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# Birth of Industry 5.0: Making Sense of Big Data with Artificial Intelligence, "The Internet of Things" and Next-Generation Technology Policy

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## Abstract

Driverless cars with artificial intelligence (AI) and automated supermarkets run by collaborative robots (cobots) working without human supervision have sparked off new debates: what will be the impacts of extreme automation, turbocharged by the Internet of Things (IoT), AI, and the Industry 4.0, on Big Data and omics implementation science? The IoT builds on (1) broadband wireless internet connectivity, (2) miniaturized sensors embedded in animate and inanimate objects ranging from the house cat to the milk carton in your smart fridge, and (3) AI and cobots making sense of Big Data collected by sensors. Industry 4.0 is a high-tech strategy for manufacturing automation that employs the IoT, thus creating the Smart Factory. Extreme automation until ''everything is connected to everything else'' poses, however, vulnerabilities that have been little considered to date. First, highly integrated systems are vulnerable to systemic risks such as total network collapse in the event of failure of one of its parts, for example, by hacking or Internet viruses that can fully invade integrated systems. Second, extreme connectivity creates new social and political power structures. If left unchecked, they might lead to authoritarian governance by one person in total control of network power, directly or through her/his connected surrogates. We propose Industry 5.0 that can democratize knowledge coproduction from Big Data, building on the new concept of symmetrical innovation. Industry 5.0 utilizes IoT, but differs from predecessor automation systems by having three-dimensional (3D) symmetry in innovation ecosystem design: (1) a built-in safe exit strategy in case of demise of hyperconnected entrenched digital knowledge networks. Importantly, such safe exists are orthogonal—in that they allow ''digital detox'' by employing pathways unrelated/unaffected by automated networks, for example, electronic patient records versus material/article trails on vital medical information; (2) equal emphasis on both acceleration and deceleration of innovation if diminishing returns become apparent; and (3) next generation social science and humanities (SSH) research for global governance of emerging technologies: ''Post-ELSI Technology Evaluation Research'' (PETER). Importantly, PETER considers the technology opportunity costs, ethics, ethics-of-ethics, framings (epistemology), independence, and reflexivity of SSH research in technology policymaking. Industry 5.0 is poised to harness extreme automation and Big Data with safety, innovative technology policy, and responsible implementation science, enabled by 3D symmetry in innovation ecosystem design.


**Keywords:** artificial intelligence, Big Data, Industry 5.0, Internet of Things, technology policy

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> ''The crisis consists precisely in the fact that the old is dying and the new cannot be born; in this interregnum a great variety of morbid symptoms appear.''
>
> **Antonio Gramsci** (1891–1937)



### Making Sense of Big Data in Flux–an Interregnum

Investments in and expectations from Big Data have placed translational research and implementation science communities under enormous and painful new pressures to rapidly edge toward innovative products and applications. Big Data in health are no exception to such a ''science push'' model of valorizing scientific discoveries, conceptualized on a linear one-way trajectory from laboratory to medical practice to society. The reality on the ground is much different, however. Innovations, unprecedented by definition, do not necessarily follow a linear line from data to knowledge to application (Didier et al., 2015; Guston, 2008; Guston et al., 2009; Özdemir, 2018; Penders, 2017).

Big Data, due to its enormous volume, velocity, and variety, not to mention contested veracity, demand innovation in the ways we make sense of Big Data in flux. Old ways of translational research and hasty solutions for implementation science are not a panacea, and unlikely to succeed in Big Data environments (Özdemir and Kolker, 2016; Pavlidis et al., 2016).

For example, a traditional reflex response to translate scientific discoveries into clinical, social, and economic progress has been to build large-scale international implementation consortia. This appears to be a global predilection to valorize multi-omics and other forms of Big Data, in both developed and developing countries (Alberts, 2012; Özdemir et al., 2015). On the other hand, Big Data and its five ''Big Vs'' noted above (volume, velocity, variety, veracity, and valorization) cannot be matched by the limited scale, speed, or geographical diversity of traditional implementation science practices, no matter how resourceful and mighty an implementation consortium could be. Moreover, Big Data require real-time analytics for sense making and to capture value from their ever-changing temporal, spatial, and hierarchically distributed open form and fluid nature. In short, in the digital and Big Data age, harnessing discovery science is not what it used to be. The old ways of doing science are arguably dead, but the ways forward, and those that bode well with responsible innovation, are not clearly visible on the horizon for Big Data implementation science, and in the dynamic domain of Big Data in health in particular.

Today, Big Data in health have us on the verge of great prospects, but looking at the current implementation science practices that bring together the physical bodies and resources of investigators in the form of implementation consortia does not inspire confidence that we are well poised to harness the promises of Big Data, or can weather its unintended consequences without turmoil to individuals and society (Özdemir and Patrinos, 2017).

In the beginning of the 20th century, Antonio Gramsci, a prescient social theorist quoted above, observed that the old ways of doing things are dead and yet, the new designs and ways forward cannot be born. Gramsci was referring to an interregnum, historically reserved to indicate a temporal discontinuity in governance, a state and period of confusion and unsettling chaos between the end of one royal sovereign and its successor. Gramsci broadened and transferred the interregnum concept, however, to situations when one social order deceases, and yet the new order and ways of doing things are not yet apparent or are at the design stage, thus not robust enough for practice (Bauman, 2012; Gramsci, 1971).

We suggest that Big Data are now at an interregnum because the reflex tendency of consortia building and similar physical scale-up methods to translate discovery science to global innovation is ill suited and insufficient for Big Data, and its open form and fluid attributes. Instead, we need cyber-physical systems (CPS) for Big Data implementation science as discussed below.

