2

TECHNOLOGICAL CHANGE AND THE FOURTH INDUSTRIAL REVOLUTION

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Klaus Schwab, executive chairman of the World Economic Forum, coined the term "fourth industrial revolution" for "the staggering confluence of emerging technology breakthroughs, covering wide-ranging fields such as artificial intelligence (AI), robotics, the internet of things (IoT), autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage and quantum computing, to name a few."[1]

This chapter argues that the "staggering confluence" will drive deglobalization, diffuse military power to smaller entities, and change the character of competition between the great powers. If managed well, these advances will provide significant advantages to the United States in its competition with both China and Russia, even as it allows smaller powers to challenge it. If managed poorly, the convergence of technology will severely undercut US security.

Deglobalization Has Started

The Economist defines globalization as the "global integration of the movement of goods, capital and jobs."[2] Over the last seven decades, the

combination of lower labor costs, increasingly efficient freight systems, and trade agreements based on Bretton Woods provided major regional cost advantages for manufacturing. The resultant globalization transformed agricultural societies into industrial powerhouses.

While the process may seem irreversible, the globe has already gone through repeated periods of deglobalization, ranging from the decades that followed the First World War and the 1970s oil shocks back to the centuries that followed the collapse of the Roman Empire. As recently as 2008–09, a global financial crisis once again devastated global trade. Academics, think tanks, and respected news journals all speculated that the collapse of the financial markets would result in a rapid and long-term decrease in global trade. In February 2009 *The Economist* noted that each element of globalization appeared to be in trouble.[3]

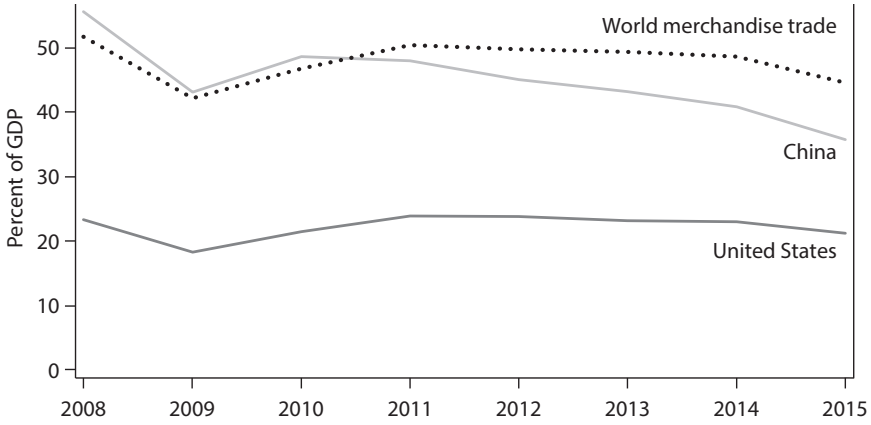
In fact, the global economy defied deglobalization predictions and bounced back. World Bank statistics show global merchandise trade, as a percentage of GDP, recovered quickly from the 2009 crisis, almost reaching precrisis levels by 2011. Optimism returned that global trade would once again lead global economic growth.

The optimism was premature. Even as worries about deglobalization faded, trade, as a percentage of global GDP, flattened and then declined. While the world economy continued to grow slowly from 2011 to 2016, the growth of international trade lagged behind—instead of exceeding—the growth rates. Most alarming, the steepest decline was from 2014 to 2015, when the rate of manufacturing decline approached that of 2008–09 even though the global economy grew by 0.3 percent (figure 2.1).[4]

It was not just manufacturing. When the World Bank added services to merchandise, total trade followed the same pattern. Growth, as a percentage of global GDP, declined slightly each year since 2012 (figure 2.2).[5] Once again, US and Chinese trade statistics moved in parallel.

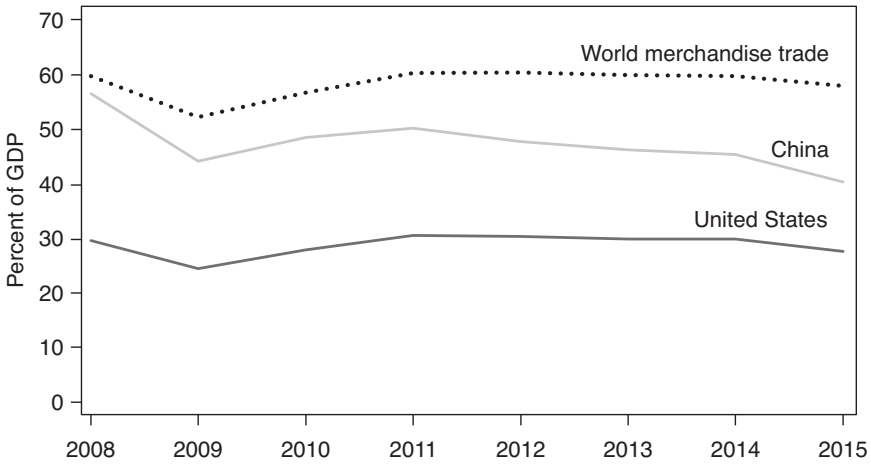
In summary, according to the World Bank the total value of global merchandise trade increased sharply from 1995 to 2008, dropped sharply in 2008, climbed steeply until 2011, then flattened from 2012 to 2014 and fell sharply in 2015—dropping from $18.995 trillion to $16.482 trillion.[6] Thus, two of *The Economist*'s key measures of globalization—

FIGURE 2.1 Merchandise Trade as a Share of GDP, 2008–15



Source: World Bank, "Merchandise Trade (% of GDP)," accessed December 28, 2016, http://data.worldbank.org/indicator/TG.VAL.TOTL.GD.ZS/countries?display=graph.

FIGURE 2.2 Total Trade (Manufacturing and Services) as a Share of GDP, 2008–15



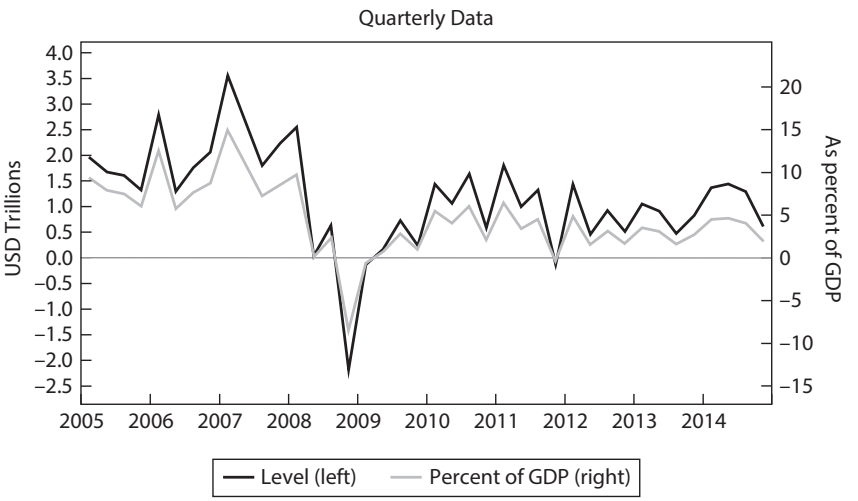
Source: World Bank, "Trade (% of GDP)," accessed December 28, 2016, http://data.worldbank.org/indicator/NE.TRD.GNFS.ZS/countries/1W-CN-US?display=graph.

the movements of goods and of services—have in fact been declining since 2011.

