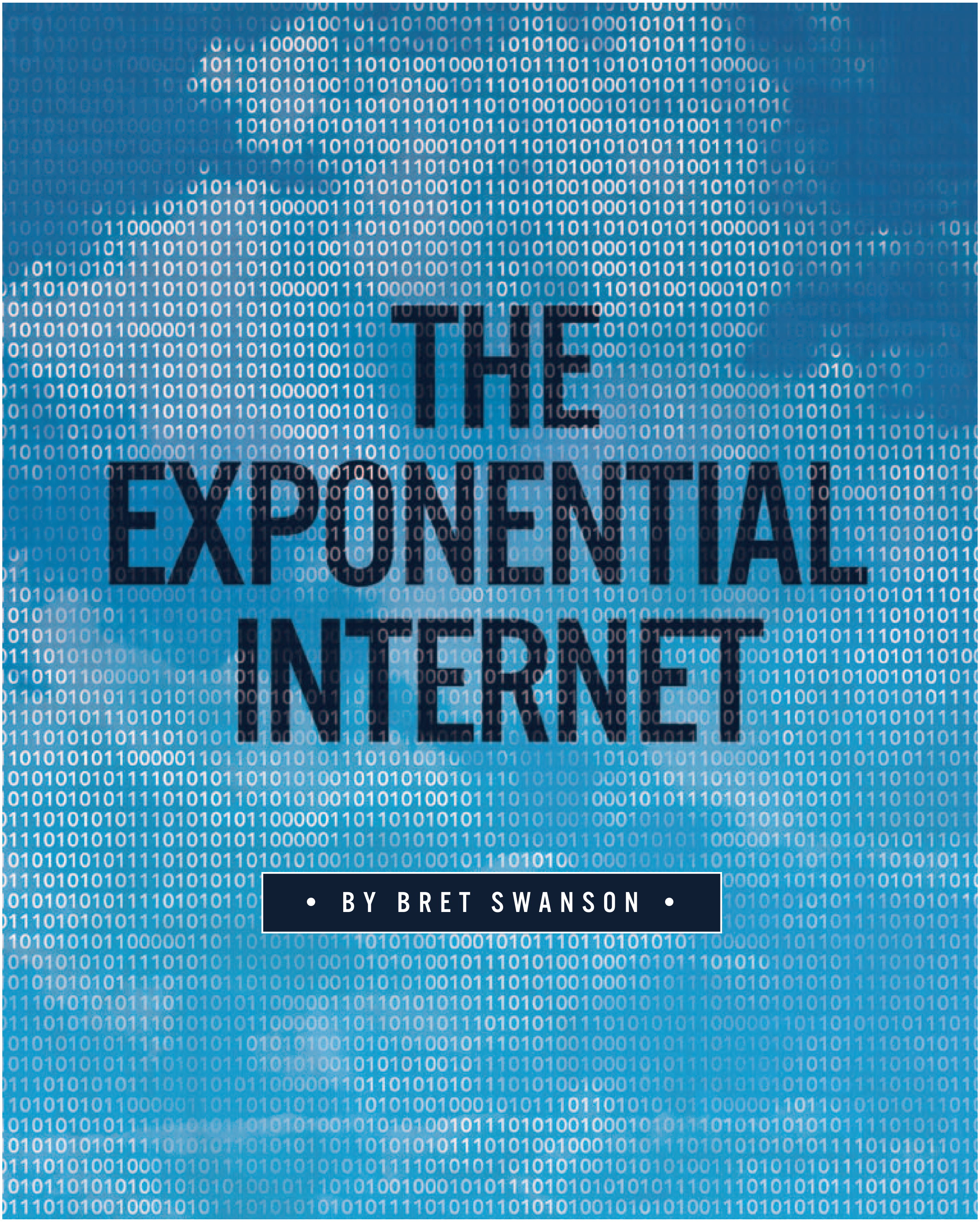


THE EXPONENTIAL INTERNET

• BY BRET SWANSON •

In October 1910, *The New York Times* published an analysis of a perplexing new question in transportation technology. The article's title was "Auto vs. Horse." The crucial inputs in this comparison were oil, gasoline, hay, and oats, and the output was passenger miles per dollar. What was its verdict? "Six-Day Test Shows Motor Car Cheaper and More Efficient Than Animal." At 1.57 cents per passenger mile versus 1.84 cents, the auto beat the equine – by a nose.

IN THE DIGITAL WORLD, THINGS CAN GET VERY BIG, VERY FAST.