What appear to be promising new solutions to address the Big Data valorization interregnum, the CPS, Internet of Things (IoT), Industry 4.0, smart factory, and artificial intelligence (AI), are not yet in the mainstream thought in medicine and life sciences (Burrus, 2014). The healthcare personnel and graduate students in life sciences ought to be exposed to and experienced in the emerging concepts of the IoT, AI, smart factory, and Industry 4.0, and the ways in which they might transform knowledge translation and medical implementation science in the near future. These new technologies are envisioned to impact society and daily life in unprecedented ways (Didier et al., 2015), not to mention manufacturing and retail services for scientific products, and possibly, even basic scientific discovery and serendipity in the next decade (Schwab, 2017). Yet, such emergent expectations, concepts, and practices are currently left, by-and-large, to the domain of financial investors, industrial engineers, smart factory entrepreneurs, and information and communication technology (ICT) experts.

Big Data in health, such as precision medicine, require not only mass scale production but also custom manufacturing of systems diagnostics in flexibly designed smart factories. The manufacturing design is, therefore, a cornerstone of medical implementation science. The IoT, AI, or whichever tools might be utilized to translate Big Data to knowledge-based innovation in the future, will have to address the attributes of real-time flexibility in manufacturing for customization versus mass production of healthcare innovations.

This technology governance and policy analysis have therefore three interlinked objectives:

1. We discuss the definitions, contexts, and the unprecedented ways in which the IoT and Industry 4.0 offer transformative potentials for Big Data, from discovery to implementation science to the retail and services industry,
2. Show that the new Big Data implementation tools such as Industry 4.0, surprisingly and ironically, are themselves at an interregnum (as with Big Data itself) because their (e.g., Industry 4.0) design has not yet addressed the systemic vulnerabilities associated with automation and extreme integration, and
3. Introduce two new concepts and governance instruments, symmetrical innovation design and Industry 5.0, as remedies to the current impasse in our toolbox

for translating Big Data to disruptive innovation with safety and robust global governance for new technology policy.

## Until Everything Is Connected to Everything Else

### *Welcome to the IoT*

We live in a hyperconnected world and nothing seems too far, virtually. This was not always so. An unprecedented convergence over the last decade in three technology domains cultivated extreme automation, hyperconnectivity, and ultimately, the IoT:

1. Broadband wireless internet availability and emergence of an inescapable, ubiquitous, and distributed computing environment across the planet,
2. Miniaturized sensors built into everyday objects and manufactured products as diverse as the milk carton in the refrigerator, home security and health monitoring systems, and collecting, connecting, and communicating data with sensors embedded in other products and humans, and
3. Collaborative robots (cobots) powered by AI and machine learning that permit real-time data analyses, learning, and sense making from Big Data streaming in from the embedded sensors of the IoT.

The IoT refers to this pervasive hyperconnected computing environment, and the associated societal, industrial, and scientific practices, and human values in flux, which are collectively changing how data, knowledge, and innovation are currently produced and consumed. Not only humans and other living organisms but virtually any object, animate or inanimate, are connected to the IoT and ''talk'' to each other through sensors and wireless connectivity, tracked in real-time, and in a state of constant learning from the Big Data they are generating and consuming at the same time.

If the self-tracking enabled by Quantified Self Movement (Stewart et al., 2013) or Direct-To-Consumer personal genome testing seemed too intense, in the context of the IoT, the quest is one of ''quantified planet,'' and perhaps beyond.

''Connect the unconnected'' is the motto for the IoT, irrespective of the nature of the connected things. In other words, a virtual replica of the physical world, and increasingly, replicas of biological and living matter are being produced and connected to each other with the advent of the IoT. The boundaries among the virtual, physical, and biological worlds have thus become blurred, creating the CPS.

The Intel makes the interesting point that ''most IoT smart devices are not in your home or phone—they are in factories, businesses, and healthcare'' (Intel, 2017). The applications of IoT range in size from miniscule to mammoth factory machines, smart buildings, and smart cities. Some are old and others are new. Automated teller machines (ATMs) have been online since 1974. ATMs are one of the oldest smart connected devices. More recent applications are smart power meters, digital locks, and smart dust made up of ''computers smaller than a grain of sand [that] can be sprayed or injected almost anywhere to measure chemicals in the soil or to diagnose problems in the human body'' (Intel, 2017). Size matters, too, in the case of smart cities. Using mobile and fixed sensors, the city of Dublin has been creating a real-time digital map of the city that, in effect, might be utilized in the future for crisis management and various other purposes for city governance.

Kevin Ashton, who coined the term IoT in 1999, explained that the IoT is not simply barcoding of objects nor robots executing predetermined computer scripts:

> In the twentieth century, computers were brains without senses—they only knew what we told them. That was a huge limitation: there is many billion times more information in the world than people could possibly type in through a keyboard or scan with a barcode. In the twenty-first century, because of the Internet of Things, computers can sense things for themselves. It's only been a few years, but we already take networked sensors for granted. One example is GPS-based location sensing (Gabbal, 2015).

According to some analysts such as Gartner, a technology research firm, the number of wirelessly connected smart objects, excluding smartphones or computers, has exceeded 8 billion worldwide by end of 2017. Over 20 billion connected objects are estimated by 2020 (Gartner, 2017). Intel, a stakeholder in the Big Data innovation ecosystem, forecasts a much larger figure, over 200 billion wirelessly connected objects by 2020 (Intel, 2017). With a conservative estimate, there were more connected things, 8.4 billion, than the number of humans on the planet by the end of 2017, with North America, Western Europe, and Greater China representing 67% of the global IoT (Gartner, 2017).

## Industry 4.0–The Prospects

### *A fourth industrial revolution in the making?*

It is not uncommon for new technology practices to be framed under an ethos of ''revolution'' in scientific discourse and the mass media (Özdemir et al., 2017a; Pavlidis et al., 2016). Not surprisingly, the current introduction of the IoT and CPS to factories, supply chain management, and manufacturing has been heralded as the Industry 4.0 (Kagermann, 2014) or the fourth industrial revolution (Schwab, 2015, 2017).

However, not everyone agrees that we are at the dawn of a fourth industrial revolution (Garbee, 2016). The term ''fourth industrial revolution'' has been reportedly in existence for more than 75 years. It was introduced in 1940 in Albert Carr's article entitled ''America's Last Chance'' (Carr, 1940).