As one would expect, another measure of international trade activity, global financial flows, declined very sharply during the crisis. However, unlike global trade flows, financial flows never recovered (figure 2.3). As noted in a policy brief for the Centre d'Études Prospectives et d'Informations Internationales in Paris, "The 'Great Retrenchment' that took place during the crisis has proved very persistent, and world financial flows are now down to less than half their pre-crisis levels."[7]

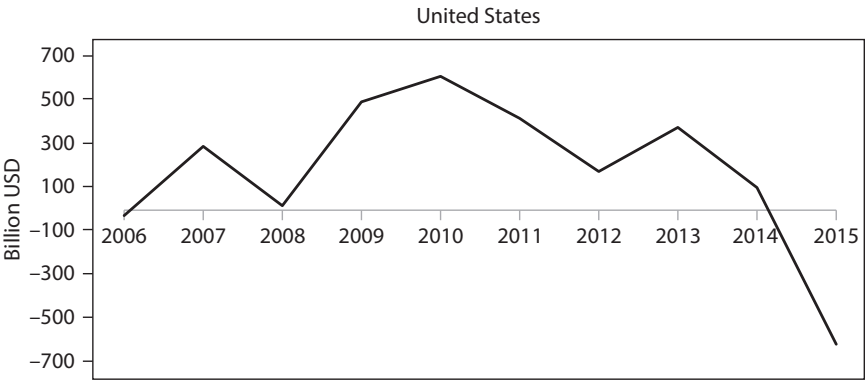
These decreases in financial flows hit developing countries particularly hard. Capital inflows to these countries initially rebounded after the 2008 crisis but slowed again after 2010 and then turned negative in 2014. In 2015, over $700 billion in capital left developing economies, greatly exceeding even the $145 billion net outflows during the Great

FIGURE 2.3 Global Gross Financial Flows, 2005–14



Source: Matthieu Bussiere, Julia Schmidt, and Natacha Valla, "International Financial Flows in the New Normal: Key Patterns (and Why We Should Care)," CEPII (Centre d'Études Prospectives et d'Informations Internationales), March 2016, accessed May 26, 2016, www.cepii.fr/PDF_PUB/pb/2016/pb2016-10.pdf.

FIGURE 2.4 Net Financial Flows to Developing Economies, 2006–15



Source: United Nations, 2016, "World Economic Situation and Prospects," http://www.un.org/en/development/desa/policy/wesp/wesp_current/2016wesp_ch 3_en.pdf.

Recession (figure 2.4).[8] In contrast, foreign direct investment (FDI) into the United States is growing rapidly. In 2016, FDI flows into the United States reached $391 billion, more than double the $171 billion inflow of 2014. Outflows in 2016 were only $299 billion.[9] Thus, in 2016, the United States saw a net inflow of investment capital of $192 billion. In 2015, as shown by the latest statistics available from the Department of Commerce, nearly 70 percent of the FDI was invested in the manufacturing sector.[10]

Amplifying the effect of reduced financial flows has been their regionalization or balkanization. After decades of coming closer together, global markets and banking systems are pulling apart. While cross-border goods, services, and financial flows represented 53 percent of the world economy in 2007, they are a mere 39 percent now.[11] In November 2014, Kristin Forbes, a leading economist and member of the Bank of England's external monetary policy committee, noted that gross cross-border capital flows for advanced economies had dropped to levels not seen since 1983. "Financial globalization has sharply reversed and shows little signs of returning even to levels of the late 1990s," she said, urging a rethink of the "assumption that global financial

integration is an unstoppable trend."[12] On October 5, 2016, the *Wall Street Journal* noted the slowdown is not limited to developed economies but is also hitting emerging economies in both goods and services.[13]

In March 2016, the *Harvard Business Review* counterargued that globalization was not slowing but still increasing rapidly. It stated, "Cross-border data flows have grown by a factor of 45 over the past decade, and they're projected to post another ninefold increase by 2020."[14] McKinsey Global Institute analysts wrote that data flows accounted for $2.8 trillion of value—exerting a larger economic impact than the global trade in physical goods.[15]

While an increase from near zero to $2.8 trillion is very impressive growth, it should be kept in perspective. According to the World Bank, global GDP was $74 trillion in 2015.[16] Further, the authors of the study admit it is very tricky to translate the number of terabytes of data flowing across borders to a dollar value. For our purposes, the key issue is whether the data flows are in fact increasing globalization—and that is impossible to tell. Globally, 70 percent of internet traffic during peak hours in 2015 came from video and music streaming; this is expected to increase to 82 percent by 2020. According to Cisco, "A growing number of M2M (machine to machine) applications, such as smart meters, video surveillance, healthcare monitoring, transportation, and package or asset tracking, are contributing in a major way to the growth of devices and connections. . . . By 2020 the consumer share of the total devices, including both fixed and mobile devices, will be 74 percent, with business claiming the remaining 26 percent."[17] It is difficult to see how data that are heavily about entertainment and day-to-day operation of personal devices contribute heavily to globalization. This subject certainly requires further research.

Factors Driving Deglobalization

No single industry or social development is driving deglobalization. It is being driven by the cumulative effect of technological, political, and social trends across the globe. Perhaps the primary driver, least subject

to reversal, is the elimination of regional labor cost advantages that encouraged manufacturers to locate their production in low-labor-cost regions. Robotics, 3D printing, and artificial intelligence are driving manufacturers to reconsider not only how and what they make, but where they make it.

> *As I look at innovations, in a sense they are lacking. Our productivity growth is actually very, very low now in the United States and other countries. So I think there's a danger trying to stomp out these things when they may be what are actually going to make people's lives better.* —John B. Taylor

How We Make Things

The movement to automation is a global trend that is accelerating. According to Boston Consulting Group, 25 percent of all manufacturing will be automated by 2025. In 2015 electronics manufacturing robots' operating costs were the same as Chinese labor, about $4 per hour.[18] Since then, robot costs have continued to decrease, but Chinese labor costs are increasing rapidly.[19]

The world is on the very front end of the shift from labor to automation. A new Price Waterhouse Cooper study estimates 38 percent of US jobs could be lost to automation in the next fifteen years.[20] Robot sales are expected to reach four hundred thousand annually by 2018.[21] This estimate does not account for the newly developed "cobots," or collaborative robots. They assist human workers and thus dramatically increase human productivity. At an average cost of only $24,000, they will appeal strongly to the smaller companies that account for 70 percent of global manufacturing.[22] Further, converting to automation creates a virtuous circle. A Price Waterhouse Cooper survey showed 94 percent of those CEOs who had already adopted robots say the robots increased productivity.[23] Thus, those who buy robots are encouraging others to buy them.

Even as robots are changing traditional manufacturing, 3D printing, also known as additive manufacturing, is creating entirely new ways to manufacture a rapidly expanding range of products. The ability to print everything from medical devices to aircraft parts to buildings and bridges, combined with a recent order-of-magnitude increase in the speed of printing, is already challenging traditional manufacturing. In April 2016, Carbon Inc. introduced a commercial 3D printer that is one hundred times faster than previous printers.[24] It plans to push the speed to one thousand times faster. The Department of Energy's Oak Ridge National Laboratory is partnering with Cincinnati Inc., a manufacturer of high-quality machine tools, to develop a process to print metal two hundred to five hundred times faster.[25] In May 2017, MIT developed rapid liquid printing, which is faster and also allows a much greater range of products.[26]

Commercial firms are exploiting these advances. United Parcel Service has established a new facility called Direct Digital Manufacturing with one hundred printers that will all run twenty-four hours a day, seven days a week, and require just one employee per eight-hour shift.[27] UPS plans to expand the plant to a thousand printers and is already establishing additional 3D printing facilities worldwide.[28] In a Price Waterhouse Cooper survey, 52 percent of the CEOs expect 3D printing to be used for high-volume production in the next three to five years. This is up from 38 percent only two years ago.[29]

What We Will Make

Three-dimensional printing will have a major impact on manufacturing by bringing two other changes: design for purpose and mass customization. For the first time, designers can design an object to optimally fulfill its purpose. Current manufacturing techniques often require that optimal design be subordinated to manufacturing limitations. While the designer may have envisioned the most efficient form for a product, that form may be impossible to machine or build. Three-dimensional printing frees the designer to create virtually any form and see it printed

to specification. Design for purpose is already changing how we make things and will have a major impact on production.