If economic growth is a central objective in our American project, then technology is the engine that must power our way. The automobile was an engine of "the American Century." There is a great debate, however, about whether American innovation is as potent as it once was. A supplementary question is whether the technological advances we are making are creating jobs. The skeptics acknowledge one arena of substantial innovation is the Internet. One of the most thoughtful doubters, economist Tyler Cowen of George Mason University, however, thinks the Internet is mostly "cheap fun" that isn't driving job and income growth.

These are big questions with deep implications for economic policy. To get at some possible answers, it is helpful to step back and look at the recent history of information technology. Consider the world of two decades ago during, say, the administration of President George H.W. Bush. In 1990, there was no broadband, no Web, no digital mobile phones, and just 5 million analog cell phones. A terabyte drive, a device that can store one million megabytes – if such a thing had existed – would have cost $5 million. Today, a terabyte drive comes standard in most desktop computers or can be purchased on eBay for $69.99. The United States now has 84 million residential broadband links and 327 million mobile phone subscriptions. As it happens, Internet traffic in 1990 was about one terabyte per month. Today, Internet traffic in the United States alone is around 12 exabytes per month – a 12 million-fold rise. The Internet cloud is roiling old industries and creating new ones. Is it, however, creating broad and deep value for the U.S economy? We think it is, and some macro numbers tell us what is happening. U.S. info-tech investment in 2011 totaled $472 billion. Over the last several years, computers, communications networks, and software have accounted for between 42 percent and 47 percent of all of the nation's non-structure fixed investment. Since 1980, the nonresidential fixed investment share of GDP has doubled to more than 10 percent, and information technology accounted for all of the increase.

In the 1980s, there was confusion about why the new information technology didn't seem to boost productivity. Economist Robert Solow famously quipped: "You can see the computer age everywhere but in the productivity statistics."

Many studies since, however, have shown dramatic productivity and growth effects from information technology. As Harvard's Dale Jorgenson recently concluded, the digital sectors are America's most potent innovators, but their effects on other industries are even more important. "Replication of established technologies," Jorgenson and his colleagues found, "recently through massive investments in IT hardware and software, explains by far the largest proportion of U.S. economic growth."

Like the century-old analysis where the auto barely edged the horse in transportation efficiency, however, even these important insights from eminent economists don't tell the whole story. Based on empirical data, they are necessarily backward-looking. A difference of two-tenths of a cent between the auto and horse could not foretell the century ahead. Therefore, a more granular look at today's digital hypergrowth and some educated guesses about what comes next might be helpful.

> **"DATA IS THE NEW OIL."**
>
> – ANDREAS WEIGEND
> FORMER CHIEF SCIENTIST AT AMAZON.COM.

An overview of the Internet, mobile, "big data," and cloud sectors may (1) show just how important this industry is to the economy and jobs; (2) highlight the key policies needed to sustain growth in the sector; and (3) serve as an example of how technological innovation in other sectors might boost America's long-term growth rate and thus its cultural and fiscal health. The Unseen Internet Much of the world still thinks of Google as a "search" company – a firm with an algorithm that finds and parses information on the Web. We've long referred to Google instead as an Internet infrastructure company. Google reports that in 2010, its data centers consumed 2.26 terawatt-hours of power – that's two billion kW-hours. Thus, the opening of its newest digital warehouse in chilly Hamina, Finland, a $273-million facility meant to take advantage of the cold air and seawater to cool its servers. Facebook is building a similar data center in Luleå, Sweden. Data center pioneer Equinix operates six million square feet across 98 facilities. Globally, Internet data centers now consume around 2% of all electricity. The American digital economy more broadly considered may now account for 10% of electricity consumption. These massive data centers and ever-growing broadband webs power the new multimedia services that are disrupting and enlivening the aging broadcast worlds of TV and radio. Today, YouTube alone receives 48 hours of video uploads each minute, or eight years of content uploaded every day. It streams three billion videos per day and is now launching 100 new professionally produced high-definition (HD) channels.

Or consider Netflix, the successful DVD-through-the-mail movie distributor. Within just one month of introducing its streaming-only subscription plan in December 2010, Netflix streams jumped 38% to 200 million in January 2011. Netflix streams, according to Sandvine, may account for 32.7% of downstream traffic during peak evening hours in the United States.

MOBILE REVOLUTION

In the digital world, things can get very big, very fast.

The revolution in mobile is perhaps the best example of this powerful scale effect. At the end of 2011, there were six billion mobile subscriptions worldwide. For the first time, smartphone sales exceeded PC sales – 488 million versus 432 million. The United States surpassed the 100 percent penetration barrier – more wireless subscriptions (327.6 million) than people.