This is not to say, however, that technologies cannot cause disruptive societal change (and vice versa) or a discontinuity between past and present scientific practices, thus justifying the use of the term fourth industrial revolution. In this context, a brief history of the past three industrial revolutions since the 18th century is informative, before we discuss the prospects and the challenges of Industry 4.0.

Steam power and its applications toward textile and iron industries in the 18th and the 19th centuries have contributed to the emergence of the first industrial revolution. This was accompanied by liberation of humans from dependence on animal power, and a move from agrarian to industrial, and from rural to urban societies. The second industrial revolution materialized in the late 19th to the early 20th century. It was characterized by mass production enabled by electric power, disruptive innovations such as the light bulb and telephone, and new industries built on steel and oil. The third industrial revolution was enabled in the second half of the 20th century by computerization and automation of production, the rise of personal computers, the Internet, and ICTs.

The term ''Industry 4.0'' was coined and promoted by Henning Kagermann and colleagues as part of the German federal government's high-tech strategy, and in response to the digitization of manufacturing over the previous decade (Kagermann, 2013; 2014). Germany has had a historical stronghold in manufacturing. It is not surprising that the initial advocates of the IoT, CPS, and Industry 4.0 have emerged from Germany. The Industry 4.0 practices are spreading to diverse science and technology domains, including Big Data in health. As such, the physical and the virtual worlds are being connected across the planet. Together, the IoT and CPS have enabled this Industry 4.0 movement. One can produce a digital and real-time replica of all objects, living and inanimate, in a given space and time, whether it is on a factory floor, hospital, building, smart city, or in retail and customer services.

It is interesting to note that, while practices such as the barcoding of objects have allowed a structural and static mapping of the supply chain and factories in the 20th century, the availability in the 21st century of sensors and pervasive wireless Internet connectivity has created the CPS, and ultimately, the real-time, functional and dynamic mapping of not only factories and manufacturing but also all things, living or inanimate. In this context, an analogy from the life sciences and genomics medicine is in order. For example, sequencing of the human genome has provided an initial structural map of the genome. Yet, it was the emergence of functional genomics and postgenomics technologies such as proteomics that brought about a functional and dynamic representation of the genome in living cells. In this sense, the IoT and Industry 4.0 practices in manufacturing, and more recently, in retail and customer services, are more than a simple structural barcoding map. They promise a real-time display of all things on the planet.

### *Applications in smart factories and retail services*

Klaus Schwab, the Founder and Executive Chairman of the World Economic Forum, has commented on the prospects of Industry 4.0:

> The possibilities of billions of people connected by mobile devices, with unprecedented processing power, storage capacity, and access to knowledge, are unlimited. And these possibilities will be multiplied by emerging technology breakthroughs in fields such as artificial intelligence, robotics, the Internet of Things, autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage, and quantum computing.

With Industry 4.0 and smart factories, mundane and repetitious tasks are being phased out of humans to cobots who can perform them swiftly, and without human supervision (Fig. 1). The allure of cobots is not trivial for the employers: cobots can work day and night shifts, and do not require lunch or coffee breaks. When the complexity of a task exceeds certain thresholds, or requires tacit knowledge that cannot be codified, tasks are channeled directly to human intelligence, or rerouted from cobots to humans (Fig. 1).

There are numerous emerging applications of the Industry 4.0. An obvious and low-hanging fruit is the supply chain management in smart factories. The German company Trumpf, known for manufacturing machines that help manufacture other machines, such as tools to cut and work metal sheet, has been implementing Industry 4.0 on the factory floor by making its products and machines ''smart'' through packing them with sensors and wireless connectivity. Axoom is an online platform developed by Trumpf as an Industry 4.0 enabler. Axoom connects the smart machines produced by Trumpf and other manufacturers. Before the supply of raw materials runs out, a new supply can be ordered on time by Axoom, thus automating and integrating manufacturing in the smart factory in real time.

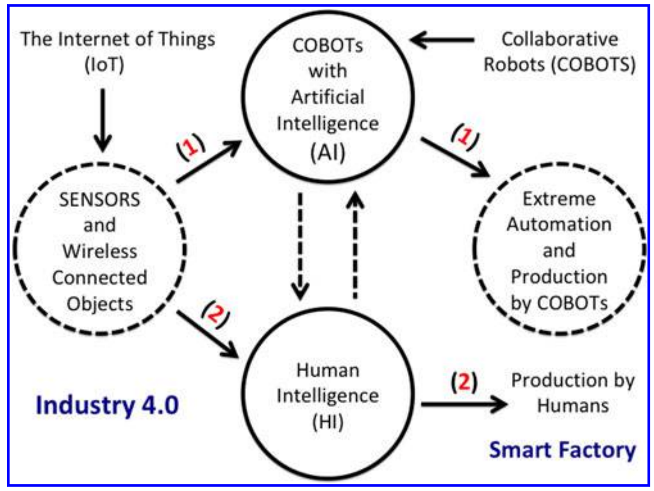


**FIG. 1.** Industry 4.0 and the Smart Factory. Sensors embedded in various animate and inanimate objects situated in diverse physical spaces and time zones across the planet collect and relay Big Data to (1) cobots that achieve extreme automation and production by AI in smart factories. When the complexity of sense making exceeds a certain threshold or requires tacit contextual information, sensors relay Big Data for sense making by (2) human intelligence (HI) and production. After providing contextual or tacit information, humans may refer the tasks back to the cobots (note the two-directional dashed lines between AI and HI in the figure). AI, artificial intelligence; cobots, collaborative robots.

Because cobots are equipped with AI, they are quite different than the robots of the 20th century that would require prior programming. Cobots engaged in smart factories and Industry 4.0 employ AI and machine learning; they do not need to be explicitly programmed, but can learn from the Big Data they collect and process. Some have even suggested that, ''what the steam engine did for the physical tasks, AI will do it for cognitive tasks'' (Berube et al., 2017). Autonomous vehicles equipped by AI learn from Big Data on human driving, while natural language processing examines previous conversations and learns how to respond to customers and human users.