The second impact will be mass customization. With some forms of advanced manufacturing, 3D printing in particular, there is essentially no cost to changing the specifications of the object being printed. Thus, every item can be customized. Globally, manufacturers are seeking to respond to consumer demand for unique items. Only local facilities using advanced manufacturing techniques can deal with the rising demand for mass customization in everything from clothes to cars. This is driving manufacturers to return manufacturing to the markets they serve.

Where We Make Things

By reducing labor costs while simultaneously increasing customization, productivity, and quality, these new technologies are bringing manufacturing back to America. The United States lost manufacturing jobs every year from 1998 to 2009—a total of eight million jobs. But in the last six years, it regained about one million of them.[30] With the cost of labor no longer a significant advantage, it makes little sense to manufacture components in Southeast Asia, assemble them in China, and then ship them to the rest of the world when the same item can either be manufactured by robots or printed where it will be used.

Another major factor accelerating the shift of manufacturing back to the United States is the reduction in risk to intellectual property. Local manufacturing also reduces shipping costs and reduces—even, in some cases, eliminates—inventory. "Just in time" local production means no finished items in stock—only a small supply of input materials.

Service Industries Are Coming Home Too

Service industries are following suit as artificial intelligence takes over more high-order tasks. Call centers are already moving from low-wage areas back to the United States. Early adopters of AI-driven customer

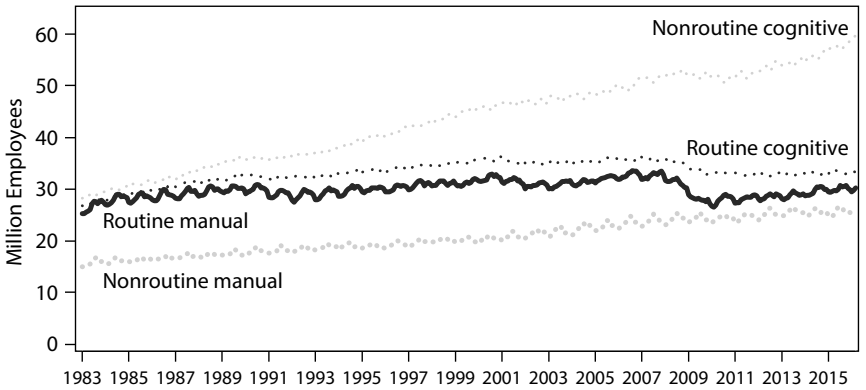
service centers like United Services Automobile Association have achieved very positive results.[31] Pairing AI with humans has resulted in lower costs (fewer humans) and higher customer satisfaction as the problems that AI can't resolve are handled by Americans.

Nor is artificial intelligence limited to routine call center tasks. The sophistication of artificial intelligence is growing so quickly that in 2015 the Georgia Institute of Technology employed a software program it named Jill Watson as a teaching assistant for an online course. All of the students thought Ms. Watson was a very effective and helpful teaching assistant. None guessed she wasn't human.[32] Baker & Hostetler, a law firm, announced it has hired her "brother," Ross, also based on Watson, as a lawyer for its bankruptcy practice.[33]

Even as AI moves into sophisticated tasks, robotics will also take over mundane tasks like delivery, stocking, cleaning, etc. Many back office tasks will also go the way of telephone operators and call center staffs. Service jobs that require the human touch or have to deal with non-routine tasks will remain, but massive numbers of humans will be replaced. Further up the knowledge ladder, artificial intelligence is already handling tasks formerly assigned to associate lawyers, new accountants, new reporters, new radiologists, and many other specialties. In short, nonroutine tasks, whether manual or cognitive, will still be done by humans while routine tasks—even cognitive ones—will be done by machines. And this is not a new phenomenon. Computer technology has been eating jobs since 1990 (figure 2.5).[34] A study by the St. Louis Federal Reserve indicates that if routine jobs had grown at the same rate as nonroutine, America would have fifty million more jobs.[35] The jobs were lost to automation.

With labor costs much less of an issue, better communications links, better infrastructure, more attractive business conditions, and effective intellectual property enforcement will encourage services to return to developed nations. The few, more complex questions that require human operators will be better handled by native language speakers who are intimately familiar with the culture.

FIGURE 2.5 Routine vs. Nonroutine Jobs and Cognitive vs. Manual Jobs, 1983–2016



Source: US Bureau of Labor Statistics, 2017, "Current Population Survey (Household Survey): Series LNU02032201, LNU02032204, LNU02032205, LNU2032210, LNU2032211, LNU2032212." As suggested by Maximiliano Dvorkin, "Jobs Involving Routine Tasks Aren't Growing," Federal Reserve Bank of St. Louis, https://www.stlouisfed.org/on-the-economy/2016/january/jobs-involving-routine-tasks-arent-growing, and "Job Polarization," The FRED Blog, St. Louis Fed, https://fredblog.stlouisfed.org/2016/04/job-polarization.

> *I like the example of freestyle chess, where the human provides the strategy and a machine explores tactics and potential moves. A good player plus a machine can beat any human and any machine.* —James Timbie

Other Technologically Driven Trends

The reduced demand for transportation fuel, alternative energy technologies, and increased energy efficiency are already reducing the global movement of coal and oil. At the same time, wind, solar, and thermal are growing rapidly. In 2014, 58.5 percent of all net additions to global power systems were renewables.[36] In 2015, 68 percent of the

newly installed capacity in the United States was renewable.[37] Energy from renewable sources can be traded across adjacent borders, but not globally. Thus the increases in renewable energy production will steadily reduce the long-range shipment of coal, oil, and gas.

With Morgan Stanley predicting that more electric vehicles will be sold in 2040 than gas vehicles, the source of transportation fuel will move from petroleum to electric energy.[38] Fracking, alternative energy, and new efficiencies have already dramatically reduced the US need for imported energy.[39] If other nations can make similar advances in these areas, large segments of the energy market will become local. Growth in these energy sources will slow and perhaps eventually reverse the global trade in gas and oil.

> *In 2030, the United States will be able to produce about 95 million metric tons of liquid natural gas, which is basically larger than any other place on the earth, including the Middle East. So having that ability to interface with other countries using the energy resource, I think, could be a very big part of how the United States thinks of global interdependence.* —Tsunehiko Yanagihara

A further driver of fragmentation is the effort by authoritarian governments to segment the internet. In his book *Splinternet,* Scott Malcomson notes that when the web took off in 1995, Russia and China started saying they wanted "more control over our particular parts of it."[40] They have been trying to gain that control ever since. Initially, total control was considered an impossible goal, but China has steadily improved its ability to control what people can access inside its territory. As Simon Denyer described recently in the *Washington Post*, "What China calls the 'Golden Shield' is a giant mechanism of censorship and surveillance that blocks tens of thousands of websites deemed inimical to the Communist Party's narrative and control, including Facebook, YouTube, Twitter, and Instagram."[41] There is to be no turning

back. In 2017, China passed a new law on cybersecurity that codified and strengthened its control of the internet to include requiring corporate data to be stored inside China.[42] In actively discouraging outside information companies, China and other totalitarian nations have decided that connectivity's threats to stability exceed the benefits of global connection. Restricted access to the internet will inevitably reduce these nations' participation in the global economy.

