of the continued relevance of tactile, concrete experience and of Silicon Valley's recognition of it, from the flourishing of Apple Stores since their introduction by Steve Jobs in 2001 to the revival of Moleskine notebooks. It is also one of the best expressions of the grounds for optimism about the coexistence of algorithms and human intuition, a theme that also underlies this book.[20]

But since the appearance of Apple Stores, clouds have returned to the horizon. For example, from the inauguration of the stores to spring 2017, employment in American department stores had shrunk by a third. There are still physical niche markets, but none of the historic major chains except Walmart has the resources to compete with Amazon; two great chains that had weathered over a century of recurring depressions and recessions, Sears and Macy's, were struggling in 2017. Amazon's own retail ventures are unlikely to match the tempting exhilaration of experimenting with rows of Apple devices, and of receiving personal support and repair service on the spot. New owners of Polaroid patents may have revived instant photography, and Kodak has announced it is bringing back Ektachrome color slide film, but Kodachrome is probably extinct forever. Production of 35mm motion picture film

continues, yet it depends tenuously on the leverage that a small number of star directors wield with studios and exhibitors.[21]

Messy, by the economist and writer Tim Harford, arrived in 2016 as a welcome corrective to a business self-help genre dominated ever since Benjamin Franklin by organization and system and admonitions to methodical habits. No wonder a transatlantic public weary of management jargon rejoiced at the idea of sweet disorder. It makes an excellent case that disorganization can be creative, even if it falls into a countergenre of its own, including Kathryn Schultz's *Being Wrong* and Harford's earlier volume *Adapt*. Yet like most other business gurus, Harford undervalues luck. Drawing on a study by the Nobel Laureate economist Paul Samuelson from the 1980s and on more recent research on rewards for investments and management, the finance economist Moshe Levy has argued that most of the superior returns attributed to talent can be explained by luck. Narratives of success like Harford's reflect survivorship bias, the use of striking examples without consideration of how many other people sharing the same traits, experiences, or strategies were unsuccessful. As on Wall Street, a style performing brilliantly in one market environment may be a flop in another. When contemplating Silicon Valley's big winners —Amazon's CEO Jeff Bezos is featured in *Messy*—we can retrospectively find brilliant strategies. Yet we also find potentially fatal crises.[22]

"Messy" behavior that wins contests may be maladaptive in power; Harford was bold enough to praise Donald Trump's improvised oratorical style, yet what made Trump a successful campaigner appeared to be failing to win broad approval in the first year of his presidency. Of course, Bill Clinton, another notoriously disorganized chief executive, was reelected, survived scandal and

impeachment, and is still remembered nostalgically by millions, so Harford may yet be right. Nevertheless, critics have also noted that messiness contributed to the mixed record of the Clinton presidency.[23]

At its best, *Messy* illustrates the principle the sociologist Charles Tilly called the Invisible Elbow, that apparently planned accomplishments are actually the products of a cascade of contingencies. But messiness falls short as a watchword. First, literal messiness is costly. There may not be a truly scientific estimate of the hours lost in looking for misplaced objects and documents—studies seem to be funded by companies selling solutions for tracking keys and business records—but most of us have found that messiness can take precious time from creativity. Second, at least one of the people Harford characterizes as messy, Charles Darwin, may have pursued multiple research projects at once. But Darwin was a careful and organized worker who ran his investigations as a family enterprise. In the Cambridge University natural history museum his labels are still highly regarded. Third, corporate management doesn't really believe in messiness for the great majority of employees. Conformity prevails. Efficient performance-monitoring software denies creative mistakes to most of the rank-and-file workforce, whether white- or blue-collar. Messiness may thus be just another status marker, a privilege of the post-leisure overclass. Elites, researchers have suggested, use nonconforming behavior like the Facebook CEO Mark Zuckerberg's hoodie to signal their immunity to the masses' norms, the so-called red sneakers effect. And no wonder, since Harford's employer, the London-based *Financial Times* newspaper, described its readership in May 2017 as "the world's most desirable audience, with the largest purchasing power and highest net worth." In other words, if you're not already in the one percent, don't try this at home.[24]

first chapter, is that it promotes what the originator of the concept of disruptive innovation, Clayton Christensen, calls business process innovation. It reduces transaction costs by matching buyers and sellers with automated software. The social benefits are real but limited; platform companies can promote competition and benefit consumers by holding inflation in check. The risks are also real and have been well documented by critics: loss of consumer privacy, sometimes unconscionable boilerplate in terms of service agreements (Ancestry.com's contract claims broad ownership rights to customers' DNA data), current oligopoly, and potential monopoly. Less commonly noted is another consequence of Wall Street's romance with platform-based efficiency. It has diverted capital and talent from riskier but ultimately more broadly beneficial market-creating innovation. Nineteenth-century continuous process innovations did not just reduce friction. In eliminating some jobs, they created many others, often more skilled and highly paid. Some economists believe that this phase of technology was a one-time event that will never be repeated. Yet there is reason to doubt any pronouncement about the future based on extrapolation from the recent record.[26]