The initial focus of Industry 4.0 applications has been on the supply chain management, manufacturing and production. The sensors embedded in smart products have expanded the applications to the domain of service and retail industries (Fig. 2). Notably, such ''smart services'' within the Industry 4.0 paradigm do not have to be related to the primary use of a given smart product. Take, for example, the car industry. Smart objects and sensors in cars can collect ambient

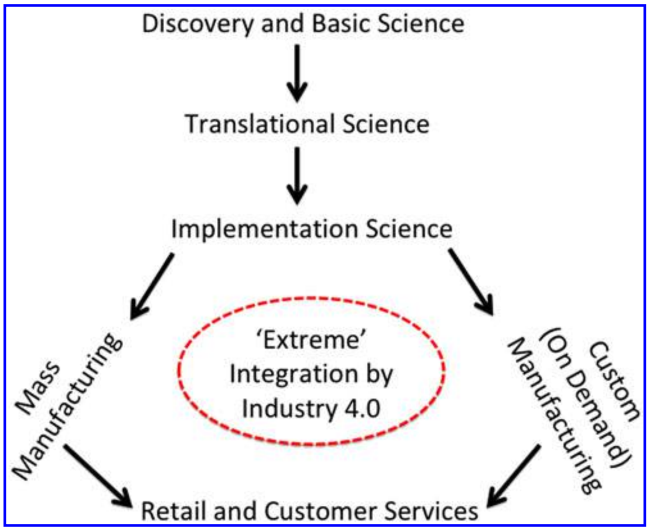


**FIG. 2.** Innovation fields envisioned to be impacted by extreme integration and Industry 4.0. As a concept, Industry 4.0 has been initially coined to impact production and manufacturing systems, but its applications have extended to retail and customer service industry as well. While serendipity and human intelligence will continue to be important, discovery science, too, may be impacted by AI, automation, extreme integration, and Industry 4.0.



temperature and humidity information from the windshield wipers for real-time weather forecasting, or passenger lifestyle and mobility data that can feed into a host of societal applications, intended or unintended. This means the locus of organizational power and bottlenecks are shifting from ''producing things'' to software and data network platforms, and collecting and making sense of Big Data.

Amazon Go is a new prototype of a futuristic retail store where there are no cashiers and no checkout is required (Leswing, 2017). The store, in Beta trial in downtown Seattle and opened to Amazon employees in early 2017, offers milk, bread, and other staple groceries, as well as ready-made foodstuff. Amazon Go employs some of the technologies that have enabled Industry 4.0 and the self-driving cars: computer vision, sensor fusion, and machine learning that can sense and itemize in a virtual cart the products taken from or returned to the shelves in the retail store. With no cashier or checkout line, Amazon Go automatically charges the customer's account upon leaving the store. A key question that is debated increasingly is, therefore, whether the cobots, AI and Industry 4.0, will supplement human labor and liberate workers from mundane tasks and have humans focus more on tasks that demand executive skills, or conversely, supplant certain types of professions and employees such as cashiers in retail stores, or those earning a living driving taxis and trucks, who might potentially be replaced in the future by automated checkouts and autonomous vehicles.

### *Industry 4.0 prospects in medicine and life sciences*

Industry 4.0 has not been firmly at the epicenter of clinical medicine and life sciences yet. This contrasts with other fields such as AI, the automotive industry and self-driving cars, industrial engineering, supply chain management, manufacturing, customer, and retail services where the IoT and Industry 4.0 are prominently featured and debated.

Precision medicine is a type of Big Data in health that stands to benefit from the IoT and Industry 4.0. Precision medicine-related Big Data emerge from multiomics (Adadey et al., 2017; Alessandrini et al., 2016) and broadly framed environmental (envirotome) research (Hekim and Özdemir, 2017). The availability of affordable sensors (embedded, wearable, mobile, environmental, etc.), and the vast communication and computing capabilities of the IoT, open up enormous possibilities for innovation in participatory and precision medicine. For example, patient- and citizen-centric data can be collected beyond randomized controlled trials so as to understand the broader context dependency of emerging precision treatments and scientific claims for inventions. The open and distributed nature of the IoT can permit peer-review of Big Data collected in community settings for triangulation and validation by independent users and scientists. Patients, citizens, and healthy individuals can have greater ''upstream'' opportunities to contribute to scientific design, and research agenda setting, in addition to sense making from Big Data.

Industry 4.0 can help design flexible manufacturing systems for precision medicine diagnostics that are custom made for vertical (niche) markets and patient subpopulations, as well as mass production for horizontal markets and large populations. In diagnostics retail services, Industry 4.0 would allow patients to access precision medicine diagnostics, for example, through automated pharmacies integrated with genetic counseling and other clinical services.

In translational science, extreme connectivity at the scale of Industry 4.0 could permit collection of real-life and deep phenotyping data for precision medicine, through sensors embedded in objects (e.g., in passenger cars as noted earlier, or with wearable smart textiles) from patients and healthy individuals in the course of a routine day at work or home. AI might potentially be harnessed to conduct real-time association analysis between multiomics Big Data and deep phenotypes. Such prospects would certainly enrich the efforts for omics biomarker discovery using robust and relevant phenotypic data, and real-time association analysis powered by AI. In rural communities with logistic challenges or geographies that are not readily accessible by ground, air, or sea transportation, the IoT and CPS could help collect phenotypic Big Data from neglected and underserved populations (de Andrés et al., 2017).

Similar to supply chain management and scheduling time-sensitive tasks in manufacturing, adherence to medicines can be enhanced by smart monitoring systems powered by the IoT to remind patients when to take their medicines, and prevent adverse drug-drug and drug-food interactions.

