Atlantic Council
FutureScape

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STRATEGIC FORESIGHT INITIATIVE

Rising Robotics and the Third Industrial Revolution

Six years ago, Bill Gates created a buzz in the high tech community when he published an article in *Scientific American* suggesting robotics was becoming the next "new thing." Entitled "A Robot in Every Home,"[1] the Microsoft cofounder's essay argued presciently that the state of robotics paralleled that of the computer industry in the 1970s when it approached a tipping point, launching the PC revolution.

Just as Gates' own innovative software, Moore's Law (the exponential increase in processing capacity and lowering of the cost), and then the Internet spawned ubiquitous personal computers, several trends are converging to push robotics to a new level, becoming widely accessible to household consumers. Until now, the vast majority of industrial robots, more than 70 percent, have been used in auto assembly plants and more recently in electronics assembly. There have been no standards or software applications for wide use in robotics, as was the case for personal computers in the 1970s. Each industrial task robot—a device with three or more axes of motion (think hand, wrist, elbow) reprogrammable for different tasks—has had to be individually developed. (See the timeline on p. 4 for a brief history of the evolution of robots.)

Robotics is at an inflection point. The new era in robotics and automation that is beginning to unfold is part of the larger information and communication technology (ICT) revolution, steady improvements in artificial intelligence (AI), sensing technology, and the digital economy (is not an ATM a type of robot?). Indeed, robotics' rise is a byproduct of a transformation that has been dubbed the Third Industrial Revolution (the first was the application of steam power to production in the late eighteenth century, the second was the invention of the modern assembly

Emerging Technologies and Society

The Emerging Technologies and Society project is a collaboration between Singapore's Risk Assessment Horizon Scanning Programme Office (RPO) in the National Security Coordination Secretariat (NSCS) and the Atlantic Council Brent Scowcroft Center on International Security's Strategic Foresight Initiative (SFI). Initiated by RPO, the project focuses on the political, economic, and societal impacts of significant innovations arising from the science and technology fields. Through a series of meetings with leading researchers and private enterprises in the Silicon Valley, the project explores topics ranging from ubiquitous robotics and its impact on human capital developments, to algorithmic risk, quantum computing, and their challenges to national security.

Through horizon scanning efforts, RPO enhances policy making capabilities through engaging analysis, robust processes, and leading-edge systems. The SFI, which strives to forge greater cooperation on futures analysis among its main partners around the world, has rapidly become a hub for an expanding international community of strategic planners in government and the private sector.

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1 See Bill Gates, "A Robot in Every Home," *Scientific American*, January 2007.