The second chapter turns to the revolution made possible by the most powerful algorithm of all, Google's PageRank, and its roots in the analysis of influence and impact in the sciences. With the advent of the web and later of social media, this originally elitist technique was transformed for a populist environment. In journalism and the arts, far from promoting the "long tail" (the large number of works below the best-seller lists), a concept made famous by the former *Wired* editor Chris Anderson, it tends to multiply random initial advantages, a cascading effect. The rise of mobile computing, of social media, and of new and allegedly more precise advertising options has

simultaneously threatened the efficiency of much of journalism by taking resources from the producing of news and opinion to optimizing it for the algorithms of social media.

The third chapter considers the efficiency movement in education. The computerization movement in higher education is almost a century old, dating back to Thomas Edison's dream of replacing what he considered "two-percent-efficient" textbooks with 100 percent efficient classroom films. Yet while computers have made impressive progress in educating themselves, there is little evidence in either test scores or popular culture that computers have done much for mass literacy or numeracy. In fact, they have been increasing rather than reducing inequality by multiplying the advantages of an early start.

The fourth chapter examines the revolution in geography created by digital maps and geographic information systems (GIS). It frames this in the context of wayfinding, the skills used by men and women in the absence of compasses and even maps. We have grown much more precise but less sophisticated. The electronic map, especially when displayed on a small-screen mobile device, is extremely efficient in providing information about a particular place but much less so in putting it in a broader context, a hyperfocus effect. There are many times when the direct routing of a smartphone Global Positioning System (GPS) is exactly what is needed, when detours are out of the question. But the fastest route is not necessarily the most efficient way to get the most out of a journey. GPS may be more efficient than human wayfinding most of the time, but it can weaken one of humanity's most valuable skills.

The fifth chapter, on medicine, considers the obstacles to efficient medicine created by programs for medical efficiency. Laboratory automation is one of the

outstanding successes of computerization; the cost of sequencing a human genome is now within the reach of the middle class. The interpretation of genetic information has been much less straightforward so far. The electronic medical record once promised to relieve health care providers, especially physicians notorious for ambiguous handwriting, of many of the burdens of note taking. Instead, the need for both consistent and detailed medical records has increased the human burden, creating a new administrative specialty of code entry and a cottage industry of coaching providers on categorizing procedures for maximum fees: "upcoding." Even when it is working successfully, medical quantification will have limits because patients are not passive recipients of interventions. Their culture, values, and attitudes toward life and toward risk, and their relationships with doctors and other providers, can't be separated from outcomes. The ability of a professional to motivate healthier choices—an inefficient process of persuasion—often matters more than medications. Just as a book is a kind of place, just as a large-format map is more than the sum of its details but a territory that should be understood as a whole, so the patient's body and mind are a terrain, not just a set of notes and data points, helpful though those may be.[27]

The concluding chapter presents a heterodox view of efficiency and inefficiency. It is no surprise to psychologists that the extreme memory for details in which computerized knowledge excels can be detrimental to understanding. Drawing on the work of the sociologist Harry Collins in *Artificial Experts*, I will suggest that every human being has a vast store of tacit knowledge that could never be imparted to an artificial intelligence program in a lifetime. These intuitive understandings can inform our career decisions and purchases, our education, our experience of places, and our health. The consequence is

that more algorithms should be optimally inefficient, taking more time for deeper analysis (as some search engine researchers have advocated), and providing what-if advice rather than definitive answers.