When we first started building 3G mobile networks in the mid-2000s, many thought it a silly and wasteful exercise. How would we ever use this capacity? Too much bandwidth at too much expense, and not nearly enough applications and services. Mobile device screens were thought too small and too lifeless to watch video, surf the Web, or read, not to mention play games or video chat. There were no mobile "apps" as we know them today.

Just a few short years later, a 2011 Credit Suisse survey of U.S. wireless carriers found their networks running at 80% capacity, meaning many network nodes are tapped out. The projected unusable abundance of 3G wireless capacity had, thanks to the iPhone and its smartphone cousins, turned into a severe shortage in many big cities. As of October 2011, 500,000 distinct Apple iOS apps had been downloaded 18 billion times on 250 million iOS devices. Google's competing Android OS marketplace of devices and apps is, by many measures, growing even faster and now powers some 52% of U.S. smartphones. This spring Apple passed the 25 billion download mark.

Ericsson and Cisco both estimate mobile data traffic grew 130 percent in 2011, reaching a level almost 200 times greater than 2007.

U.S. service providers invested $26 billion in wireless infrastructure in 2010, and again in 2011. For the decade 2001-10, U.S. wireless investment was $232 billion. Investments in 4G networks are now in full swing, and with its new multimedia capabilities, HTML5 (the first major upgrade of the Web's basic language since the mid-1990s) will bring much greater power and flexibility to the Web and mobile devices.

I, CLOUD

Hotmail, Yahoo! mail, and Gmail were early examples of mass-market applications hosted not on PCs or office servers but in the cloud. Consumer remote back-up providers like Mozy, Carbonite and Dropbox gained widespread adoption in recent years.

Salesforce.com revolutionized the customer relationship management (CRM) business with its cloud service. Moving a step beyond, Salesforce.com now serves as a sort of app store for the enterprise world.

The thousands of Web apps hosted in the cloud today are second nature. Cloud, like many big ideas, arrived with a bang but became a cliché rather quickly. Not for too much longer will we even think about "local" versus "cloud." Storage, bandwidth, and processing will increasingly be seamlessly integrated, making best use of the power of local devices and cloud resources.

Amazon is a key cloud computing platform for many smaller companies. Its Web Services (AWS) and Elastic Compute Cloud (EC2) allow Web companies and start-up developers to rent its mighty storage-compute-network infrastructure. "Each day," notes BusinessWeek, Amazon "adds enough computing muscle to power one whole Amazon.com circa 2000, when it was a $2.8 billion business."

Facebook's new Open Graph program will further transform the company from a social network into a cloud-based multimedia platform. IDC thinks cloud services could reach 5 zettabytes (or 1021 bytes) by 2020.

BIG DATA

"Data is the new oil," says Andreas Weigend, former chief scientist at Amazon.com. "Oil needs to be refined before it can be useful. Big data startups are the new refineries." From tick-marks on stone thousands of years ago to hand-written ledger entries in centuries past, data has been around for a while. Yet, the recent explosion in digital data – and our capacity to create, collect, store, transmit, massage, and analyze it – is something wholly new.

As recently as 2000, analog storage still trumped digital storage. All the same, a 2011 article published in the journal *Science* found that by 2007 analog storage had actually declined in absolute terms and digital storage had grown 15 times larger than analog (see Fig. 1). IDC estimates the world created or replicated 1,800 exabytes of data in 2011, up from 130 exabytes in 2005. It thinks we will approach almost 8,000 exabytes (8 zettabytes) by 2015.

Data has always driven financial markets. Yet, new data sources will increasingly drive other industries – medicine, retail, social networks, geo-location, sports, and sensor data from millions of cameras, machines, cars, planes, factories, weather stations, and network nodes.

The McKinsey Global Institute looked at Big Data from an economic perspective. It estimates intensive collection, analysis and implementation of fine-grained medical data will boost annual economic value in the U.S. health care sector by $300 billion. McKinsey thinks personal geolocation services could expand annual consumer surplus by $600 billion globally.

WHAT'S NEXT

The rise of multimedia content delivered over the Web is a fundamental departure from the early days of e-mail, data exchange and simple websites. A new set of hardware and software technologies will take us well beyond existing notions of Web video and cloud computing.

Firms like OnLive and Otoy are now bringing this new vision to life. Imagine a supercomputer built not of microprocessors (CPUs) but of thousands of graphics processors (GPUs). One of the world's most powerful supercomputers is IBM's Roadrunner at the Los Alamos National Laboratories, which runs at one-petaFLOPS (FLOPS is a basic unit of measure for a computer's performance, with one petaFLOP equaling 1015 FLOPS). With 1 percent of the space and for 3 percent of the cost, we can now build a graphics supercomputer that delivers three times Roadrunner's performance – three petaFLOPS.