During the 2016 US elections, both candidates reflected the changing attitude among Americans concerning trade. While the assumption that global trade is good may still exist among policy-makers and economists, it is rapidly fading among voters. In 2002, the Pew Research Center found that 78 percent of Americans supported global trade. By 2008, the percentage had fallen to 53 percent.[43] In 2014, when Pew changed the question from whether trade was good for the nation to whether trade improved the livelihood of Americans, favorable ratings plunged. Only 17 percent of Americans thought trade led to higher wages, and only 20 percent believed it created new jobs.[44]

The public mood has begun to change in Europe too. Dissatisfaction with past policies and priorities pushed by elites has created a palpable populist narrative. Voters have focused inwardly on economic and cultural issues. Nationalist parties have been present in various nations in Europe for decades, but a confluence of factors has raised their profile and power dramatically. Brexit and the strengthening of right-wing parties across Europe from Poland to Denmark seem to reflect a political pushback against globalization. While the Macron victory in France provided relief, it is important to remember that the far right still made major advances in France. The National Front's success was repeated in Germany's September 2017 election where the hard-right Alternative for Germany surged to finish third and became the first far-right party to win seats in the Bundestag since 1961.[45]

Since the financial crisis of 2008, more than 3,500 protectionist measures have been instituted globally, as well as numerous additional administrative requirements that have increased the difficulty of conducting international trade.[46] The trend toward protectionism is not

slowing. On November 11, 2016, the *Wall Street Journal* reported that the "Group of 20 largest economies imposed a total of 85 new measures that restrict trade between mid-May and mid-October."[47] The December 2016 meeting of the World Trade Organization's Trade Policy Review Body noted that of the 2,978 measures recorded since 2009, only 740 had been removed.[48]

In October 2016, the *Wall Street Journal* noted, "The risk now is that politics, economics and finance are combining in a way that threatens to throw globalization into reverse, hanging a sword of Damocles over the world economy. Years of sluggish growth, stagnant wages and rising inequality are fueling a growing political backlash against what some say is unfair competition from foreign firms and foreign workers across developed countries, most clearly evident in the US election and in the Brexit vote."[49]

This shift from globalism has not been limited to the United States and Europe. In its 2016 year-end roundup issue, *The Economist* noted:

> Indeed for most people on Earth there has never been a better time to be alive. Large parts of the West, however, do not see it that way. For them progress happens mainly to other people. Wealth does not spread itself, new technologies destroy jobs that never come back, an underclass is beyond help or redemption, and other cultures pose a threat—sometimes a violent one.[50]

Social Reactions

The American public and much of Europe have turned against globalization. Three of the primary drivers are unemployment, rising inequality in wealth, and concern for the environment. In fact, new technologies have historically caused significant political and social disruption when they shifted the basis for wealth generation. If the historical pattern holds, the fourth industrial revolution will cause major disruptions in employment as the knowledge and skills required change significantly. For those who can adapt or who possess the capital to invest in the new

technology, the future looks good. As we have seen in previous industrial revolutions and over the last thirty years in the United States, it has increased the income and wealth inequity greatly. The negative impact has been—and will continue to be—focused on the older, less educated, and poor. This will create much greater demands on US social safety networks.

The third driver, the environment in the form of global warming, has resulted in a great deal of political organization on both sides of the issue. There is a growing "buy local" movement driven by the desire to reduce the environmental impact of production. Local manufacturing, services, and food production create jobs near the consumer while dramatically reducing transportation energy and packaging waste. The people who support these movements see continued global engagement as a negative element in community life.

We're in a very, very pivotal time right now, and creating a literate, scientifically literate public is essential for the future of the country and the health of our globe. —Lucy Shapiro

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Will Deglobalization Continue?

The key question is whether recent reductions in trade and financial flows are simply a cyclical downturn or are actually signs of a sustained long-term shift in global trade patterns. I argue that the convergence of new technologies, reinforced by political and social forces, will dramatically change what, how, and where we make things. Trends in energy production, politics, and the internet's balkanization will accelerate these changes, retarding—if not entirely reversing—globalization. Over the next decade or two, these trends will result in the localization of manufacturing, services, and energy production. Profits, politics, and social trends will all drive trade patterns toward regional trade blocks, thus reducing global networks and fundamentally altering the international

security environment. Even if political and social movements were to shift back in favor of globalization, the converging technologies will still make it more profitable to produce in the target market, and that will fundamentally change the global economy.

> *World orders are not self-sustaining. They can and do fail in very dramatic and impactful ways. Economic interdependence among nations is not in and of itself enough to prevent the dissolution of world orders or indeed world wars.* —James O. Ellis, Jr.

The Fourth Industrial Revolution Is Changing the Character of War

The fourth industrial revolution will drive massive changes in the economic, political, and social spheres and will inevitably change warfare too. Clausewitz's primary trinity of passion, chance, and reason will continue to define the fundamental nature of war and technology will not eliminate the fog and friction. However, fourth industrial revolution technologies are already changing the character of war—and these changes are accelerating.

Twenty-First Century Technologies

As just a sampling, the following will focus on how the dramatic improvements in nano-energetics, artificial intelligence, drones, and 3D printing are producing a revolution of small, smart, and cheap weapons that will redefine the battlefield.

Nanotechnology

The field of nanotechnology will have major impacts across societies and conflicts. One notable application has been nano-explosives. As early as 2002, nano-explosives generated twice the power of conventional explo-

sives.[51] By 2014, open-source literature claimed nano-aluminum created ultrahigh burn rates, which give nano-explosives four to ten times the power of TNT.[52] The obvious result is that small platforms will carry great destructive power.

Artificial Intelligence

Two areas of artificial intelligence are of particular importance in the evolution of small, smart, and cheap weapons: navigation and target identification. They are essential for autonomy, and autonomy will be required if these weapons are to be employed in the thousands. The global positioning system (GPS) has proved satisfactory for basic autonomous drone applications such as the Marine Corps's K-MAX helo-drone in Afghanistan.[53] However, GPS will be insufficient for operations in narrow outdoor or indoor environments, dense urban areas, and areas where GPS is jammed. Academic and commercial institutions are working hard to overcome the limitations of GPS to provide truly autonomous navigation for drones.[54] The University of Pennsylvania has already developed a quadcopter that "uses a smartphone for autonomous flight, employing only on-board hardware and vision algorithms—no GPS involved."[55] Essentially, this recreates the inertial plus visual navigation system that guided the Tomahawk cruise missile before the advent of GPS.

While such a system cannot be jammed, it would only serve to get a drone to the target area but not to ensure it could hit a specific target. At that point, the optical systems guided by AI could use onboard multispectral imaging to find a target and guide the weapon.[56] In short, the AI necessary for many types of autonomous drone operations currently exists—and is operating aboard small, commercial drones.

It is exactly that autonomy that makes the technological convergence a threat today. Because such drones will require no external input other than the signatures of the designated target, they will not be vulnerable to jamming. Not requiring human intervention, the autonomous platforms will also be able to operate in very large numbers. They can be launched as precision strike weapons or sent to an

area and then commence active hunting for prioritized targets. They can also be programmed to wait patiently prior to launch or even proceed to the area of the target and then hide until a specified time or a specified target is identified.

Drones

Clearly, commercial drone capabilities have increased dramatically in the last five years, and usage has spread widely. Still, small drones can only carry a limited payload. This limitation can be overcome with two separate approaches. First is the use of explosively formed penetrators (EFPs).[57] The second, and less technically challenging, approach is to think in terms of "bringing the detonator."

Weighing as little as a pound, EFPs can destroy even well-armored vehicles. In Iraq, coalition forces found EFPs in a wide variety of sizes—some powerful enough to destroy an Abrams tank. Others were small enough to fit in the hand—or on a small drone.[58] And of course nano-explosives could dramatically increase the destructive power of the weapons. The natural marriage of improvised explosive devices (IEDs) to inexpensive, autonomous drones is virtually inevitable. New 3D printers can manage the previously very difficult task of forming the copper plates that become the projectiles.[59] Thus, we can expect small and medium-size drones to pack a significant punch even against protected targets.