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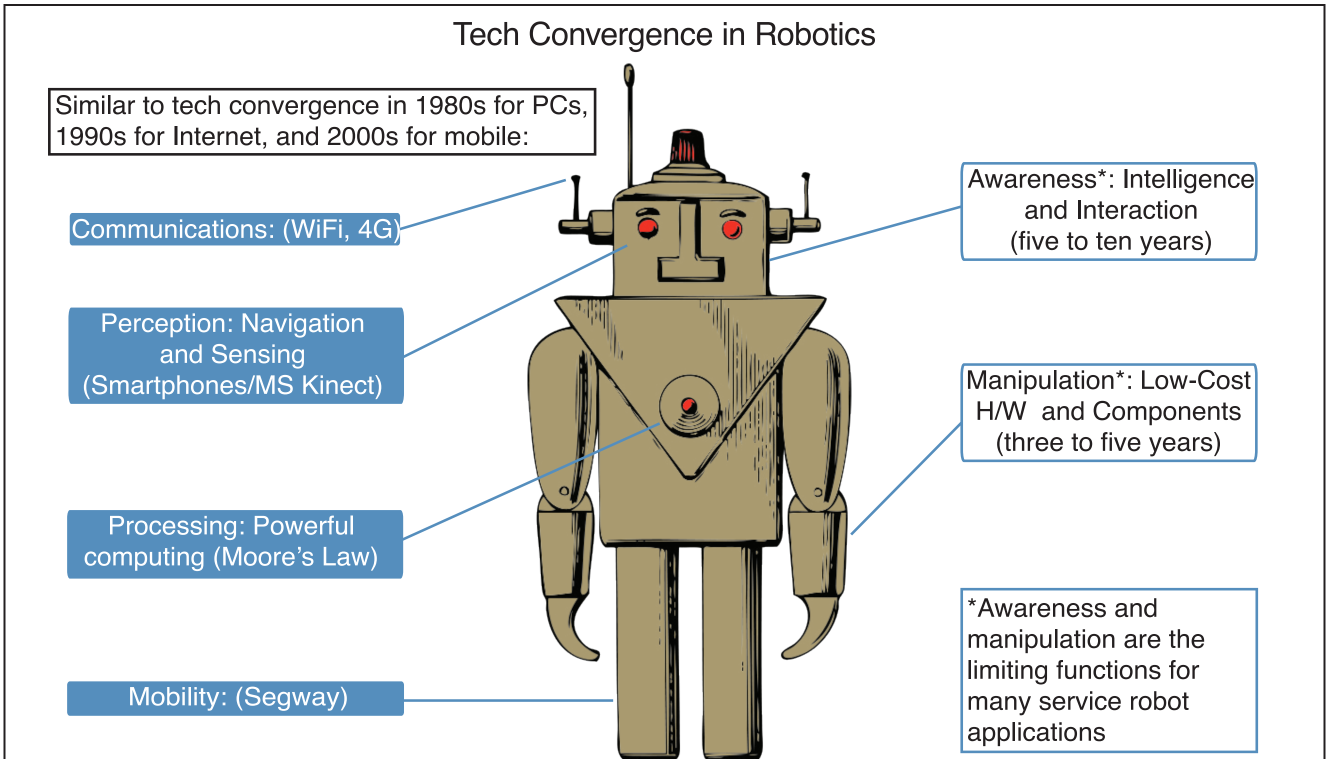


Based on concepts presented by Dr. Richard Mahoney, Director Robotics Programs at SRI International, to the Atlantic Council in April 2013.

line in the early twentieth century). The Third Industrial Revolution is the convergence and synergy of ICT, robotics and artificial intelligence, advanced manufacturing systems, 3D printing, nanotechnology, and big data into a highly networked, intelligent, and global knowledge-based economy. In terms of social and political impact, robotics should be viewed along with ICT and nanotechnology as an important economic enabler and a critical component of this historic technological transformation.

The Next Phase

The advance of robotics, like the US Shale Revolution, is the result of substantive R&D efforts of governments, businesses, and universities over the past two decades. In the United States, the Defense Advanced Research Projects Agency (DARPA) and NASA; in Japan, FANUC and government funding; in South Korea, the Ministry of Knowledge Economy and firms such as Samsung and LG; and in Europe, firms such as ABB and the European Network of Robotic Research (EURON) have driven investment for improvements in hardware (e.g. prehensile hand movements) and software. South Korea has invested $100 million annually since 2002 and Japan is investing $350 million over the next ten years into humanoid robots alone. The European Commission has invested $600 million into robotics and cognitive systems in its Sevent Framework Program, and plans $900 million for manufacturing and robotics in its Horizons 2020 program. DARPA, with a $2.8 billion annual budget, has driven much robotics innovation and the US National Robotics Initiative, playing a venture capitalist role, is investing in dozens of robotics projects, from its driverless car and robotics challenges, to bots to disarm IEDs.[2]

Such investments and some remarkable contributions from small US start-ups are driving down prices exponentially (from the $200,000-$300,000 range to $22,000 or less)—with ever faster and more sophisticated algorithms, sensor technology, and AI. This results in more capable machines both qualitatively and quantitatively and at much lower costs.

In the period to 2030, we will move from Roomba vacuum cleaners, robot lawn mowers, single-task industrial task

2 See *A Roadmap for US Robotics: From Internet to Robotics*, Academic consortium, sponsored by Robotics in America (RIA), March 19, 2013.

machines, and UAVs to self-driving cars and personal service robots.

