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ECONOMIC PERSPECTIVES

PROJECTING THE GROWTH AND ECONOMIC IMPACT OF THE INTERNET OF THINGS

Adam Thierer and Andrea Castillo

The next big wave of data-driven technological innovation will connect physical devices embedded with tiny computing devices to the Internet in an effort to seamlessly improve the measurements, communications, flexibility, and customization of our daily needs and activities. This "Internet of Things" (IoT) is already growing at a breakneck pace and is expected to continue to accelerate rapidly.

Adam Thierer of the Mercatus Center at George Mason University writes in a 2015 journal article that as is the case with any emerging technology, some groups have already started petitioning policymakers to limit or control IoT technologies out of fears of poor privacy or security outcomes. Policymakers are already investigating these issues. The Senate Committee on Commerce, Science, and Transportation recently held a hearing related to these issues, and in January the Federal Trade Commission (FTC) released a major report recommending a variety of privacy and security "best practices" for IoT. While some of these concerns are understandable, as Thierer writes in his 2014 book *Permissionless Innovation*, good public policy requires an appropriately weighted consideration of the projected benefits of any new development alongside the costs of regulatory interventions aimed at preemptively addressing perceived (and in some cases entirely hypothetical) fears.

In a testimony before the Senate Committee on Commerce, Science, and Transportation, Thierer highlighted that industry research groups have published several recent analyses that project the economic and social benefits of IoT technologies. While the methodologies, specific technologies analyzed, and final figures among these studies vary, they all indicate an industry consensus that the coming decades will be characterized by the introduction of billions of "smart" devices, millions of job opportunities, and trillions of dollars in economic growth and cost savings. The total number of connected devices in use globally—including such items as smart home appliances, "wearables," smart metering systems, and autonomous vehicles—is projected to grow from 10 billion in 2013 to anywhere from 19 billion to 40 billion

by 2019. The cost savings and productivity gains generated through "smart" device monitoring and adaptation are projected to create $1.1 trillion to $2.5 trillion in value in the health care sector, $2.3 trillion to $11.6 trillion in global manufacturing, and $500 billion to $757 billion in municipal energy and service provision over the next decade. The total global impact of IoT technologies could generate anywhere from $2.7 trillion to $14.4 trillion in value by 2025.

This summary provides a brief explanation of IoT technologies before describing the current projections of the economic and technological impacts that IoT could have on society. In addition to creating massive gains for consumers, IoT is projected to provide dramatic improvements in manufacturing, health care, energy, transportation, retail services, government, and general economic growth. Poorly considered policies should not prevent us from reaping these enormous benefits.

WHAT IS THE INTERNET OF THINGS?

IoT, sometimes called "machine-to-machine" (M2M) communication technologies, is a series of networked "smart devices" that are equipped with microchips, sensors, and wireless communications capabilities. The underlying drivers of the Internet revolution—massive increases in processing power, storage capacity, and networking capabilities; the miniaturization of chips and cameras; and the digitization of data and assembly of "big data" repositories—have dramatically lowered the costs of integrating microchips, sensors, cameras, and accelerometers into everyday devices. Existing technologies and tools can be cheaply integrated with the Internet to engage with external information and react according to preprogrammed commands. The major categories of IoT technologies include "smart" consumer technologies, wearables, "smart" manufacturing and infrastructure technologies, and unmanned transportation.

"Smart" Consumer Technologies

Consumer products will be designed with sensors and wireless capabilities to dynamically automate routine tasks. Mundane appliances that consumers have long taken for granted—like refrigerators, cooking devices, lights, and even weight scales—all will soon be networked, sensing, automated, and communicating as "smart" home technologies. Refrigerators are being designed to measure and record internal temperatures, monitor for bacteria or spoilage, and even keep track of food stocks to alert owners when supplies are running low—or just order a new delivery directly from the nearest grocery store's website. Thermostats can already learn and adjust to household behavior and program themselves to save money on heating and cooling bills. Networked consumer products are expected to provide dramatic economic benefits by lowering the costs of household drudgery through automation, freeing up time for more productive activities, and extending the use and life of household goods by improving maintenance.