The "bring the detonator" approach applies to aircraft, vehicles, fuel, chemical facilities, power distribution networks, and ammo storage facilities as targets. In each case, the objective is to use the drone to detonate the large supply of explosive material provided by the target. Even a few ounces of explosives delivered directly to the target can initiate the secondary explosion that will destroy it.

Even as small commercial drone sales move into the millions, larger commercial versions are showing capabilities normally associated with much more expensive, manned platforms. Today, the Aerovel Flexrotor has a range of two thousand miles and forty-plus hours of endurance. It

flies autonomously, launches and recovers vertically, and has a suite of onboard multispectral sensors.[60] It is currently used for surveillance and survey of large remote areas at a fraction of the cost of manned platforms. Defiant Labs' DX-3 is designed specifically to conduct geographic and resource surveys of remote regions to include Canada's environmentally hostile far north. It launches from a truck, navigates autonomously for up to nine hundred miles, and carries a variety of payloads.[61]

Military drones are also pushing performance parameters. The decade-old Israeli-designed Harpy and the US Navy's Tern are vertical launch, autonomous drones that carry sixty- and five-hundred-pound payloads respectively over one thousand kilometers. Kratos's XQ–222 Valkyrie can deliver five hundred pounds out to three thousand miles.

Additive Manufacturing

This brings us to how additive manufacturing/3D printing will allow drones to be employed as rounds of ammunition. Researchers at the University of Virginia 3D-printed and assembled an autonomous drone with a range of twenty kilometers (forty if sent one way) for only $800—most of the cost was the Android phone used for navigation. It took about a day to print the body.[62] Thus a small factory with only one hundred 3D printers using the new Carbon 3D printing technology could produce ten thousand such autonomous drones a day. If the UPS factory of one thousand printers becomes the standard, it could produce one hundred thousand a day. The key enabler will be Department of Defense preparation so that it can provide the unique elements such as explosives, guidance, and targeting software.

It is one thing to have access to thousands of drones. It is quite another to have the logistics and manpower available to effectively employ them. One method that demonstrates it can be done is the Chinese system that mounts eighteen Harpy unmanned combat air vehicles (UCAVs) on a single five-ton truck.[63] The Chinese can transport, erect, and fire these fairly large drones (nine-foot wingspan) with a two-person crew. A similar-size truck could be configured to carry hundreds of US

Switchblade-size or Israeli Hero-size drones.[64] Thus a single battery of ten trucks could launch thousands of autonomous, active hunters over the battlefield. The key is autonomy, since it would be nearly impossible to provide sufficient pilots for each battery.

Drones could also be configured in standard twenty-foot shipping containers, which would create two major advantages. First, any truck or ship that can carry a container becomes a potential weapons platform. Second, it is almost impossible to preempt weapons in this configuration—there are simply too many twenty-foot containers to be targeted in a preemption campaign. The Russians have noted this and already sell their powerful Club K cruise missile system in a container indistinguishable from a standard shipping container.[65]

Implications for the Modern Battlefield: Land, Sea, Air, Space, and Cyber

Drone swarms may make defense the dominant form of warfare in ground, air, sea, and space domains and be able to attack the physical elements of the cyberdomain. As noted, commercially available autonomous drones have ranges out to two thousand miles and payload up to dozens of pounds. Military drones under development have ranges out to three thousand miles with payloads up to five hundred pounds. Combining nano-explosives, artificial intelligence, and additive manufacturing could create units capable of launching hundreds to tens of thousands of smart drones in wave attacks at ranges exceeding today's ground fire support systems or tactical aircraft. The cumulative impact of improved missiles and autonomous drones in large numbers will be to make domain denial much easier than domain usage.

Land Domain

On land, the family of small, smart, and cheap autonomous weapons may create a situation similar to that between 1863 and 1917 when any person in range moving above the surface of the ground could be cheaply

targeted and killed. The result was static trench warfare. Like that historical period, the defense dominated because defenders could dig in. The offensive force had to expose itself to move. Today, missile and drone launchers can be protected in bunkers or simply by blending in to the congested terrain ashore. They can be inside any number of buildings or shelters or simply dug in. They will not emit any signal until they move to fire. In contrast, a system on the offensive will have to move in order to cover the distance from its home base to the objective. It will both create a targetable signature and have only the protection it can carry. How will a mechanized brigade be able to move if an enemy can launch 10,000 autonomous drones to hunt and kill its vehicles?

Sea Domain

Obviously, swarms of autonomous drones can also threaten any naval force trying to project power ashore. The drones will not need to sink a ship to achieve a mission kill. For instance, a drone detonating against an aircraft on the deck of a carrier or firing a fragmentation charge against an Aegis combat system's phased array radar can degrade that platform's capabilities to the point of a mission kill.

Undersea weapons will provide a much greater challenge to navies. Vietnam, Japan, South Korea, Australia, China, and Indonesia are all upgrading their submarine forces. However, a submarine force is expensive, complex, and difficult to operate. Unmanned underwater vehicles may provide a much cheaper deterrent. Since 2014, the US Navy has operated a fleet of semiautonomous underwater gliders that have the capability to operate for five years without refueling by changing their buoyancy.[66] They can patrol for weeks following initial instructions, then surface periodically to report and receive new instructions. Similar drones are being purchased globally for about $100,000 each, but commercial firms are striving to reduce the cost by 90 percent.[67] If developed as a weapons system, they could dramatically change naval combat. Offensively, they can become self-deploying torpedoes or mines with transoceanic range. Defensively, they can be used to rapidly establish

smart minefields in maritime choke points. They can be launched from a variety of surface and subsurface platforms or remain ashore in friendly territory until needed, and then launched from a port or even the beach.

Sea mines should be a particular concern to trading nations. Simple moored and floating mines have the distinction of being the only weapon that has denied the US Navy freedom of the seas since World War II. Mines have become progressively smarter, more discriminating, and more difficult to find. They have sensors that can use acoustic, magnetic, and other signals to attack a specific kind of ship.[68] And, of course, self-deploying mines can also be used against commerce. Launched from shore bases, these systems will allow any nation bordering, for example, the South China Sea and its critical straits to interdict trade. While they cannot stop trade, damaging a few ships will cause dramatic increases in maritime insurance rates as well as sharp decreases in the owners' willingness to risk their assets in the contested waters.

Air Warfare

For air power, the key problem will be protecting aircraft on the ground. An opponent does not have to fight modern fighters or bombers in the air. Today, China has developed the capability to destroy US headquarters, ships, runways, and most aircraft stationed in Japan with a combined ballistic and cruise missile attack.[69] Soon a much wider range of potential opponents will be able to dispatch hundreds or even thousands of small drones to hunt US aircraft at their home stations. Even if aircraft are protected by shelters, the radars, fuel systems, and ammunition dumps will be highly vulnerable. While the Flexrotor may seem too expensive to expend at $200,000 a copy, it costs less than operating a B-2 for two hours or an F-35A for just over four hours or firing one Javelin anti-armor missile.[70]

Manned aircraft will remain vulnerable due to basing issues even as cruise missiles and vertical launch drones become both more capable and cheaper. While the Tomahawk is an old system, it can serve as an example of what cruise missiles can do. A Tomahawk Land Attack Missile

(TLAM) cost $785,000 in FY 2013 dollars. If additive manufacturing can achieve the 40 percent savings Lockheed projects for satellites, a TLAM will cost about $470,000. These missiles carry a thousand-pound warhead for up to 1,500 miles (Block II).[71] While somewhat expensive, missiles such as these can provide long-range heavy strike—particularly if the warhead uses nano-explosives. Since they can be fired from a variety of land and sea launchers, they can be either dispersed or hidden in underground facilities (to include commercial parking garages and commercial ships) until minutes before launching. They will thus be immune to most preemptive strikes and much less expensive than ballistic missiles. The combination of cheap drones and much more capable cruise missiles provides relatively cheap, difficult to preempt, long-range, precision strike.