These anticipated applications of Industry 4.0 enabled by the IoT and CPS are only the tip of the iceberg for a much broader range of conceivable applications in medicine and life sciences: from discovery to translational research, to omics implementation science.

With an aging world population, the rise of chronic diseases and their treatment costs, and the shortage of medical staff for long-term care, medical care will likely be migrating, in part, from hospitals to home care. The IoT and Industry 4.0 resonate well with such anticipated shifts in medicine and health policy as well.

### Industry 4.0—The Unchecked Assumptions

Innovation ecosystems need to be governed, and cannot be left alone to their own course (Guston, 2015; Özdemir 2017, 2018). The decisions concerning the selection of conceptual frameworks (epistemologies) that inform innovation ecosystem governance are important because they influence what, why, where, how, and for whom the innovations materialize or not.

How do we develop global governance frameworks and innovative technology policy for Industry 4.0 and similar network-driven practices in the digital age?

A willingness to examine and awareness of the unchecked assumptions in Industry 4.0 ecosystem design are important first steps in building global governance models that are innovative, relevant, robustly efficient, and responsible. We list below four design asymmetries in Industry 4.0 conceptualization and its design that we think are hitherto unchecked assumptions and shortcomings, which need to be addressed to achieve the twin goals of efficient and responsible innovation ecosystem design.

#### *Design asymmetry 1: extreme integration without a "safe exit strategy" from networks*

An awareness of the unchecked assumptions in innovation ecosystem design contributes to sustainability, stability, and transparency of innovation processes and their impacts, not to mention accountability in societal distribution of new power systems created as a result of innovations. In this context, most of us have come to accept, uncritically, the framing of Industry 4.0 under the dogma ''connect the unconnected until everything is connected to everything else.''

Being connected can be useful from a practical standpoint, but such narrow focus on extreme integration and making connections among the unconnected are not without its problems. The emerging applications and the enormous potentials of Industry 4.0 notwithstanding, the current innovation ecosystem designs and their global governance ought to be questioned against the risk of monolithic reliance on a single epistemological frame such as extreme integration at all costs, and of all things on the planet. Moreover, extreme integration and hyperconnectivity pose system scale vulnerabilities that have been little considered to date.

Highly integrated continuous/porous networks are vulnerable to systemic risks such as total network collapse in the event of failure of one of its parts, for example, by hacking or Internet viruses that can fully invade integrated systems. Consider, for example, the WannaCry malicious software and cyberattack that inflicted extensive damage at the UK National Health Service and elsewhere in 2017:

> WannaCry malicious software has hit Britain's National Health Service, some of Spain's largest companies including Telefónica, as well as computers across Russia, the Ukraine and Taiwan, leading to PCs and data being locked up and held for ransom. […] The co-ordinated attack had managed to infect large numbers of computers across the health service less than six hours after it was first noticed by security researchers, in part due to its ability to spread within networks from PC to PC (Hern and Gibbs, 2017).

Domino effects that lead to large-scale network damage in fully integrated systems are not necessarily limited to electronic medical records (EMRs) or caused only by Internet viruses and malicious computer software. Take, for example, the North American power grid that is one large connected network and a significant engineering accomplishment of the 20th century. However, a combination of natural and human factors led to a massive electric power blackout in eight states in the northeastern United States and in the Canadian province of Ontario on August 14, 2003, affecting nearly 50 million people. The network failure occurred after failure of an alarm system in northern Ohio that rapidly cascaded into a blackout in the northeast power grid (Minkel, 2008). The power was restored only after 4 days in some affected regions.

Social scientists and philosophers have long noted, therefore, the double-edged nature of networks and uncritical networking in human practices and societies. Networks bear the potential to create power structures that can lead to hegemony if they are left unchecked (Bourdieu and Wacquant, 1992; Foucault, 1980; Haraway, 1988; Özdemir et al., 2015). Pragmatically, automation and integrated networks can enable innovations, and help bring new ideas and human practices up to scale. On the other hand, extreme integration and sticky networks without safe exit mechanisms in place can create monocultures in science, diminished creative outputs, and system scale vulnerabilities (Özdemir et al., 2015, 2017b; Thoreau and Delvenne, 2012).

At this early stage of Industry 4.0 conceptual development and emerging applications, not to mention vast expectations to connect-the-unconnected across the planet with the IoT, it seems equal attention is warranted for safe exit strategies from integrated networks if and when needed, or prudent measures to contain local failures within an IoT connected network so local events and failures do not scale up to adversely impact the entire networks.

#### *Design asymmetry 2: filter bubbles versus open systems*

Filter bubbles can potentially emerge as a corollary of extreme integration brought about by Industry 4.0. Filter bubbles refer to a situation when monocultures such as an ethos of extreme integration, or entrenched, uncritical thinking and narrow epistemologies dominate how we make sense from science and technology. Other defining features of filter bubbles are (1) lack of reflexivity and awareness on how our own values influence the type of conclusions we draw in science and society and (2) lack of appreciation of the societal and human power-related contexts in which science and technology such as the IoT and Industry 4.0 are situated.

The race to collect Big Data from users by Industry 4.0, and personalization of online searches by the Internet giants such as Google and Facebook based on where we login, what we have searched for in the past, and other user attributes are creating filter bubbles that increasingly define (and narrow) the range of our online experiences, exposure to alternative epistemologies, and how we consume data and information (Pariser, 2011). Such personalization of online experiences by Internet firms brings experiences that are familiar to and consistent with our past preferences. However, the filter bubbles and online networks that are personalized based on past preferences also limit the creative sparks from chance encounters with people and ideas that are unprecedented or markedly different than our own.

While the Internet, wireless connectivity, AI, and their spin-offs such as the IoT and Industry 4.0 bear the potential to democratize data, knowledge production, and consumption, they can also constrain open systems through unchecked filter bubbles, and have the Internet instead close in on itself by limiting exposures to diverse conceptual frames, data, and knowledge.