Manufacturing

Robotics has been a driver of “inshoring,” returning manufacturing to the United States. There are approximately 120,000 industrial robots in the United States, just behind Japan and Italy. Extrapolating from 2011 statistics of the International Federation of Robotics (IFR), there are in excess of 1.4 million operational industrial robots worldwide.[3] From a concentration in the auto industry, robotics has begun to spread to electronics assembly, and increasingly to food and beverage and other packing, distribution, and shipping operations.

In a dramatic example of how robotics is transforming the workplace, FOXCONN, which employs 1.2 million Chinese and assembles some 40 percent of the world’s consumer electronics, has announced it will purchase one million robots over the next three years.[4] Increasingly, jobs that require low-skilled, repetitive physical labor will be done by robot, in what can be considered a qualitative leap in the pace of automation that some have compared to economic transformation at the beginning of the twentieth century when the workforce engaged in agriculture in the US dropped from 40 percent to 2 percent as industry took off and agriculture became mechanized.[5]

The chart below depicts current robot deployment and also suggests the growth potential for use of robots.

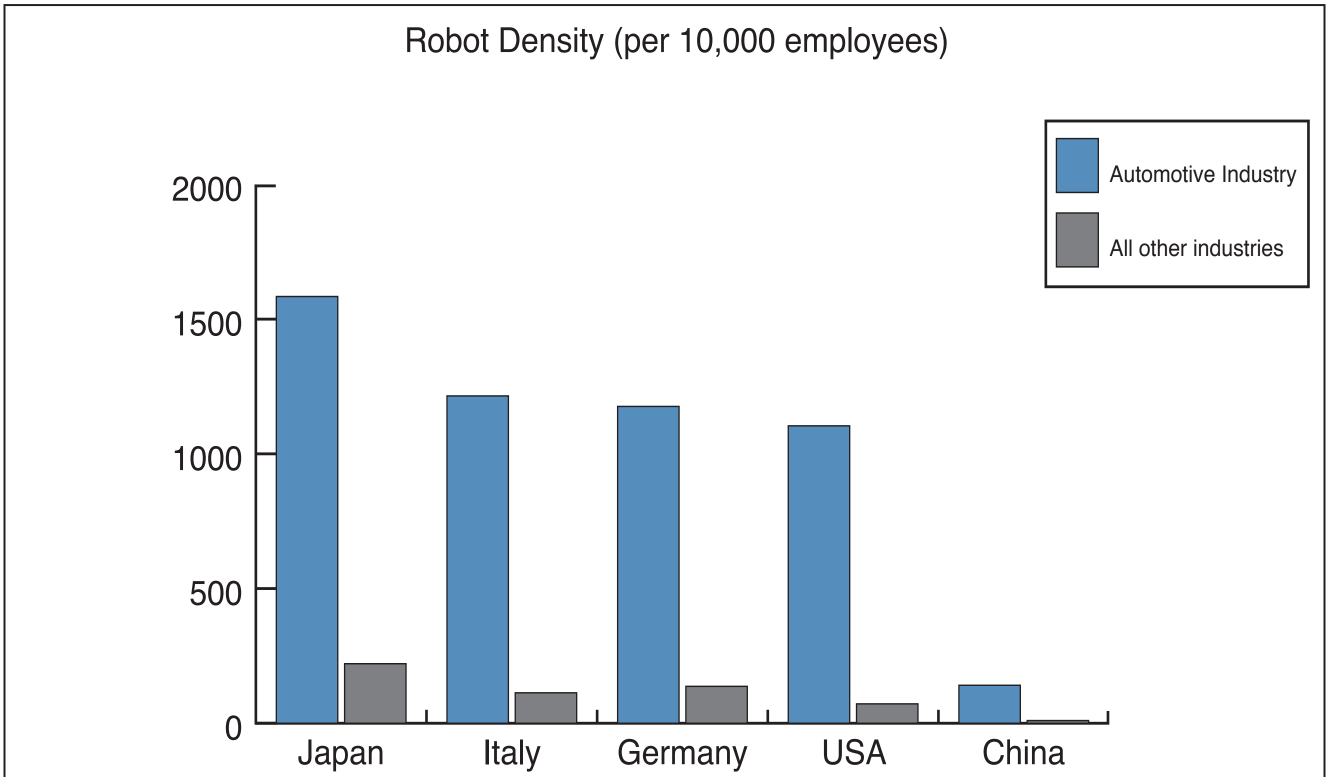
The Tipping Point

Two new developments are emblematic of the tipping point of exponential growth—in both quantity and quality—that robotics is nearing. The first is Willow Garage, a startup founded by former Google architect Scott Hassan in 2006, which developed the first open source common Robot Operating System (ROS) now widely disseminated to researchers and industry. This is the sort of enabling