Wearables

Wearables are a subset of consumer technologies that integrate networked devices into portable accessories like watches, jewelry, clothes, and glasses to collect data, track activities, and customize experiences to users' needs and desires. Wearable technologies are among the fastest-growing segment of the IoT and promise to have widespread societal influences in the coming years, particularly in the areas of personal safety and security, health, wellness, fitness, personal organization, communication, and fashion. Popular examples of wearables include fitness tracking and feedback products like Jawbone and FitBit that allow individuals to continuously measure and share daily fitness activities to isolate and improve their outcomes. Sophisticated wearable health devices will soon remind users to take medications or contact medical professionals as necessary and eventually help users track and even diagnose various conditions before advising a course of action. Other experiments with implantable "hearable" devices, "smart" contact lenses and glasses, and even tactile networked patches and fabrics seek to cheaply and seamlessly monitor other health vitals like blood glucose levels, blood pressure, brain activity, and stress. Dr. Eric Topol explains in his book *The Creative Destruction of Medicine* that these and other advances will improve preventative medicine and save billions of dollars in health care costs.

"Smart" Manufacturing and Infrastructure Technologies

While flashy IoT applications to consumer technologies understandably generate the most media buzz, networked devices perhaps hold the most promise to cut costs and raise efficiency in production, manufacturing, and even traditional municipal waste services.

In this age of "Industry 4.0," factory managers will create networks of connected production facilities along entire value chains that can autonomously communicate with each other and direct changes in response to unexpected developments. Devices will provide constant, accurate measurements of output, resource depletion, and capital depreciation to isolate sources of waste and maximize factor productivity. Smart infrastructure technologies can allow government planners to measure and monitor traffic management, waste and water services, and even police services to lower costs and improve services for citizens. The dramatic improvements to marginal production and cost reduction in manufacturing wrought by IoT technologies are projected to generate billions in revenue growth and productivity over the next decade.

Intelligent Vehicles and Unmanned Transportation

Adam Thierer and Ryan Hagemann of the Mercatus Center at George Mason University predict that networked vehicles and aircraft equipped with sensors, wireless communication, and dynamic programming will make unmanned transportation widely available and generate considerable benefits for consumers and manufacturing. "Autonomous vehicles" or "driverless cars" are automotive technologies that permit automobiles to operate without human assistance. Driverless cars are expected to dramatically reduce the number and costs of highway deaths and injuries while lowering the costs of shipping and transportation. Autonomous

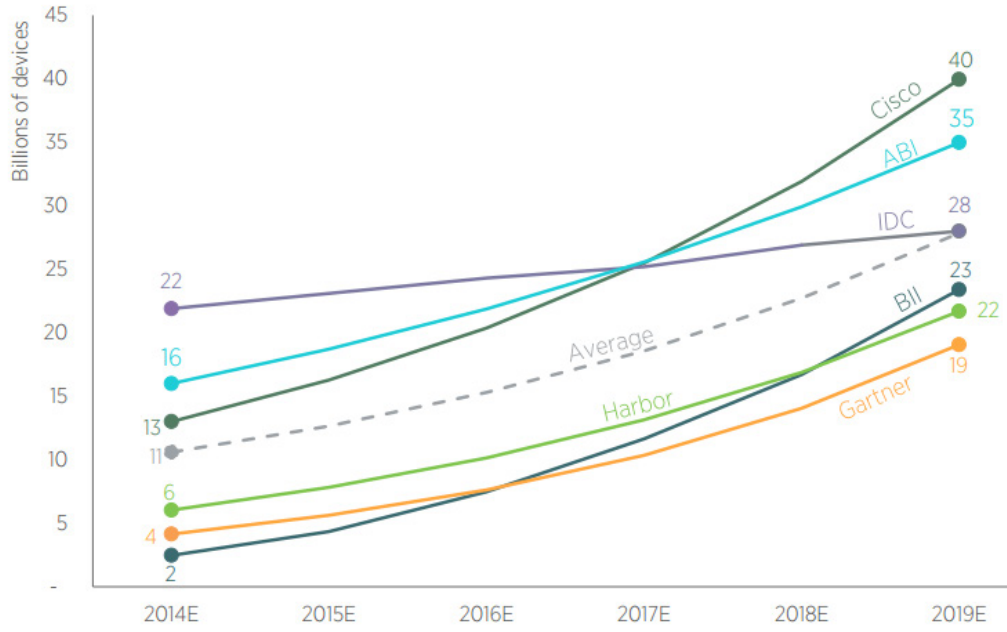
vehicles can also be used in manufacturing and warehouse capacities to improve speed and efficiency while lowering human injury and costs. Even short of fully autonomous systems, more "intelligent vehicle" technologies could produce significant social and economic benefits. On-board vehicle technologies are already an integral part of the expanding IoT universe. Experts at *Ars Technica* predict that "the automobile could be the first great wearable computer" and "your car might be the second most–used computing device you own before too long."