To the extent that futures are envisioned as a linear extension of past user practices by Industry 4.0, filter bubbles will likely be posing a real threat to the openness, efficiency, and creativity anticipated to be cultivated by the IoT and Industry 4.0.

### *Design asymmetry 3: acceleration versus deceleration of innovations*

Innovations in science and technology are, generally, future-oriented practices (Borup et al., 2006). They depend on mobilization of expectations on and investments for new opportunities and capabilities, as well as a sense of immediacy/actionability, thus bringing the futures to the present. Governments, publics, economy and trade ministries, academics, industries, funders, and philanthropists have invested in knowledge-based innovations over the past decades and are under enormous pressures to provide returns for their investments. Yet, by its very definition, innovations are unprecedented products, processes, and services, and may never come to fruition or not until after considerable time lag after an investment is made. This seems to hold for innovations as public goods and/or in the private sector due to inherently unknown and unknowable nature of innovation that cannot be simply and narrowly projected as a linear extension of the past practices and ideas.

Still, framing of new technologies and anticipated innovations as ''revolutions'' is not uncommon by innovation actors if and when they need to further legitimize the projected futures in the present to garner social capital.

Put in other words, the framing of new scientific practices and technologies as revolution often has an unchecked political dimension to garner human or organizational power and investments by innovation actors. Despite possible ephemeral gains, overpromises of technological artifacts as revolutions can be detrimental in the long term for robust and socially attuned impacts, trustworthiness, and sustainability within an innovation ecosystem.

Instead, we can choose to embrace multiple possible innovation futures, broader range of outcomes, and social contingencies that actually shape innovation trajectories.

For example, Phase III clinical trials in pharmaceutical development are large-scale research studies required for regulatory registration and market introduction of drug candidates. However, only a small fraction of compounds make it to the market as drugs with regulatory approval. Often forgotten is the fact that Phase III trial networks employ numerous staff across multiple countries and create a mutual dependency for the livelihood of many persons and families. It is not uncommon that such networks can potentially be entrenched within filter bubbles and a Phase III clinical trial team/network might continue or even accelerate despite evidence of diminishing returns and failure of a drug candidate in the clinic. Such political and social factors impact the outcome of drug development and the types of evidence produced, but are not always taken into account by scientific communities. Hence, acceleration and revolution narratives have had historically a strong buy-in by scientists and innovators because they help sustain, mostly for short-term gain and immediacy, the status quo investments and thinking in an innovation ecosystem, and to the detriment of new ideas, long-term sustainability, and socially attuned responsible innovation.

Considering both acceleration and deceleration as the twin governance narratives, not to mention the opportunity costs of new technologies and innovations, would serve well for long-term sustainability of innovation ecosystems, be they guided by Industry 4.0 or other new approaches.

### *Design asymmetry 4: technology versus societal outcomes*

Thus far, drivers of the Industry 4.0 theory and practice have been solution-oriented professions such as engineering, investors, and industries that recognized with foresight the need to reinvent their organizations in the digital age, and with emergence of the IoT. The Industry 4.0 impacts on society (and vice versa) have been relatively understudied compared to technical research on Industry 4.0 and the IoT.

The normative dimensions of Industry 4.0 (responsible/irresponsible, ethical/unethical) and policies that will define global governance of Industry 4.0 are also lacking, again perhaps because its initial drivers were mostly solution-oriented professions rather than social sciences and humanities (SSH) scholars.

The discussions on ''Industry 4.0 and Society'' have tended to focus on either a dystopian fearful future shaped by the IoT where cobots with AI replace humans, or a future that will invariably be benevolent and prosperous for all with the introduction of the Industry 4.0. Both visions subscribe, however, to technological determinism and as if the emergence of Industry 4.0 and its societal shaping and impacts are preordained and inevitable. They do not yet acknowledge the need to broaden our understanding of Industry 4.0 outcomes and its multiple possible futures in society.

This asymmetry from understanding Industry 4.0 as a narrow technical and logistics issue ought to be addressed by next-generation and broadly framed SSH and global governance research on Industry 4.0 and society, as discussed in the next section.

## Industry 5.0

### *Toward a symmetrical innovation ecosystem design*

Our discussion above has highlighted the existing asymmetries and limitations within the Industry 4.0 innovation ecosystem design. They are important to remedy for a robust, sustainable, and responsible innovation ecosystem design in the digital age, and particularly for the networked large-scale scientific practices such as Industry 4.0.

Chief among these asymmetries is the need to consider a safe exit or containment strategy in the event a section of a highly connected IoT network collapses, exposed to malicious software or other nondigital threats that can propagate rapidly in open networks.

We propose here Industry 5.0—as an evolutionary, incremental (but critically necessary) advancement that builds on the concept and practices of Industry 4.0. For our purposes, addressing the above hitherto underappreciated four asymmetries in the Industry 4.0 ecosystem design under innovative global governance frameworks is timely, and the primary objective of the Industry 5.0. Others may wish to name it differently as Industry 4.0 Plus, Industry 4.0 Symmetrical, Industry 4.0-S, or other terminology—so long as the above potentially disabling gaps and asymmetries in the Industry 4.0 innovation ecosystem design are considered.

Industry 5.0 offers a three-dimensional (3D) symmetry in innovation ecosystem design as we outline below.

Reinstating symmetry in ecosystem designs is possible, we suggest, by a built-in safe exit strategy from the Industry 4.0 innovation ecosystem, in case of demise of hyperconnected entrenched digital knowledge networks. Importantly, such safe exists should be orthogonal—in that they can offer ''digital detox'' by employing pathways unrelated/unaffected by automated open networks, for example, electronic medical records versus material/article trails on certain vital medical information.

The word orthogonal refers to the situation, for example, when two parameters, X and Y, are positioned perpendicular to each other, and so what changes happen in the X do not affect the Y, and vice versa. In psychology, orthogonal can refer to qualities and personality characteristics that are completely independent from each other.