3 See the IFR website, www.ifr.org, statistics 2012.

4 See Xinhua News Service, July 30, 2011: http://news.xinhuanet.com/english2010/china/2011-07/30/c_131018764.htm.

5 See Erik Brynjolfsson and Andrew Mcaffee, *Race Against The Machine: How the Digital Revolution is Accelerating Innovation, Driving Productivity, and Irreversibly Transforming Employment and the Economy* [Kindle Edition], for a compelling argument on robotics and the future of work.



Data compiled through 2011 from International Federation of Robotics.

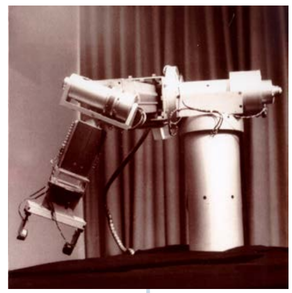
A Brief History of Robotics

1495 | 1940 | 1950 | 1960 | 1970 | 1980

1495
Around 1495, before he began work on the Last Supper, Leonardo Di Vinci designed the first humanoid robot.

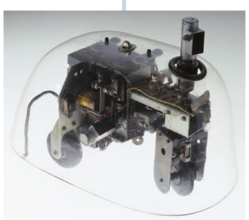
1954
The first programmable robot is designed by George Devol. He called it "Universal Automation."

1969
The Stanford Arm was the first electrically powered, computer-controlled robotic arm.



1974
A robotic arm (the Silver Arm) that performed small-parts assembly using feedback from touch and pressure sensors was developed.

1948
British robotics pioneer William Grey Walter creates the first "turtle" robots, which mimic life-like behavior with very simple circuitry.



1961
The first UNIMATE industrial robot is installed in a General Motors automobile factory in New Jersey.

1970
Shakey, the first mobile robot controlled by artificial intelligence, was created at the Stanford Research Institute (SRI).

1988
The Locomotion featured a body that steers and propels all wheels so that it can spin, drive, or do both. Its software can mimic a tank, car or any wheeled machines.

1990 — 1995 — 2000 — 2005 — 2010

1993
Demeter autonomously mows hay and alfalfa. It maneuvers with GPS and uses a camera to determine the difference of cut and uncut crops.

1997
NASA's PathFinder lands on Mars and the Sojourner Rover robot captures images of the planet.

1998
Scottish hotel owner Campbell Aird is fitted with the world's first bionic arm.

1999
Sony builds Aibo. One of the first robots intended for the consumer market.

2000
The United Nations estimated that there were 742,500 industrial robots in the world.

2001
The Food and Drug Administration (FDA) approves the CyberKnife to heal tumors anywhere in the body.

2004
Cornell University revealed a robot capable of self-replication.

2008
Willow Garage start-up creates the first standardized Robot Operating System (ROS).

2008
Sebastian Thrun rides passenger in Stanley, a driverless Volkswagen Toureg. They won $2 million in a race across the Mojave Desert.

2010
SRI International unveils its Autonomous Robotic Manipulation Project (ARM) with the Defense Advanced Research Projects Agency (DARPA). ARM is focused on matching the dexterity of the human hand in a robotic device.

2010
Xbox Kinect is released. It reduces cost and increases sensing capabilities for robots.

2011
Baxter, a $22,000 robot weighing about 75 kilograms (165 lbs), is unveiled. Unlike other manufacturing robots, Baxter's limited speed and size allow it to be easily trained and employed alongside human workers, sensing capacity.

technology that may lead to qualitative leaps in robotics capabilities. In addition, Willow Garage developed a two-armed, wheeled, human-size robot, PR2, a research and development tool that facilitates robotics innovation and can use the ROS software.