San Diego-based Kratos Defense and Security Systems Inc. has dramatically upped the ante in the field of drones with the XQ-222 drone. Its 1,500-mile combat radius is over two times the F-35's, and it can fly three thousand miles if sent on a one-way mission. It also has low-observable features, a five-hundred-pound payload, and no requirement for an airfield to launch or recover. It takes off with a rocket assist from a stand and lands using a parachute.[72] Kratos promoted the XQ-222 at the 2017 Paris Air Show, suggesting that the drones could fly in tandem with F-16 or F-35 fighters to dramatically increase the capabilities of existing aircraft.[73] Even at $2 million a copy, they are orders of magnitude cheaper than the F-35. And of course, their presence at the Paris Air Show indicates America will not be the only nation with this capability.

Modern drones and cruise missiles outrange modern fighter-bombers and thus can strike those aircraft at their easy-to-detect airfields—even expeditious ones. Thus they can push the vast majority of air bases out of range of their targets. While the United States has a capable tanker fleet, the refueling orbits will also be within the range of drones like the XQ-222. Today, only bombers can outrange drones. The fact drones can be launched from commercial, oceangoing vessels may also make bomber bases vulnerable.

> *Somebody has got to step up and make procurement efficiency the top priority. The F-117 [stealth fighter] development program worked well because there were only eight people in Congress who knew about it.* —Sam Nunn

Space Warfare

In space, the advent of micro- and cube satellites paired with commercial launch platforms will allow a middle power to develop an effective space program for surveillance, communications, navigation, and even attack of other space assets. Surveillance and navigation satellites are already within reach of most small or medium powers—or they could simply buy the services from a commercial provider such as Planet Labs as even the United States does.[74] Thus it will be hard to hide bases ashore or even moving forces at sea.

Cyberwarfare

While one would not normally think of drones as part of conflict in cyberwarfare, it is important to remember that all networks have nodes in the real world. Some are quite exposed. For instance, satellite downlinks and points where fiber-optic networks come ashore are known and vulnerable. Smart drones provide a way to attack these nodes from a distance.

Mass Returns

Since the 1980s, US forces have bet on precision to defeat mass.[75] This approach helped numerically smaller Allied forces defeat Iraq's much larger army (twice) as well as initially drive al-Qaeda and the Taliban out of Afghanistan using a very small ground force. However, technological convergence is pointing to the revival of mass (in terms of numbers) as a key combat multiplier. Additive manufacturing can make cheap drones fast enough that they can be used as rounds of ammunition.

How will US forces, which are dependent on a few exquisite platforms—particularly air and sea—deal with the small, smart, and cheap? Currently, the Defense Department is testing various directed energy weapons and electronic attacks to deal with the exponential increase in potential targets. However, like all weapons, directed energy will be subject to countermeasures. It is imperative that these systems be tested against a thinking, reacting red team that employs countermeasures such as autonomy, smoke, and shielding from electromagnetic energy. And one should keep in mind that land-based systems will have major advantages in power available and protection over any sea- or air-based systems. Thus, a directed energy system will also make domain denial easier.

The Return of Mobilization

After the fall of the Soviet Union, the United States abandoned the concept of mobilization. A primary driver was the fact that the US defense industry simply lacked the surge capability to rapidly equip a mobilized population. Mobilization in World War II was possible because industry could rapidly convert from civilian to military production. By 1990, the complexity of modern military weapons systems, plus the manufacturing plants and skills needed to produce them, made such a rapid conversion difficult if not impossible. Three-dimensional printing is inherently flexible since the product produced depends only on the materials the machine can use and the software that is loaded. Thus, as additive manufacturing assumes a greater role in industry, the possibility of industrial mobilization will reemerge. However, to succeed, mobilization must be planned to provide the necessary government-unique items such as warheads and target recognition software, quickly and in sufficient quantities.[76]

The Impact of the Fourth Industrial Revolution on Russia and China

Russia and China will be affected very differently by the fourth industrial revolution. Each will benefit, but neither as greatly as the United States.

Major investments, the free exchange of information, the free movement of people, and a relatively light regulatory environment seem to be necessary to maximize the benefits of this revolution.

Russia has none of these assets and is further restricted by severe domestic challenges. A fundamental problem for Russia is that its economy relies very heavily on oil exports, yet it cannot control the price. US shale oil is currently profitable at $50 a barrel on average, and some very productive plays have cost below $30 a barrel. America's ability to rapidly increase oil production in response to price increases means the price of oil is likely to remain in this range for the next decade or more. Despite OPEC's efforts to drive up oil prices, oil remained around $50 a barrel in mid-2017.

Compounding its problems, the Russian economy performs well below other European nations. In 2016, the Russian GDP of $1.3 trillion was below that of Italy despite Russia's population being 2.4 times the size of Italy's.[77] Even using purchasing power parity, Russia's 2016 GDP per capita ranked seventy-second in the world—just behind Greece.[78] Nor is Russia's economic future promising. To free itself from dependency on oil, Russia is trying to diversify by increasing manufacturing. Yet to do so, it will require major foreign direct investment. The lack of a robust legal system, lack of clearly defined property rights, and continuing sanctions have dampened the enthusiasm of foreign investors. While Russia had a positive FDI inflow of $10 billion in 2016, that did not compensate for the previous four years' outflow of $70 billion.[79] With Putin likely to remain in power—and with him, crony capitalism—a surge in foreign investment is highly unlikely.

Thus Russia's economy remains stagnant and its population is declining sharply, with a projected drop of 10.5 percent by 2050.[80] Russian journalist Irina Grigoryeva has reported that the country is set to lose one million working-age people annually, resulting in an ongoing GDP growth rate hit of 0.4 to 0.5 percentage points.[81] Nor can Russia turn to a financial reserve to make up the difference. Because it planned its

2015 federal budget on oil at $100 a barrel, it has burned through its entire rainy day fund of over $90 billion.[82]

Even with all these problems, Russia will undoubtedly gain some benefits from the enormous increases in productivity created by the convergence of robotics, artificial intelligence, and 3D printing. However, Russia clearly lacks the political, economic, and social structures necessary to fully exploit the fourth industrial revolution.

Militarily, Putin's major effort to improve Russia's armed forces has clearly paid off. Quality and size have both increased over the last decade. However, that growth is coming to an end. Despite some highly publicized rollouts of new weapons prototypes and announcements of major expansions, the Kremlin actually cut its 2017 military budget by 25.5 percent. The cuts will remain at least through 2019.[83]

China is better positioned than Russia to benefit from the revolution but still faces major issues. Economically, China has been experiencing the normal middle-income slowdown of developing states. But it also faces a litany of major problems: a rapidly aging population, disastrous environmental conditions, massive public and private debt, a housing bubble, and the rising cost of labor. It must contend with all these problems even as it attempts to take the next step in development and shift from an export- to a consumer-based economy—all while trying to incorporate the changes driven by the fourth industrial revolution. Adapting is going to both help and hurt China. Economically, it will allow China to deal with the increasing cost of Chinese labor that has driven many manufacturers to cheaper Southeast Asian countries. In 2000, labor represented only 30 percent of China's manufacturing costs. By 2015, it was 64 percent.[84] Further, Chinese labor costs will continue to rise as China ages.