The key premise of ''an orthogonal exit'' is that whatever happens in hyperconnected networks does not impact the orthogonal exit pathways, and hence our use of the safe exit strategy terminology. Because the IoT is an open hyperconnected global network, and the prevailing framework in the digital age is one of extreme integration, it would be prudent to maintain orthogonal exits as safety valves for the constituents of networks (Fig. 3).

For example, in underground coal mines with an extensive network of mining corridors, safe exit systems exist, or alternatively, refuge stations and safe havens connected to the surface through a borehole supply air, water, and food in case of partial or complete collapse of the mine.

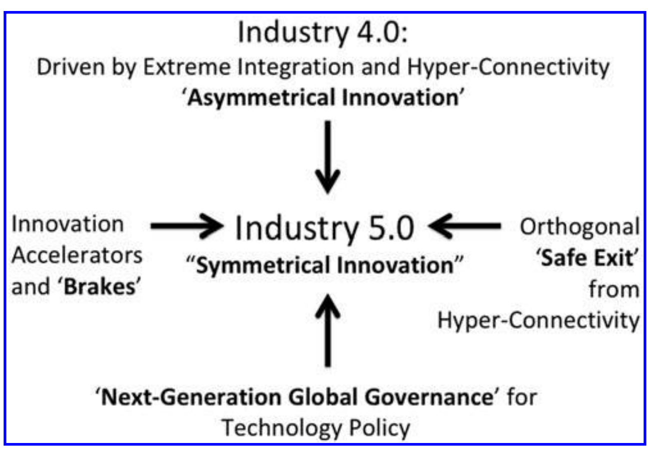


**FIG. 3.** Industry 5.0: Addressing the lack of symmetry in Industry 4.0 ecosystem design by (1) Innovation Brakes, (2) Next-Generation Technology, and Society Research where the opportunity costs and analytical frameworks are made explicit, and (3) designing Orthogonal Safe Exits that are independent from hyperconnected systems automating manufacturing and production.

Notably, this system level design consideration for a safe exit from the innovation ecosystem could also help diversify and enrich dominant conceptual frameworks that guide innovation practices, and by extension, remedy the filter bubbles that could exist in an Industry 4.0 innovation ecosystem. In fact, one might argue that the acceleration narrative that has historically dominated science and innovation fields can benefit by bringing in scholars who are orthogonal and unrelated to an innovation ecosystem so as to have a symmetrical take on both acceleration and deceleration.

A symmetrical approach to innovation ecosystem design is required for dynamic and anticipatory governance of the societal context and impacts attendant to Industry 4.0 applications as well. As noted earlier, much of the current discourse on societal projections of Industry 4.0 is polarized on dystopian fearsome futures or invariably benevolent outcomes. It is time to move beyond such determinism in mapping and governing Industry 4.0 in society.

A key topic that has been debated in regard to the societal impacts of Industry 4.0 is whether the cobots with AI will supplement or supplant certain types of jobs such as taxi and truck drivers. The future of work in the age of IoT and Industry 4.0 is a topic that warrants further SSH research.

A second societal issue, one that is relatively underappreciated at the moment, is that whoever controls the data platforms will control the political power associated with the IoT and Industry 4.0. Big Data have recently been called the new oil of the 21st century (The Economist, 2017). The IoT and Industry 4.0, by virtue of their capacity to transform and translate Big Data to applied knowledge and innovation, further augment the powers stemming from Big Data platforms. This calls for political science research on Industry 4.0 to make the new associated power structures in society, people, organizations, and countries with ''haves'' and ''have nots,'' transparent and thus more accountable. This brings us to another neglected question on the types of SSH research methodologies that are well suited to study Industry 4.0 in society. The history of science over the past three decades, most notably since the launch of the Human Genome Project in 1990, is instructive in this regard.

We have moved on over the past three decades in particular, or have been asked to move on by university administrators, funders, and other powerful innovation actors, to increasingly large, expensive, multinational ''big science'' projects (Birch, 2015; Halffman and Radder, 2015; Vermeulen et al., 2013). This transformation in the culture of science has materialized in both developed and developing country science contexts as well (Özdemir, 2017, 2018; Özdemir et al., 2015; Springer, 2015; Thoreau and Delvenne, 2012). Together, with the rise of big science projects, considerable funding was made available to support SSH research, but often in preordained attempts by scientists and funders to preempt societal barriers to emergence of new technologies. These brands of SSH research in big science projects have tended to subscribe, however, to technological determinism rather than nurturing some of the key goals of independent and critical SSH research: to broaden debates from a narrow technical to a larger sociotechnical context, and importantly, making power relationship in science and technology more transparent and thus accountable. Other scholars have argued that certain types of SSH research in big science projects, branded under ''societal research,'' have actually led to ''compressed foresight'' (López and Lunau, 2012; Williams, 2006), thus posing threats and limits in our collective imaginations to creatively respond to the unknowns associated with new technology and innovation (Nordmann and Schwarz, 2010; Özdemir, 2017).

We suggest that compressed foresight or uncritical SSH research on technology futures does not serve well for cultivating robust, sustainable, and responsible innovations attuned to societal values. Uncritical SSH research can also lead to ''regulatory capture'' by lack of independent analyses of emerging technologies and innovations (Chomsky et al., 2017; Özdemir, 2018). The unknowns on the innovation trajectories are best deciphered, we suggest, by a much broader take on science and society. Industry 4.0 in society and the attendant SSH research demand that we question not only knowledge but also how we know what we think to know, that is, epistemologies (frameworks) that underpin the coproduction of knowledge. Such reflexivity, a state of cognizance of how our own values as scientists or SSH scholars might influence the type of conclusions we arrive at, has not always been at the forefront of societal research annexed to the big science projects.