Jerry Brito, Eli Dourado, and Adam Thierer of the Mercatus Center at George Mason University explain that "Unmanned aerial vehicles" (UAVs) or "Unmanned Aircraft Systems" (UASs), informally known as "drones," employ similar networked concepts to automate aerial operations. UAVs will provide enormous productivity gains and cost savings in agricultural output, product delivery, and journalism and data gathering, as well as providing another exciting outlet as a good old-fashioned consumer hobby.

PROJECTED TECHNOLOGICAL ADVANCEMENTS

Industry analyses of market trends anticipate robust growth in the total number of networked devices in use over the next decades. An estimated 10 billion wirelessly connected devices were already in use globally in 2013, according to ABI Research analysts. Similar research from other organizations provides a wide range of estimates of the total number of IoT devices anticipated to be in operation by 2019, from a low of 19 billion to an optimistic projection of 40 billion devices. These and other projections are discussed in more detail below.

Figure 1. Industry Estimates of Total Internet of Things–Connected Devices by 2019



Source: John Greenough, "The Internet of Things is Rising: How the IoT Market Will Grow Across Sectors," *Business Insider Intelligence*, October 8, 2014. Produced by Adam Thierer and Andrea Castillo, Mercatus Center at George Mason University, 2015.

Cisco projects that 40 billion intelligent things will be connected and communicating by 2019.

ABI Research estimates that more than 35 billion networked devices will be in use by 2019.

International Data Corporation (IDC) predicts that around 28 billion networked devices will be in use by 2012 and that 212 billion devices will be connectable by 2020, 15 percent (around 31.8 billion) of which will be installed and operational by the end of 2020.

Gartner anticipates that 19 billion IoT devices will be in operation by 2019 and 25 billion devices will be online by 2020.

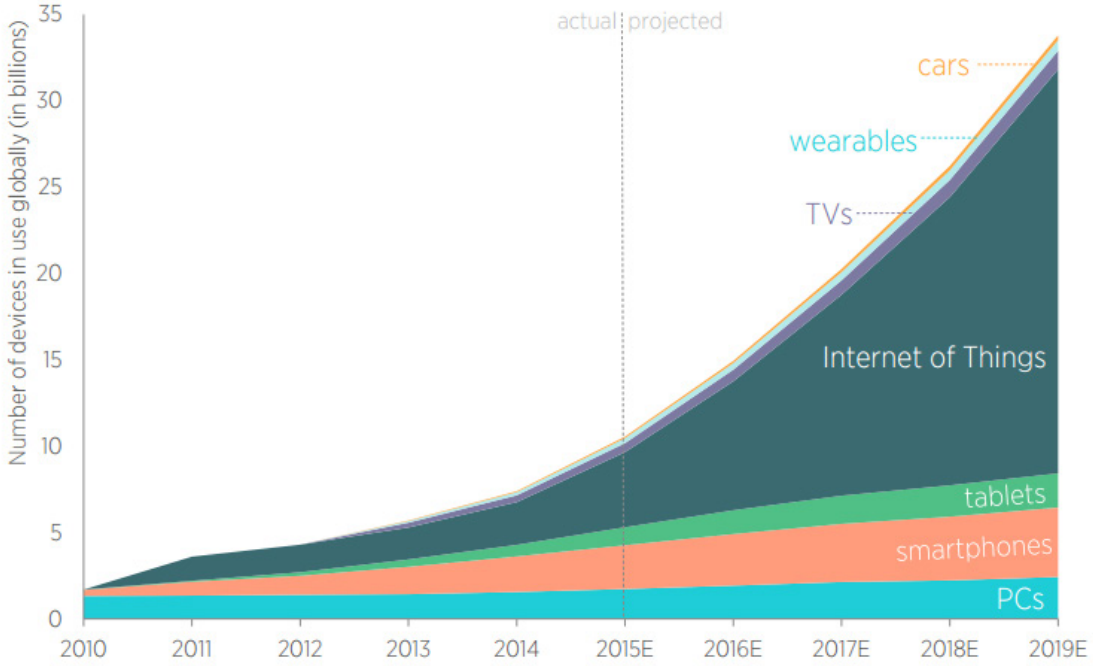
Harbor projects that 21.7 billion IoT devices will be connected and in use by 2019.