Used unthinkingly, algorithms can be counterserendipitous, but they do not have to be so. Their real problem is a familiar one, going back to the earliest market research. Established patterns, verified scientifically, can be upended creatively in ways that the data could never have predicted. Market research once declared that Americans liked weak coffee; then came Starbucks. It is also true, of course, that unaided intuition has often failed. But findings of behavioral economics should not depress or intimidate us. Data analysis and tacit knowledge complement rather than oppose each other.[28]

Algorithms themselves need and are getting new approaches. The programming technique called fuzzy logic accepts the need for initially suboptimal solutions in exploring the world. Catherine D'Ignazio, who studied serendipitous computing as a researcher in the MIT Media Lab and developed an innovative news program, has found that major search and media companies have been trying to build more serendipity and information diversity into their services and recommendations, but it has not been easy. If more sophisticated and discerning algorithms are possible, it's likely they will originate in academic projects and start-ups rather than in the major platform companies. These initiatives, and the insight of a new generation into the mutually beneficial coexistence of digital and analog thinking, give me hope that technology —after financial crises and alarms of stagnation—can once again renew itself.[29]

1

FROM MILL TO PLATFORM

HOW THE NINETEENTH CENTURY REDEFINED EFFICIENCY AND THE TWENTY-FIRST HAS TRANSFORMED IT

We are living in a second age of efficiency. Journalists and entrepreneurs do not use that word as often as they used to. We'll see synonyms later. But never far from our minds is consciousness of the value of getting the greatest possible output from available inputs, whether increasing production or profits, or reducing time.

My claim that preoccupation with efficiency in the short term may harm efficiency in the long run risks being considered a heresy by some and a truism by others. I hope to show that it is an obvious proposition when one reflects on it. It is also obvious, as I shall suggest in succeeding chapters and in the Conclusion, that combining efficient algorithms with holistic analog understanding can produce far better results than using either strategy alone. But it is not always simple to defend the obvious. It is helpful to see efficiency as a concept that has developed over the past two hundred years or so, and as a set of practices that are much older. The idea of efficiency, as we shall see,

the platform corporation, so profitable for its investors so far (especially the early ones), has been such an underachiever. Enthusiasts will insist that major innovations commonly have troughs of disappointment; the best is yet to come. This is especially the viewpoint of Facebook and its founder, Mark Zuckerberg, who in early 2017 published a manifesto acknowledging mistakes and vowing to build better communities and a better planet with the help of Facebook's users. To many adversaries such promises have long been "silicon snake oil" and "future hype"—to quote the titles of 1990s and early 2000s books by disillusioned technologists. To critics on the left in particular, the new bosses are not so different from the old bosses, just equipped with state-of-the-art surveillance and manipulation in place of the goon squads of yore. Some wary journalists see an existential threat to their own profession in declarations like those of Zuckerberg. I am not sure any organization really has such power. I will suggest at the end of this chapter that the most serious unintended consequence of platform efficiency may be its opportunity cost, its claim on resources that would in the long run do more to promote real efficiency.[2]

One paradox of the movement for efficiency is that innovations that have promoted efficiency and rationality have arisen in spite of discouraging data, driven by intuition and emotion. That does not mean that gut feelings alone are a more reliable guide than data-based analysis, but only that data, and tools for analyzing it, never can take the place of the imagination in foreseeing future patterns of human behavior. Most such intuitions fail. The exceptions fill inspirational and business books. Venture investment has a high failure rate built into it. Yet out of the inefficient maelstrom emerged some of the world's most efficient technology.

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The history of efficiency should rightly start with nature itself. As biophysicists have discovered, DNA stores energy far more densely than the most advanced technological systems. The control of gene expression allows complex and robust organisms to develop with stunning speed. Tiny variations in the genomes of fruit flies can produce strikingly different behaviors. Evolution has been prodigiously successful in optimizing the flow of information. Leveraging limited resources is our biological heritage.[3]

The quest for efficiency seems to be built into human biology as well, as revealed by anthropological and archaeological evidence. There have been tens of thousands of years of innovations in tool making that sometimes reached dead ends but occasionally produced masterpieces of functionality. Think of the Australian Aborigines' boomerang, or the Central Asian steppe nomads' composite bow. Is any cutting tool more efficient than traditionally forged Japanese blades, or sharper than the obsidian knives flaked expertly by pre-Columbian Native Americans?