The Ethical, Legal, and Social Implications (ELSI), launched in 1990 in the context of the Human Genome Project, or its similar versions branded onto other technology domains such as nanotechnology, has tended to dominate research methodologies for understanding ''technologies in society.'' ELSI research has been a source of considerable funding for SSH scholars, but has also been critiqued for several important shortcomings, including compressed foresight, and lack of sufficient independence from science and technology

TABLE 1. TWO RESEARCH APPROACHES TO SITUATE INDUSTRY 5.0 IN SOCIETY: ETHICAL, LEGAL, AND SOCIAL IMPLICATIONS (ELSI) VERSUS POST-ELSI TECHNOLOGY EVALUATION RESEARCH

| *Comparison* | *ELSI* | *PETER* |
|---|---|---|
| Aim | A ''science enabler'' position that seeks to make science proceed (or obtain legitimacy) through a narrow and linear innovation framework | Critical social science research to situate new technology and science in a broader societal and political context |
| | Tends to subscribe to technological determinism | Questions the conceptual frames (epistemology) of scientific knowledge and innovation |
| Analytical focus | Downstream impacts of science and new technology | Upstream, anticipatory and design focus |
| | Tends to view the technology future as preordained and imminent | Views multiple possible technology futures (in plural) |
| Politics of technology | Usually bracketed out | Critical social science research on politics and power relationships among innovation actors; ''Unpacks the politics,'' thus making science and social science more accountable |
| Analytical distance between the analyst and technology | The analyst is embedded among science and technology actors, or has narrow analytical distance from science/technology, which may limit the ability of SSH scholars to say ''No'' to science and technology teams, thus risking co-option and endorsement of technological determinism | The analyst tends to operate at a safe analytical distance from science, technology, and its actors |
| | | Greater empowerment of the SSH scholars for the ability to say ''No'' to science and technology teams and sustain independent critical SSH analysis |
| Reflexivity and the role of human values in knowledge coproduction | Reflexivity, if considered at all, is limited to the context in scientific communities (Type 1 reflexivity) | Reflexivity is considered in both scientific communities and in SSH research |
| | | Considers politics and human values as factors that shape both science and technology (Type 1 reflexivity) and social knowledge and SSH scholars (Type 2 reflexivity) |
| Time frame | Post-hoc or post-facto scientific impacts | Anticipatory or real time with technology development |
| Opportunity costs considered? | No | Yes |
| Symmetry in design? | Accelerator role primarily. | Accelerator and decelerator for science and technology |
| | That is, asymmetrical, and focused on enabling science through the lens of technological determinism, rather than the symmetrical accelerator/decelerator function | Has a built-in sustainability strategy for ''safe exits'' from entrenched and hyperconnected networks in the digital age |
| | | That is, considers both acceleration/deceleration and extreme integration/safe exits from digital networks |

ELSI, Ethical, Legal and Social Implications; PETER, Post-ELSI Technology Evaluation Research; SSH, social science and humanities.

actors for critical SSH research, among others. Balmer et al. has aptly noted, for example:

> […] social scientists have identified a number of problems with the ELSI programme, including the emphasis it tends to place on a simplified, linear model of innovation, the attention given to the outcomes of research and innovation over practices, the assumption that it is easy to classify outcomes as ''negative'' or ''positive,'' and the distinction between ''science'' and ''society'' that it continues to embed. Such dissatisfaction with ELSI has led to the development of a range of more or less explicitly ''post-ELSI'' approaches to the work of social science in such interdisciplinary contexts. Such work often emphasises the need for deeper collaboration, interdisciplinarity, coproduction of knowledge, upstream (or mid-stream) engagement, and real-time technology assessment (Balmer et al., 2015).

Hence, we call for Post-ELSI Technology Evaluation Research (PETER) as an integral part of the proposed Industry 5.0 scheme. In Table 1, we outline several key conceptual tenets of PETER. Importantly, PETER considers the technology opportunity costs, framings (epistemology), independence, and reflexivity of SSH research in technology policymaking and global governance.

There will be various specific subtypes of PETER informed by emerging SSH research applications in the post-ELSI space (Balmer and Bulpin, 2013; Balmer et al., 2015; Fisher et al., 2015) and newer and conceptually rigorous fields of SSH scholarship such as responsible innovation (Fisher, 2005; Fisher et al., 2006; Guston 2015) to situate Industry 5.0 in society, including its political and power dimensions.

## Outlook and Conclusions

In November 2017, the U.S. Food and Drug Administration (FDA) approved a ''digital drug'' with sensor that digitally tracks if patients have ingested their medication. The drug is approved for treatment of certain mental health disorders such as schizophrenia:

> It's a pill with a sensor embedded inside which records that the medicine was taken. The sensor generates an electrical signal when it comes into contact with stomach fluid. This signal is then transmitted to a wearable patch on the patient's body, which then sends the information to the patient's smartphone. With the patient's consent, their doctor and up to four other people can be alerted when the drug is ingested (Gulland, 2017).

It is too early to say if the digital drug will improve real-life drug adherence in patients. Yet, it signals that the era of the IoT and Industry 5.0 applications in medicine may not be too far ahead. Big Data in health offer similar prospects but the Big Data implementation science itself is at an interregnum as discussed in the introduction of this analysis. Innovation in the way we make sense of Big Data can benefit from the IoT, AI, and Industry 5.0 with built-in amendments to the design of future innovation ecosystems.

Industry 5.0 is about building complex and hyper-connected digital networks without compromising long-term safety and sustainability of an innovation ecosystem and its constituents. Considering built-in orthogonal safe exits from the digital networks, recognizing the need for both acceleration/deceleration, and innovation in global governance for technology policy are three measures to bring about a 3D symmetry in future applications of Industry 5.0.

Industry 5.0 is poised to harness extreme automation and Big Data with safety, innovative technology policy, and responsible implementation science, enabled by 3D symmetry in innovation ecosystem design.

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**Abbreviations Used**

3D = three dimensional
AI = artificial intelligence
ATM = automated teller machine
Cobots = collaborative robots
CPS = cyber-physical systems
ELSI = Ethical, Legal, and Social Implications
ICT = Information and Communication Technology
IoT = Internet of Things
PETER = Post-ELSI Technology Evaluation Research
SSH = social science and humanities

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