Machina Research reports that roughly 7.2 billion "machine-to-machine connected consumer electronic devices" will be in global use by 2023.

Business Insider Intelligence (BII) estimates that will be a total of 23.4 billion IoT devices connected by 2019 and that adoption will be driven by enterprise and manufacturing sectors.

Several analyses attempt to separate or isolate the total numbers within specific categories of IoT devices that will be connected over the next decade. Business Insider Intelligence provides historical and projected data on the number of installed IoT devices compared with PCs, smartphones, and tablets along with "smart" TVs, wearables, and "smart" cars (which are counted separately from IoT) from 2010 to 2019, which are displayed on the chart below. Growth in the number of installed IoT technologies is projected to exceed that of personal computers a factor of ten over the next four years, increasing from roughly 4.3 billion in 2015 to 23.4 billion by the end of 2019. Business Insider Intelligence anticipates that businesses will account for most of the growth in IoT-connected devices, projecting that almost 10 billion devices will be used in enterprise applications. "Smart" home, security, and energy devices will be another major consumer market and are projected to constitute almost 2 million of the total connected devices by 2019.

Figure 2. The Internet of Everything: Devices in Use Globally



Source: John Greenough, "The Internet of Everything 2015," *Business Insider Intelligence*. Produced by Adam Thierer and Andrea Castillo, Mercatus Center at George Mason University, 2015.

Other studies focus on specific market segments.

Navigant Research predicts that more than 1 billion smart meters will be installed globally by 2022, up from 313 million in 2013.

ON World projects that roughly 100 million Internet-connected wireless lights will be in operation by 2020.

Business Insider Intelligence projects that the annual number of wearables shipped will grow from 14.04 million in 2013 to 162.8 million in 2020, and that a total of 730.58 million wearable devices will be shipped throughout those years. Smartwatches are projected to lead the market, with 503.1 million devices projected to be shipped from 2013 to 2019, followed by fitness bands and activity trackers, projected at 168.9 million devices shipped, while another 58.54 million devices are projected to be shipped from remaining wearables markets. However, these projections were revised downwards from earlier BII projections anticipating shipments of more than 300 million devices by 2018 owing to persistent barriers to adoption and underwhelming market performance.

IDC analysts report that the global wearables market reached a total of 19.2 million devices in 2014 and project that the worldwide market will swell to 111.9 million networked devices sold in 2018.

The International Federation of Robotics reports that 806,000 connected industrial robots have been installed in manufacturing and shipping facilities and projects that roughly 2.6 million will be in operation by 2020.

The Teal Group estimates that the global civilian aerial drone market, worth roughly $10 million in 2013, will grow by over 2,000 percent to reach $2.2 billion in 2023.

IHS Automotive anticipates that the number of cars connected to the Internet will grow more than six fold from 2013 to reach 152 million internationally by 2020.

Industry projections present a vision of the future where billions of formerly dormant "things" actively sense, respond, and communicate with not only the people and environments but also other devices around them. The number of connected consumer devices—like wearables, TVs, and intelligent vehicles—will grow gradually but impressively. Smart appliances and climate control devices will become normal household objects in the coming decades. Networked manufacturing, production, and industrial delivery devices will largely drive the growth in the total number of IoT devices. We will now consider some of the economic benefits that will accompany these technological advancements.

PROJECTED ECONOMIC BENEFITS

The growth in the total number of IoT devices is projected to provide substantial economic and social benefits in the way of cost savings, value creation, productivity improvements, and general economic growth. Improved industrial monitoring and automation techniques will help manufacturers and distributors to quickly pinpoint inefficiencies, minimize waste, and streamline processes. Consumer health measurement technologies will help to promote preventative health practices and identify risk factors while emergency response communications can provide near-instant care in life-threatening situations. Hospitals can cut down on costs through accurate patient monitoring and pharmaceutical management. "Smart" city technologies can help municipalities to improve service delivery and save resources through infrastructure monitoring and automatic optimization. Recent analyses of IoT technologies project these and other savings and productivity gains in agriculture, security, energy, retail, and resource extraction will amount to trillions in value over the coming decades.