Turning to the West, many ancient Roman medical instruments were so well adapted to their purpose that similar ones are used today, and their quality was not surpassed until modern times. Roman troops were famous for their ability to assemble bridges and fortifications with a speed that dazzled their adversaries. There was even a kind of mass production of oil lamps, stamped and marketed with early trademarks.[4]

Recent archaeology has revealed more dynamism and technological innovation in the ancient world than historians of fifty years ago acknowledged. The slave economy, for example, did not rule out labor-saving

machines like water wheels, just as steam engines were used on slavery-era sugar plantations in the early nineteenth century. There was a great deal of efficiency in practice. But the concept of efficiency as we know it had no clear place in ancient life. The ancient Greeks and Romans (and other Mediterranean and Near Eastern societies, including Egypt), had administrative and recordkeeping systems that worked for centuries. But they had no doctrine of systematic improvement of output. The classical historian Peter Thonemann has underlined that Roman society in particular was based on principles of patronage, loyalty, and obligation. There was no theory of wages, interest, or productivity. Prestige was often more important than functionality. Books were written and read as rolls that were stored together in chests. Writing was *scriptura continua*, no space between words, which space would have increased papyrus and parchment use slightly but made reading and education far easier. The difficulties of reading—manipulating the scroll, looking ahead to determine word breaks—were part of the performance skills of an educated person. That kind of inefficiency was a feature, not a bug in today's terms.[5]

Europe of the Middle Ages and the early modern era was a time of growing practical efficiency—but also without an underlying theory. The black letter handwriting that seems so quaint and old-fashioned today was actually a relatively rapid and legible style of writing for those accustomed to it. The Romans had the optical knowledge and the glassblowing and metallurgical skills to make eyeglasses, but there was no market for them. Aging literate people had educated slaves to read to them. The Romans made excellent cloth presses (one of which survives at Herculaneum) and could cast bronze letters, but they felt no need for printing.[6]

By the eighteenth century, Denis Diderot's *Encyclopédie*

and its Scots imitator, the *Encyclopaedia Britannica*, summarized the knowledge and improvement in dozens of trades. In *The Wealth of Nations*, Adam Smith showed how the separation of the making of pins into distinct operations by specialists could multiply the number of pins each worker could make per day. There was an even finer division of labor in the manufacture of needles in medieval Persia.[7]

Still, Smith was an exceptional pioneer. The nineteenth- and twentieth-century sense of efficiency was not quite present. A nineteenth-century political economist, whether laissez-faire or socialist, would be deeply interested in measuring just how much more productive a pin workshop would be than a traditional one. Many products were still made according to artisanal tradition and style rather than after systematic study of customer needs. The French technology theorist Jacques Ellul has pointed out that the armorers who made swords for late medieval mercenaries each followed a craft tradition and decorative style without studying the ergonomics of combat. Every soldier had to adapt his fighting style to the instrument.[8]

No eighteenth-century figure was more celebrated than Benjamin Franklin for his union of practical ingenuity with investigations of scientific theory, despite or because of the limits of his formal education. The designs of Franklin and his contemporaries—he never patented his inventions and encouraged further adaptation—for fireplace linings significantly improved the efficiency of wasteful conventional fireplaces. But late-eighteenth-century inventors still had no scientific way to quantify savings in heat produced per unit of wood. Only in the mid-nineteenth century did thinkers like the brewer and scientist James Joule develop consistent units to measure heat production: the British thermal unit and the SI (metric) Joule.

The two inventions that introduced modern efficiency were the work of other geniuses of the early nineteenth century, now known mainly to specialists: the millwright Oliver Evans and the paper manufacturer Henry Fourdrinier. If we look at plates of Diderot's encyclopedia as edited by Charles Gillispie, many of the workshops were not so different from those of the ages of Leonardo da Vinci or Galileo. Masters, assisted by journeymen and apprentices, made each product, though Smith's principle of the division of labor was beginning to spread. Goods were still fashioned individually or in small batches.[9]

Oliver Evans was the founder of continuous process efficiency. He is less well known than Franklin, Eli Whitney, Samuel Morse, or Thomas Edison, but for two centuries he was at least as influential as any of these. As Siegfried Giedion wrote in his classic *Mechanization Takes Command*, before there was any real American industry, "a solitary and prophetic mind set about devising a system wherein mechanical conveyance from one operation to another might eliminate the labor of human hands." Grain was raised to the top of the mill by a chain of buckets and conveyed by gravity through each of the stages of milling with belts, screws, and other continuous conveyances. Individually these were not entirely new; some had existed since antiquity. The idea of an integrated system that processed raw materials and semifinished products was still a breathtaking step in efficiency. Evans's system seemed shaky and he lacked Franklin's persuasive powers, but in "the power of his vision," Giedion rightly concluded, "Oliver Evans' invention opens a new chapter in the history of mankind."[10]