Chinese businessmen are fighting back by turning to advanced manufacturing—particularly robotics. The resultant massive improvements in productivity as well as dramatic reductions in personnel are allowing Chinese companies to remain competitive. To encourage this trend, China's government implemented its "Made in China 2025" program,

which subsidizes ten key high-technology sectors. In 2016, Dongguan City created a plan to replace human workers with robots at 1,000 to 1,500 factories to strengthen its role as a manufacturing hub.[85] Foxconn reduced its labor force in a single factory in Kunshan from 110,000 to 50,000 by installing robots guided by artificial intelligence. The Changying Precision Technology Company replaced 90 percent of its labor force by installing robots and decreased its defect rate from 25 percent to 5 percent.[86] As many as six hundred other major Chinese companies have similar plans.[87]

While the large-scale deployment of robots is creating greater wealth for China, the massive loss of jobs is eliminating the path to prosperity for a large swath of its population. The Chinese Communist Party (CCP) is very sensitive about the potential for layoffs to cause instability and is aware of the increasing income inequality across China. Even as it is struggling to maintain its competitive edge with its private companies, it continues to heavily subsidize its state-owned enterprises (SOEs). The current effort to consolidate SOEs into a few large firms is not producing the hoped-for efficiencies. Instead, SOEs, which are granted preferential treatment by the government, are crowding entrepreneurs out of the credit market. A key issue going forward is whether the Communist Party continues to favor SOEs over entrepreneurs. That decision is likely to be driven by concerns more for stability than for efficiency.

The CCP is clearly deeply concerned about internal stability. Through 2013 it was actually spending more on internal security forces than on external defense.[88] In 2014, it stopped releasing the internal security budget, but many analysts believe it still spends more on internal than external defense. Given the fact the fourth industrial revolution can greatly increase the striking capabilities of insurgents, the CCP is likely to monitor closely and perhaps restrict the development of these new technologies as potential threats to stability.

China is already a world leader in some technology sectors and will benefit greatly from the fourth industrial revolution. However, the requirement to balance growth with control and stability will keep China from achieving all it could in these areas. It is essential to keep in

mind that China is not a wealthy country. While it has the world's second largest economy, its huge population means that even measured with purchasing power parity, China ranks 102nd in GDP per capita—behind Costa Rica. And China will also be the first country to face the problem of growing old before it grows rich. By 2050, China's population will have decreased by 2.5 percent and have an age distribution similar to today's ultra-old Japan—but without Japan's wealth.[89]

On artificial intelligence, China has an ambitious goal. China wants to regain its place on the international stage, which they feel that they've been denied over the last 150 years.

—Karl Eikenberry

Great Power War

While Russia's nuclear arsenal remains an ever-present threat, it is one the United States has managed for decades. In contrast, Russia's economic, political, and social problems mean its long-term conventional threat to the West is declining. That said, Russia could seize select Eastern European states before sufficient NATO forces could arrive to stop them. The Baltic States, Finland, Sweden, and Poland recognize this fact, and all are taking steps to increase their defenses in the hope that will deter Russia. NATO is also looking at how to provide sufficient ground and air forces but understands their deployment will be too slow to stop a Russian invasion.

The creative use of swarms of autonomous drones to augment current forces could strongly and relatively cheaply reinforce NATO's deterrence. Deploying drones would increase Russia's uncertainty about its ability to execute an invasion while assuring that it will cost Russia much more to do so. If NATO assists frontline states in fielding large numbers of inexpensive, autonomous drones prepackaged in standard twenty-foot containers, the weapons can be stored in sites across the

countries under the control of reserve forces. In addition, prepackaged IEDs could be built in similar and smaller containers using ammonium nitrate fertilizer. With a proper initiating charge, ammonium nitrate is a powerful explosive. A twenty-foot container can hold fifty thousand pounds of ammonium nitrate, which is safe as long as it is stored separately from the detonator. And the use of standard shipping containers massively increases the number of trucks available for moving weapons around the country as well as drastically complicating any attempt to preemptively destroy them.

Further, if the weapons are prepackaged and stored, the national forces can quickly deploy the weapons to delay the Russian approach. Even Russia's advanced forces could be faced with very large numbers of attack drones and dense networks of improvised explosive devices. Then NATO only has to fly in the relatively small crews necessary to augment those forces. If NATO also invests in long-range autonomous drones, Russia will face punishment from drones launching from essentially unlimited locations outside the range of its own tactical air force. And of course the Russian rocket launchers will also be subject to attack from the same long-range drones. The addition of GRAMM (guided rockets, artillery, missiles, and mortars) munitions, smart mines, and autonomous drones—and the creative use of improvised explosive devices—could make even small nations very hard targets.

Deterrence can be achieved through either denial or punishment. If an aggressor knows he cannot succeed or knows the punishment inflicted will exceed any gain, a rational aggressor will be deterred. The small, smart, and cheap approach can make deterrence affordable for NATO.

Against China, the small, smart, and cheap can also provide effective deterrence for the allies. To maximize the advantages, the allies must defend rather than attack. These weapons will dramatically reinforce a plan to hold the first island chain while denying China the use of the waters inside the first island chain or access to the ocean beyond.[90] The allies will not seek to win by striking into China but by choking her international trade and thus exhausting her ability to fight. This strategy, combined with new technology, could both deny China access to

the Pacific and Indian Oceans and punish it severely through an economic blockade. Thus it meets both requirements for an effective deterrent. Further, while the People's Liberation Army (PLA) envisions winning short, "informationized local wars," the allies can establish a defense that ensures it cannot win quickly.

A key strength in this approach will be land-based systems fighting from the first island chain. However, to survive, today's allied air forces and logistics facilities must be dispersed. Major bases are simply too vulnerable to China's weapons.[91] US and Japanese forces have begun limited exercises to demonstrate they can operate their air forces from a wider range of bases. Given the level of threat today, it is essential that US and allied forces regularly practice these dispersed operations. Rather than operating from a very limited number of military airfields, the air forces must practice operating from the numerous civilian airfields throughout Japan. Demonstrating this capability will have a deterrent effect on China by greatly reducing the probability of a successful preemptive attack on forces in Japan. Naval forces can act as a mobile reserve behind the chain to prevent Chinese efforts to break out or overwhelm the defenses at a specific point.

However, dispersion only provides temporary respite. As long as air power is tethered to bases inside the range of China's growing arsenal of missiles and drones, it remains vulnerable to preemption. It is essential that the United States and Japan cooperate in rapidly designing and procuring long-range, advanced vertical takeoff and landing strike drones. We already have promising designs such as the XQ-222 and the Tern. The key is shifting investment from current systems to accelerate the development and fielding of these systems. When these systems are fielded, the basing possibilities become almost unlimited and deterrence is increased because China cannot contemplate a disarming conventional first strike. For the purchase price of one Ford-class carrier and its proposed air wing, the United States could buy ten thousand Kratos XQ-222 drones or thirty-three thousand loitering TLAMs. It is pretty obvious which creates a greater challenge for China.

Forces fighting on the defensive from the first island chain already have significant advantages against attacking Chinese air and sea forces. The most obvious is that Chinese forces will be fighting inside the allied air defense zone. The second is the fact that many of China's forces lack the range to reach the islands, and thus the allies will only have to fight a portion of the PLA. These advantages will grow as conflict shifts from few and exquisite platforms to the small, smart, and cheap. Using this strategy, the allies gain the advantage of thousands of independent, active hunters augmenting the relatively few but expensive weapons systems they currently own. Since it is easier to mass-produce drones in the range of one hundred to three hundred miles than those of five hundred to one thousand miles, the defense will have the advantage of numbers. And of course land forces inherently have much larger magazines and access to massive power infrastructures for directed energy weapons when they are developed.

As demonstrated by China's success with the construction of major naval and air facilities in the South China Sea, the US position is much less secure against Chinese "gray zone" incursions. The nations of Asia know that the South China Sea is simply more important to China than it is to the United States. Fortunately, all the nations involved understand the United States does have a major interest in freedom of navigation and will protect it, even in the South China Sea. Unfortunately, statements by President Donald Trump are contributing to the rising belief in Asia that the United States is no longer a reliable ally.

Conclusions

Unfortunately, the increasing reluctance of the US population to commit forces overseas, combined with the increasing cost of doing so in a conflict zone, does not bode well for America's ability to sustain our alliances. It will be necessary to reduce the cost to the United States and increase the visible contributions of our allies if we are going to maintain the exceptional strategic advantages our alliances provide.