The second emblem of change is Baxter, a next generation type of mobile, human-like robot that can work alongside humans, created by Rodney Brooks, the inventor of the Roomba robot and now chief technology officer of Rethinking Robotics, a startup launched in 2008. Baxter is a breakthrough because of what it can do, its ease of use, its smartness, and perhaps most dramatically, its cost. It has two arms and cartoon eyes in a screen interface that provides feedback to users. Its arms have seven axes of motion, and it has a mechanism called an elastic actuator that enables it to respond: its arm will stop if touched and will follow human motions.

Baxter's ability to respond to human input allows it operate in an unstructured environment. It can pick up and move things and respond to changes in its surroundings. Its cameras and sensors give Baxter a breakthrough learning ability such that anyone with no training can "program" it: Baxter mimics its user's movements. Once shown various motions and sequences, it will repeat them. But perhaps the biggest innovation is the cost. Unlike many industrial task robots that may cost upwards of $300,000, Baxter sells for $22,000.

This sort of price point changes the market. Similarly, there are now telepresence robots that can be used in hospitals and offices to allow a remote mobile presence available for as little as $15,000. Moreover, Rethink Robotics sees Baxter as a platform similar to PCs in that it plans to upgrade software so that Baxter can adapt to the needs of its consumers' required tasks.

Variations on Baxter's capabilities are emerging. ABB has a prototype dual-armed robot for precision assembly. Kawada Industries in Japan has its Nextage robot with variable arm movements designed for assembly, but, at a much higher price than Baxter. Moreover, a number of small startup firms have developed robot arms. Some more expensive devices offer more precision than Baxter, but not yet the versatility.

In all these developments, one can glean a glimpse of the future of robotics. Consider an upgraded version of Baxter mated with the intelligence capacity demonstrated by IBM's Watson and you can imagine the sophisticated tasks that could be performed.

Robots are increasingly part of what has been called a digital "second economy" of computers and networks that can perform services independent of most human activity—as in swiping a credit card, buying an online product or service, or getting an airline boarding pass online.[6] Computers, the internet, and networks combined with increasingly sophisticated robotics have begun to transform the workplace. These technologies have already moved beyond replacing those at the low end of the skills –assembly lines, packing, and moving goods. Robots already can perform surgery. Some, like IBM's Watson, can help diagnose cancer. And constantly-improving software can translate languages and do legal research, with "e-discovery" sifting through legal documents that otherwise might occupy an army of legal researchers.

Over the coming decade, robots will be replacing a wider array of jobs currently performed largely by humans. Warehousing, distribution, picking and packing agriculture, light manufacturing, surveillance and security (envision drone/robot teams), and data-entry and analysis jobs will all be done largely by robots. Airplane pilots and truck drivers may also be replaced by robots.

In the service industry, healthcare will be populated by robots making diagnoses, delivering medication to patients, and helping take care of the elderly. Indeed, Japan's robotics industry is heavily motivated by the need for robots to help in eldercare. Given the graying demographics in Japan and other OECD nations, robots are likely to play a rapidly growing role in this sector.

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6 See W. Brian Arthur, "The Second Economy", in *McKinsey Quarterly*, October 2011.

Robots will be downloading and uploading information to the cloud, sometimes via built-in software programming, some computer controlled. This will not only be a source of data collection facilitating things such as medical analysis. Robot-generated data on their own activities will facilitate improvements in robot behavior and capabilities. In addition to robots in dangerous situations looking for IEDS or nuclear contamination, some analysts forecast that by 2025 a substantial proportion of soldiers on the battlefields of the future will be robots. Think the movie *I, Robot*, as life imitates art.

Social/Economic Policy Implications: Alternative Futures

This transformational technology, particularly robotics, poses both risks and opportunities to policymakers and to society writ large. In the past, transformational technologies tended to be part of the economic process of "creative destruction," with old jobs replaced by whole new industries. But the breadth and scope of robotics and the digital economy displacing human-performed jobs is without precedent.