Connect this computer to the Internet, and you can stream any real-time interactive 3D video experience at any resolution to thousands of people using any browser on any device, from a home-theater to an iPhone. This "exacloud"—cloud computing of a scope and scale never seen before—will transform video games, movies, virtual worlds, business software, and most other media. Casual users gain access to services previously based on expensive, proprietary devices and platforms. Based in the cloud instead of on your device, interactivity thrives.

Beyond gaming, the exacloud will likely accommodate remote rendering of numerous apps and displayed content. Companies like SolidWorks and Autodesk make powerful software that runs on big-horsepower hardware to assist engineers with sophisticated 3D design and modeling. If high-powered apps, such as AutoCAD, can be hosted in the cloud, a tiny fraction of one supercomputer can replace hundreds of expensive workstations or an enterprise cluster. Although the first to make use of the exacloud's power will be games and engineering apps that require intensive graphics processing, cloud streaming will expand its scope across a wide range of applications and content.

EXPONENTIAL TRAFFIC REQUIRES INVESTMENT

The proliferation of online video, mobile devices, Big Data and new cloud-based architectures continue to drive Internet traffic growth. More mobile devices, for example, mean more of us are spending more of our time generating and consuming data. Or take the aforementioned exacloud. UC-San Diego estimates that 55 percent of total American information consumption, or 1,991 exabytes per year, is (brace yourself) video games. If just 10 percent of these games moved online, they would generate twice the worldwide Internet traffic of 2008. Video is not always the most important content on the Web, but it defines the architecture and capacity of (and often pays for) the networks, data centers, and software that make all the Web's wonders possible.

The best estimates of U.S. Internet traffic show it continues to grow at a compound rate of around 50 percent, perhaps reaching 12 exabytes per month in 2011. This is a remarkable feat, something only possible in the digital world. It does not, however, come cheap. Economist Michael Mandel notes that of America's largest infrastructure investors, the top two (and three of the top seven) are network service providers – AT&T, Verizon, and Comcast. It will take additional large investments in broadband, wireless, and data centers both to accommodate fast growing services and to spur the next wave of innovation.

AN ECONOMIC ENGINE?

So, the Internet is growing very fast. The question is though, is it doing any good?   Many point to a recent New York Times exposé of Apple's Chinese manufacturing operations as evidence that the U.S. digital economy may create profits but not jobs. The Times argued that "almost none" of the 700,000 people who design and build the iPhone and iPad work in the U.S. "Steve Jobs designed great products," professor and columnist Paul Krugman agreed. "It's very, very hard to make the case that he created large numbers of jobs in this country."

Michael Mandel, however, quickly showed this view, like the "Auto vs. Horse" comparison, to be much too narrow. Mandel estimates that since the introduction of the iPhone in 2007, the "App Economy" – which did not previously exist – has created some 466,000 American jobs.

Economists Robert Shapiro and Kevin Hassett, meanwhile, found that advances in mobile technologies boosted employment by 400,000 per year from 2007 through 2011.

These analyses, in turn, are themselves just snapshots of subsectors of the digital economy and do not capture the ongoing effects across the economy. To the economic and technological pessimists, the best retort is often the one given by Henry Ford: "If I'd asked customers what they wanted, they would have told me a faster horse." Do we lament the automobile because of its effect on blacksmiths?

PUBLIC POLICY

For half a century, the United States has led the world in digital computer and communications technology. Scientists and entrepreneurs have built our digital economy through experimentation and rapid innovation, spurred by venture capital and enabled by large digital infrastructure projects. The entrepreneurship and investment that has sustained such fast growth for so long is due, in substantial part, to light-touch government policies (at least compared to other industries). There have been mistakes, but for the most part, scientists, entrepreneurs, and big investors have been allowed to build new things, try new products, challenge the status quo, cooperate, and compete. They have also been allowed to fail.

Today there is a real risk that governments are on a path to gradually reregulate our digital economy. From Net Neutrality and digital roaming mandates for wireless networks to new limits on "behavioral advertising" and clampdowns on privacy and piracy, a host of well-intentioned new laws aim to tame the Internet.

The FCC's recent Net Neutrality order is a potential break from the basic hands-off approach. Net Neutrality could prohibit important technologies used to manage data networks and substantially restrict the business models of network operators, content producers, and online service providers. It is now being challenged in the courts, however, and there is reason to believe a heavy-handed, hard-edged Neutrality regime will be avoided.