The most important national security step we can take is to reinforce and reassure our allies in both Asia and Europe. As an aggressive and growing power, China can cause the most serious long-term disruptions in international security and the global economy. At the same time, North Korea is the most likely to cause a massive short-term disruption if it initiates a major war with South Korea. It would lose such a war, but only after massive devastation is inflicted on both sides.

Fortunately, in both Asia and Europe, US alliances are essentially defensive in nature, and therefore the technological advances favor the alliances. Unfortunately, alliances have tremendous inherent geographic and economic strengths but are unlikely to be sustained on the current trajectory. Converging problems with aging populations, infrastructure repair costs, medical costs, and surging military personnel and particularly procurement costs mean neither the United States nor its allies can continue along this path. However, if the United States takes advantage of emerging technologies, it can defend itself at much lower cost. Just as important, the lower costs mean the allies can assume more of the burden of their own defenses, which serves to reassure their populations as well as neutralize US complaints about free riding.

Working with our allies in Asia, the United States can provide deterrence against aggressive actions by either nation. Unfortunately, budget realities, not least the looming impact of rising federal debt interest payments, mean the United States must figure out how to assist allies in their defense in an affordable way. We can't continue on the path of buying fewer and fewer of ever more expensive weapons systems. We simply can't afford it.

Even as we continue to invest heavily in these legacy systems, China is refining numerous weapons systems specifically to attack their prime vulnerabilities: the need for major fixed bases and the limited range of most US aircraft. We are spending vast sums on systems for which China is already fielding increasingly effective counters. The first step the United States must take is to invest in further developing the new systems that will eliminate those vulnerabilities.

The United States has to maintain its current robust forward presence even as it begins to shift its war-fighting base from the few, vulnerable, and very expensive current platforms to the future force of smaller, cheaper, autonomous weapons that are not tied to major bases or sea platforms. Only by reducing costs can the United States maintain a viable strategic posture. A major benefit of shifting to small, smart, and many is that the United States can push its allies to follow suit. The deployment of a new generation of anti-ship cruise missiles, drones, and smart mines would greatly magnify China's challenges in either attacking another nation in the region or trying to maintain routes out of the South and East China Seas. Most important, these systems are simple and cheap enough that our allies could build, buy, and deploy their own in large numbers. A particular advantage is that large numbers of dispersed systems are not easily subject to interdiction. While China is building sufficient numbers of missiles and drones to gain confidence that it can destroy the few high-value US naval assets and the handful of Air Force and Marine air bases in Japan, it would not be able to gain that confidence about large numbers of containerized weapons stored in various locations across Japan.

Japan and South Korea both have sophisticated, capable defense industries. South Korea is already spending heavily on defense, so there it is a matter of shifting investment from legacy platforms to emerging ones. Currently, Japan, even with its support to US forces and its proposed defense spending increases, will not reach 1.5 percent of its GDP in the current ten-year plan. The United States must push Japan to at least achieve the NATO goal of 2 percent. It will be less difficult for Japan to increase its defense budget if the additional funds are spent on systems built in Japan by Japanese firms.

If Europe can overcome the rising nationalistic political environment, the fourth industrial revolution should bind its economy together more tightly as industry focuses on the regional market. The European Union has a GDP over twelve times the size of Russia's. Yet today, and for the immediate future, Russia has sufficient effective forces to be a serious threat to smaller nations in Eastern Europe. Thus for NATO the key question will remain one of unity. An essential element of keeping America

tightly engaged in NATO is for those nations to demonstrate an increased ability to defend the alliance against Russia. NATO nations can do so by exploiting the cheaper but highly capable weapons evolving out of technological advances. Combined with thoughtful tactics and focused organizations, they can clearly deter and defeat Russian conventional forces. The United States needs to lead the way in the transition.

An important caution is in order. Allied strategists must recognize that for over two centuries wars between major, capable powers have been long—measured in years and even decades. The ability to replace combat losses is essential in a long war. With a peak planned production rate of only seventeen F-35s per month and several years required to build a new carrier, the United States cannot produce sufficient systems for combat replacement in a long war. It must start moving to a more survivable, sustainable, affordable, and replaceable force.

It is very likely that all nations—to include the United States—will have to contend with significant decreases in military spending. The potential for cheaper ways to accomplish the same mission means all nations should be very interested in exploiting the opportunities that are emerging. To be in position to exploit the new technologies and encourage our allies to do so, the United States must lead their development. Since the overwhelming majority of the investment is already coming from the commercial section, the focus for the Department of Defense must be to identify key niche technologies unlikely to draw commercial money—such as nano-explosives, smart mine fuses, and weapons that ensure the small, smart, and many have maximum combat power. The Russians have long owned small thermobaric warheads, and the Poles have successfully used them to arm man-portable, hand-launched drones. This kind of mash-up between old technology and new will greatly increase the effective combat power of each.

The biggest obstacles to the transition to a new generation of weapons systems and new methods of warfare will remain the political constituency that benefits greatly from the current systems and the inherent conservatism of senior military leaders. But it must be done.

To usher in this shift, the United States needs to develop a comprehensive plan for phasing in the replacements for its current extremely

expensive and increasingly vulnerable weapons systems. Further, only if the United States leads the way in this transition will allied military leaders accept this new approach. Yet only by encouraging our Asian and European allies to rethink their procurement decisions can they afford to create real deterrent capabilities against Russia and China.

Like previous transitions (the carrier replacing the battleship, and precision munitions replacing dumb bombs), this one should follow the concept that the new technology first assists, then partners with, and finally replaces the old systems. We are well along on this path already in many areas. Today, drones have replaced manned aircraft for long-term surveillance in a low-threat environment. Cruise missiles are full partners—and often replacements—for manned aircraft. The Department of Defense has to make this a conscious procurement strategy rather than the current system of random evolution.

Today's transformations represent not merely a prolongation of the third industrial revolution but rather the dimly perceived arrival of a fourth and distinct one: velocity, scope, and systems impact. The speed of current breakthroughs has no historical precedent. In Klaus Schwab's words: "When compared with previous industrial revolutions, the fourth is evolving at an exponential rather than a linear pace. Moreover, it is disrupting almost every industry in every country. And the breadth and depth of these changes herald the transformation of entire systems of production, management, and governance."[92]

The United States' connectedness to the global economy will decrease, and thus the political will to bear the burden of providing international security—particularly in stability operations—will decrease. The high cost and perceived strategic failures in Vietnam, Somalia, Iraq, Afghanistan, and Syria have already significantly decreased the willingness of the American people to get involved in conflicts overseas. The continuing failure of allies to spend what many Americans perceive to be their fair share in their own defense remains an issue that angers many American voters.

The cumulative effect on the American public's willingness to stay engaged overseas has been remarkable. A 2016 Pew Research Center

poll on the issue reported, "Nearly six-in-ten Americans (57 percent) want the U.S. 'to deal with its own problems and let other countries deal with their own problems as best they can.'" Just 37 percent said the United States should help other countries deal with their problems.[93]

At the same time, the fourth industrial revolution will provide smaller states and even nonstate actors with systems capable of inflicting significantly higher costs if the United States does choose to intervene. Further, the vulnerability of intermediate support bases will make the host nations much less likely to allow US forces to operate from those facilities except in time of very serious threat to the host nation.

The good news is that the United States is the nation best positioned to derive maximum economic gains from the fourth industrial revolution. US businesses are rapidly adapting to do so. The Institute for Supply Management announced on October 2, 2017, that its index of manufacturing activity was at its highest reading since May 2004.[94] And despite all the challenges noted above, the United States is in a good position to derive major national security benefits from the revolution. However, just as businesses cannot continue to operate based on old concepts, the government cannot provide for national security without making major changes to take advantage of the revolution.