While mainstream economics has focused on how technological change increases inequality in the labor market, on the impact of financial crises and recession on jobs, or on how globalization disadvantages low-skill workers, it has little to offer on how the unprecedented technological transformation now underway will shape the jobs of the future.[7] Some jobs, including those with a need for human judgment and human interaction (policemen, teachers, coaches, counselors, doctors) and those that oversee, repair, and create technologies would appear to endure—at least for the foreseeable future. But that still leaves a large realm of uncertainty.

There is a raging debate among economists and social analysts, and between 'techno-optimists' and 'techno-pessimists' about whether the technology transformation underway will free humanity to new creative heights and a flourishing of civilization, or lead to a dystopia of increased poverty, purposeless, and unhappy people. The pessimists also focus on ethical, legal, and moral issues raised by the deployment of robots. While the debate is complicated by the reality of a global slowdown and recession in much of Europe, there are compelling arguments in both directions. And on the future social impact of the rise of robots, it is premature to draw conclusions.

Techno-optimism

The knowledge-based economy in general, is not labor-intensive. For example, Apple, Amazon, Facebook, Google, and Twitter have roughly $1 trillion in market capitalization. But together, they employ fewer than 150,000 people—less than the number of new entrants into the American workforce every month.

On the positive side, robotics combined with emerging technologies such as 3D printing, nanomanufacturing, nanobiotechnology, and more capable artificial intelligence may reinforce a trend toward more local, customized production, marketing and distribution, and spawn some entirely new industries, such as lab-manufactured food, vertical farming in cities, and other fields we do not yet imagine. The commercialization of robots will almost certainly benefit—and probably facilitate the proliferation of—small and medium industries (there are some 300,000 in the US, for example), and democratize the economy. Imagine a small business with a cadre of 3D printers for manufacturing a range of products and a couple of Baxter-like robots to lift, pack, and help distribute them.

"It is a safe bet," writes *Wired* magazine's Kevin Kelly, "that the highest-earning professions in the year 2050 will depend on automations and machines that have not been invented yet… Robots create jobs that we did not even know we wanted done."[8] This is illustrative of what may be called the techno-optimism argument. The robotics/digitized economy trend will certainly play a large role in healthcare, and particularly managing the welfare of graying populations.

7 For example, see Daron Acemoglu, "Technical Change, Inequality and the Labor Market," *Journal of Economic Literature*, Vol.XL (March 2002) pp 7-722.

8 See Kevin Kelly "Better Than Human: Why Robots Will—and Must—Take Our Jobs," *Wired*, December 2012.

Techno-pessimism

In their highly influential book *Race Against the Machine*, Erik Brynjolfsson and Andrew McAfee outline a future where technology destroys an array of jobs, particularly low-skill service and manual labor jobs. They do point out that technology will upgrade some jobs, but their assessment nets out with growing income inequality and suggestions of a need to devise new income redistribution, as wealth concentrates among the technology owners. While such a social course may have a logic of fairness, redistributing wealth tends to be an explosive political issue, moreso in some nations than others.

Similarly, some prominent economists are among the ranks of techno-pessimists, arguing that the role of technology is overstated, and that innovation is diminishing in advanced industrial societies. Tyler Cowen of George Mason University makes the case in his book *The Great Stagnation* that the US economy has plucked all the "low-hanging fruit" and that future economic growth and innovation will be low for a protracted period.[9] In a widely-debated paper, "Is US Growth Over?" economist Robert J. Gordon argues:

> In setting out the case for pessimism, I have been accused by some of a failure of imagination. New inventions always introduce new modes of growth, and history provides many examples of doubters who questioned future benefits. But I am not forecasting an end to innovation, just a decline in the usefulness of future inventions in comparison with the great inventions of the past. Even if we assume that innovation produces a cornucopia of wonders beyond my expectations, the economy still faces formidable headwinds.[10]

Such pessimism should be taken with a grain of salt, occurring at a historical moment where the United States has suffered the worst economic crisis since the 1930s, a protracted recession amid anemic Western economic performance. Like many predictions of peak oil over the past fifty years and laments about imminent American decline, such doom and gloom may be unwarranted.