The second of the landmarks of classic modern efficiency was the Fourdrinier paper mill. Ever since its introduction in China, and to this day in the production of Japanese artisanal papers like washi, paper was made

literature were shaped by continuous rotary methods. Giant Fourdrinier machines turned out the rolls of newsprint supplying the high-speed web-fed presses of newspaper barons like Joseph Pulitzer and William Randolph Hearst.[13]

Shopping and recreation were transformed. Department store customers entered and exited through revolving doors and changed floors with ingenious endless belts of stairs. And the West's great railroads, with their continuous circulation of vast tonnages of freight and millions of passengers, were the ultimate expression—and management challenge—of the mature industrial age. The ocean liners of the North Atlantic circulated according to reliable, fixed schedules, keeping to a wide band in each direction. Elite passengers came to expect a punctuality unheard-of in the centuries of sail. If the captain of the *Titanic* had slowed to a safe speed for avoiding sea ice as many subsequent writers and film directors have believed he should, the ship would have been over a day late and he would probably be remembered (if at all) by marine historians for timidity, not prudence.[14]

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While many of the inventors of the new processes rose from the shop floor, sometimes to great wealth, industrialists and the middle class alike were beginning to perceive that empirical skills were not enough. With continuous process efficiency arose a new set of values and a new lexicon that can be called the first efficiency movement. It motivated not only investors, bankers, and aspiring managers, but also members of the growing ranks of the professions. There was no single doctrine of industrial efficiency in the nineteenth and early twentieth centuries, but there was a firm set of assumptions.

The first was quantification. While it may not have mattered to Benjamin Franklin to measure the output of his stove versus that of conventional fireplaces, nineteenth-century elites shared a growing enthusiasm for measurement. New statistical techniques were making it possible to present and evaluate data for more precise decision making. The profession of accounting was essential to large enterprises, especially to public companies. The physicist and inventor William Thomson, Lord Kelvin, made the most famous declaration on this subject when he said in a popular lecture in 1883 that "when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind."[15]

Classic efficiency also depended on scale. While the left of the progressive movement feared monopoly, and independent producers and merchants claimed unfairness, left and right often agreed on the advantages of the big corporation for both consumers and workers. From the time of Andrew Carnegie's Edgar Thomson works in Braddock, Pennsylvania, in 1875, it was scale that permitted the installation of the most efficient and expensive new machinery, driving down prices to put pressure on competition. It was scale that let John D. Rockefeller monopolize petroleum distribution and refining and control, much of it even after the antitrust breakup of Standard Oil. And it was scale that made possible the earliest industrial robots; as early as 1921, inspired by the Ford assembly line, the A. O. Smith Co. of Milwaukee was selling a robotic machine capable of riveting ten thousand automobile frames each day.[16]

With scale came bureaucracy and professionalization. Even entrepreneurs who had learned on the job, like the

superstar telegraph operator Thomas Edison, realized they needed degreed engineers and scientists, and American universities obliged with new technical schools and courses. One empirical occupation after another was reorganized as a profession with schools, degrees, and journals endowed by dynasties like those of the Carnegies, Mellons, Rockefellers, Vanderbilts, and Guggenheims. An ideology of codes, examinations, and credentials spread to include not only medicine, law, and engineering, but new academic fields like librarianship, public accounting, journalism, and business administration. Even on the shop floor, new positions like tool room clerk were created to allow highly skilled workers to spend as much time as possible at their machines.[17]

With size, too, came the opportunity and responsibility for private planning. The efficient corporation was large enough not just to dominate its market but to shape future technology from within. General Electric, Du Pont, AT&T, IBM, and other giants were proud of their research laboratories. While Bell Labs is now famous mainly for its introduction of the transistor, no detail was too small for its research, down to linemen's leather belts and mechanics' oil cans. Even in the Great Depression, the Pennsylvania Railroad laboratories in Altoona tested supplies of everything from lightbulbs to dining-car grapefruit, according to an admiring two-part article in *Fortune* magazine in 1936, observing that it was "a nation bigger than Turkey or Uruguay. Corporately it behaves like a nation; it blankets the lives of a 100,000 citizens like a nation."[18]

The scale of great twentieth-century corporations also gave them advantages in the labor market, as described by the economist David Weil in his book *The Fissured Workplace*. The large national corporation was able not only to pay higher wages and offer better working