McKinsey Global Institute researchers estimate the potential economic impact of IoT technologies to be $2.7 trillion to $6.2 trillion per year by 2025, the largest of which will be felt in the manufacturing and health care industries. By sector, IoT is projected to create each year:

- $1.1 trillion to $2.5 trillion in value in the health care sector
- $0.9 trillion to $2.3 trillion in value in manufacturing
- $200 billion to $500 billion in value in electricity provision

- $100 billion to $300 billion in value in urban infrastructure
- $100 billion to $200 billion in value in security provision
- $100 billion to $200 billion in value in resource extraction
- around $100 billion in value in agriculture
- around $50 billion in value in vehicle use

Cisco analysts estimate that IoT will create $14.4 trillion in net profit between 2013 and 2022, which amounts to an increase in global corporate profits by roughly 21 percent. By sector, the "Value at Stake" generated by IoT is projected to be:

- $1.95 trillion for manufacturing through "smart factory" techniques
- $1.95 trillion for marketing and sales through location-based mobile advertising
- $757 billion for municipalities through "smart grid" technologies
- $635 billion for entertainment through connected gaming and media
- $349 billion for infrastructure through "smart building" technologies
- $347 billion for transportation through connected ground vehicles
- $106 billion from health care through connected patient monitoring
- $78 billion for education through connected private colleges

General Electric projects that industrial IoT technologies could add about $15 trillion to global GDP by 2030 (in constant 2005 dollars) if they raise global annual productivity growth by 0.5 to 1 percentage points. Additionally, an estimated $32.3 trillion in total global output can benefit from "Industrial Internet" technologies by optimizing information flows. The report estimates that the Industrial Internet opportunities of these sectors by 2025 will be:

- $11.6 trillion in manufacturing
- $7 trillion in health care
- $4.8 trillion in transportation

IDC estimated in 2013 that IoT market would grow at a compound annual growth rate of 7.9 percent to reach $8.9 trillion by 2020.

Business Insider estimates that IoT will add approximately $5.6 trillion in value to the global economy in between 2014 and 2019, $2.4 trillion of which will accrue to enterprise industry, $1.7 trillion of which will accrue to government and municipal services, and $1.5 trillion of which will accrue to home consumption.

Accenture estimates that the industrial IoT could add $14.2 trillion to the global economy by 2030, and that the US economy will gain at least $6.1 trillion in cumulative GDP by that year. If the US takes additional measures to employ IoT to improve domestic infrastructure, then Accenture projects that the gains to the US will rise to $7.1 trillion over that same time. Another survey assembled by Accenture finds that 87 percent of the executives surveyed believe that IoT will result in long-term job growth.

VisionMobile projects that the number of IoT developers will grow from roughly 300,000 in 2014 to more than 4.5 million by 2020.

Morgan Stanley forecasts that driverless cars will save the US economy $1.3 trillion per year once they fully penetrate the market, while saving the world another $5.6 trillion a year. Specifically, they predict:

- $507 billion in productivity gains
- $488 billion in prevented accident costs
- $158 billion in fuel cost savings
- $138 billion in productivity gains from congestion prevention
- $11 billion in fuel cost savings from congestion prevention

This growing body of research indicates that IoT will not just provide marginal consumer benefits and technological intrigue—it will change the industrial paradigm of the 21st century and can jump-start global economic productivity gains for decades to come.

CONCLUSION

Recent projections of the economic and social benefits of networked IoT technologies suggest that their technological and economic impact will be significant. These analyses predict that tens or even hundreds of millions of networked devices will proliferate globally as industrial and infrastructure inputs, consumer wearables, smart home technologies, and automated transportation services. The economic gains in terms of cost savings and enhanced productivity growth are projected to be enormous. Trillions in value will be created through cost-savings through preventative health care, minimized accidents, patient monitoring, efficiencies in manufacturing and distribution, and seamless home and municipal infrastructure improvements.

These potentially large economic gains must be considered when policymakers are debating policy for IoT. It is always easy to conjure up hypothetical worst-case scenarios about how some of these technologies may be misused, or how they might disrupt certain sectors and professions. But, as Thierer writes, if public policy is based upon fear of worst-case scenarios, then best-case scenarios will never come about. As economic historian Joel Mokyr has observed, "technological progress requires above all tolerance toward the unfamiliar and the eccentric." More generally, long-term social progress and economic prosperity hinge upon a general willingness to engage in ongoing trial-and-error experimentation with new technologies like IoT.

Policymakers should carefully weigh the costs associated with any proposed IoT regulations against the enormous projected benefits: both in the short term and long term. Smart technologies require smart regulations.

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