The digital ecosystem is ever-evolving. We build new software, hardware, and network components to provide new services and to relieve bottlenecks created by increased usage, made possible through previous abundance. Broadband enabled the rise of cloud computing, for example, and now the cloud demands ever faster and more widespread broadband. It's a never ending process.

In 2011, investment in U.S. fixed info-tech infrastructure totaled $472 billion (see Fig. 1). The broadband and mobile service providers alone invested around $65 billion.

Nevertheless, to run real-time apps from the cloud and to accommodate high-definition interactive video, we will need another decade's worth of broadband and wireless innovation and investment.

Mobile devices will increasingly rely on the cloud for content, computing, and storage. Video chat will be mostly mobile. These services will require much faster, more robust and more ubiquitous connectivity than exists today.

Today's crucial scarcity is thus wireless capacity. Part of this scarcity can be relieved through investment in new 4G networks and small-cells. A substantial portion of the scarcity, however, is due to a lack of available clean radio spectrum – the type of spectrum that can support 4G networks and the volumes and diversity of future traffic.

The Federal government, however, owns 61 percent of the best airwaves between 174 MHz and 4 GHz, while private mobile broadband providers control just 10 percent. Much of the remaining capacity in private hands is the old broadcast TV spectrum, which is trapped in a technology time capsule and is severely underutilized. Unleashing this spectrum through auctions and allowing greater flexibility to use, buy, and sell existing private spectrum is a paramount concern.

In February 2012, Congress approved auctions of part of this old, underused TV spectrum. Even in the best of

THE BYTE CHART

KILOBYTE (KB)	10^3	A paragraph of text. The first computer with randomly accessible electronic memory (MANIAC in 1948) had 5 KB of RAM. Today the graphical icon of one iPhone app is around 5 KB.
MEGABYTE (MB)	10^6	A 1989 Tandy PC had 2 MB, not even enough to store one 3-minute digital song.
GIGABYTE (GB)	10^9	An iPhone today has 64 GB of flash memory, which can store thousands of songs, photos, and videos. A DVD movie is about 10 GB.
TERABYTE (TB)	10^{12}	The monthly traffic across the Internet in 1990. Today our desktop PCs and many laptops each have terabyte drives inside. The Library of Congress contains around 40 TB of books.
PETABYTE (PB)	10^{15}	The monthly traffic across the Internet in 1996. Today Netflix alone streams around one PB of video each hour.
EXABYTE (EB)	10^{18}	The monthly traffic across the U.S. Internet in 2007. Equal to 50 million Blu-ray movies. YouTube may be approaching one EB of streamed video per month.
ZETTABYTE (ZB)	10^{21}	A thousand exabytes. All the information ever generated might total 100 ZB.

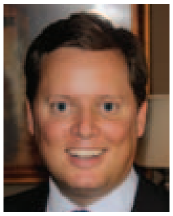
Figure 1

circumstances, however, these auctions take many years, and there is reason to believe the FCC could devalue the spectrum through overly intrusive mandates. The FCC would like to shape the industry by deciding who can bid on the spectrum, how much bidders can buy, and what business plans buyers may pursue. FCC Commissioner Robert McDowell warns against this path, blaming overly prescriptive rules for previous auction failures.

"When governments attempt to conduct social and economic engineering by foisting unnecessarily complicated mandates on the use of spectrum," McDowell told the 2012 Mobile World Congress in Barcelona, "their efforts frequently backfire."

Many of the regulatory proposals that could threaten America's digital success are justified by the widespread belief among the digital policy elite that the United States is a laggard in broadband. Yet, just the reverse is true. The United States generates more network traffic per Internet user (and per capita) than any nation, save South Korea (see Fig. 1).

The first rule of regulation of the digital economy should be humility. In such a fast-moving and healthy industry, the likelihood is low that complicated intrusions from top-down authorities will improve things. The biggest risks come not from digital innovation but well-meaning laws and rules that might slow innovation and diffusion of technology, and therefore growth across the economy. ■



NCF Fellow Bret Swanson is president of Entropy Economics, a research firm focused on technology and the global economy, and of Entropy Capital , a venture firm that invests in early-stage technology companies. Swanson is also a visiting fellow at Digital Society, serves as a "Broadband Ambassador" of the internet Innovation Alliance, and is a trustee of both Indiana State Teachers' and Public Employees' Retirement Funds. Bret Swanson writes a column for *Forbes* magazine and often contributes to the editorial page of *The Wall Street Journal*.