In a thoughtful discussion of the impact of robotics assessing the techno-optimism and techno-pessimism arguments and suggesting a third scenario, social scientist Richard Florida argues that human beings are not passive objects, and economic transformations are what societies make of them. "Our key tasks during economic and social transformations," Florida says, "are to build new institutions and new social structures and to create and put into effect public policies that leverage technology to improve our jobs, strengthen our economy and society and generate broad shared prosperity."[11] Florida concludes that the economy of the future is the "creative economy" because creativity has become "the fundamental factor of production." He argues that rather than factories or large corporations, cities are "the key organizing unit of the postindustrial economy... [the] pivot point for creativity, the great containers and connecters."

The Dark Side of Robotics

There is a growing body of literature exploring the many real and potential downside risks and ethical and social implications of robotics apart from displacing human labor.[12] Popular culture is filled with technophobic, demonic imagery of robots, from *Blade Runner* and *Terminator* to *AI* and *I, Robot*. The rise of drones has sparked intense debate about the morality of war by remote control, and one can anticipate similar debates on automated warfare when robots become infantry soldiers.[13] Will smart robots make their own battlefield decisions? Could police robots have dvanced enough AI to know whether an object pointed at them is a real gun or a water pistol?

There are a host of questions regarding efficacy and liability. However smart a machine may be, machines malfunction. Dependency on automated systems independent of human judgment and real-time monitoring,

9 See Tyler Cowen, *The Great Stagnation*, a Penguin Group eSpecial, Amazon, 2011.

10 See Robert J Gordon "Is US Economic Growth Over?" Centre For Economic Policy Research, Policy Insight No. 63, September 2012 (http://www.cepr.org/pubs/PolicyInsights/PolicyInsight63.pdf), summary in Robert J Gordon, "Why Innovation Won't Save Us," *Wall Street Journal*, December 21, 2012.

11 See Richard Florida, "Robots Aren't the Problem: It's Us," *The Chronicle of Higher Education*, March 25, 2013.

12 See for example. Patrick Lin, Keith Abney and George Bekey (eds.) *Robot Ethics: The Ethical and Social Implications of Robotics*, MIT Press, 2012.

13 See Jane Mayer, "The Predator War", *The New Yorker,* October 26, 2009, for a sampling of an increasingly heated debate.

whether electrical grids or robot cars, could pose risks and dangers. Given that AI is about software, what risk do hackers pose? Could cyber thieves hack Google-type driverless cars and steal them or wreak havoc on traffic? If a robot surgeon errs, who will be liable? Even if robots are programmed to obey laws and norms, what about cultural differences: whose laws and whose norms? How would the very nature of warfare change if some states used primarily robot soldiers and drones, removing the human risk factor from warfare, while other nations lacked such capability? If military conflict were removed from human impact, would that make conflict more or less likely? Would such automated warfare, so removed from any personal impact (e.g. friends and relatives dead or wounded) change the way citizens judge the necessity of particular wars, and dilute a level of government accountability?

In addition, there may be unanticipated social impacts from the use of robots. In the area of healthcare, for example, would dependency on robots mean a decline in surgeons' or other medical employees' skills? Similarly, will increased use of robots and decline in human interaction in education alter the learning process in negative ways? Then there are psychological and emotional issues arising from robot caregivers to handicapped and elderly. Will the ill and elderly, who tend to be socially marginalized, suffer from a lack of human interaction, or will they develop affinities for robot caregivers?

Conclusion

Robotics will be an important part of the social and economic landscape of the future. The pace and scope of deployment of robotics and the other components of the Third Industrial Revolution will largely be driven by the private sector. But the economic, social, political, and strategic consequences of the transformation that will take place will ripple through governments at every level.

Yet there is dearth of planning or even due diligence done by governments to develop an understanding of how emerging technologies such as robotics will change the way we work and live. Instead, there tends to be a large gap between the scientific and technological community and government making and implementing economic, urban, and foreign policies. The imperative for governments around the world, working with their respective private sectors, is to begin to think through consequences of the imminent robotics explosion and fast approaching technology revolution and prepare for, take advantage of, and mitigate the downside risk of these developments.

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