

Expanding Industry 4.0: Social science approaches to studies of technology change

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“We are at the beginning of a revolution that is fundamentally changing the way we live, work, and relate to one another. In its scale, scope and complexity, what I consider to be the fourth industrial revolution is unlike anything humankind has experienced before”
(Schwab 2017, 7).

1) Introduction

In the last five years, Industry 4.0 has become a common research topic across various sectors and disciplines. What, precisely, Industry 4.0 refers to is not universally agreed. For some, it marks the emergence a fourth industrial revolution, following the introduction of steam and mechanics in the 1700s, the harnessing of electricity and mass production in the 20th century, and the influence of computers post-World War II. For others it marks a shift in the political economy of production, following the introduction of lean manufacturing in the 1970's, outsourcing in the 90's and the basics of automation in the early 2000's. In either case, reference to Industry 4.0 seeks to acknowledge a “transition point” that marks the acceleration of more advanced and pervasive digitisation, particularly in spheres of production.

“...think about the staggering confluence of emerging technology breakthroughs, covering wide-ranging fields such as artificial intelligence (AI), robotics, the internet of things (IoT), autonomous vehicles... We are witnessing profound shifts across all industries, marked by the emergence of new business models, the disruption of incumbents and the reshaping of production, consumption, transportation and delivery systems” (Schwab 2017 p.7).

This narrative of transition has been mainly driven by engineers and management scholars (Brynjolfsson & McAfee 2014, Schwab 2017), as well as supported by industry actors (WEF 2017). But it has also been explored more critically by international institutions (ILO 2019, World

Bank 2018) and social science research (Lawrence et al. 2017). The latter have raised concerns regarding the potential implications of this change for the future of enterprises, the nature of work and broader society. As a consequence, there are calls for alternative visions of technological change that better address concerns of social change, justice and sustainability.

We acknowledge these critiques, however, taking Industry 4.0 as an emergent phenomenon we argue that the concept requires first a more detailed examination to ensure that alternative visions do not reflect similar limitations. In this paper, we do this by drawing on social science literature – particularly ideas from innovation studies, social practice theories, development studies and sustainability transitions. The critical literature in these fields has remained largely disconnected from discussions regarding Industry 4.0, yet we suggest that they provide improved theoretical and analytical understanding.

2) Definitions: What's in a name?

Examining the terminology around Industry 4.0 reveals how research related to the reordering of society and the economy might inform our understanding of Industry 4.0. We reflect on three associated terms here: 'Industry 4.0', 'the fourth industrial revolution', and more broadly 'technological change'. Often used interchangeably, each makes different connections to the literature, embeds different underlying assumptions about the processes and outcomes of change, and introduces different critical sensitivities.

Industry 4.0

Industry 4.0 has been closely associated with technical advances in production and disruption of incumbent systems. Empirical research, however, challenges claims of disruptive technical innovation. Such arguments come from a number of angles, including ethnographic studies that suggest technological changes have so far been incremental, and not occurring universally in all firms (Krzywdzinski 2017, Pfeiffer 2016). This argument is even more compelling if one takes a global perspective where change has yet been limited to specific sectors and locations in global production (UNCTAD 2017). In addition, longitudinal analysis of technological change within the economics literature suggest a more gradual evolution of technology, with industry, employment and skills profiles evolving over several decades rather than a dramatic change (Acemoglu & Autor 2011, Autor 2015). If, as such critics argue, technological change is debatable, or incremental then it challenges assumptions about the inevitability of disruption and the types of impact on society.

The Fourth Industrial Revolution

If one does agree with the view that a “fourth industrial revolution” is emerging, then the literature on the history of technical change suggests further reflection is needed on this transition. Scholars exploring historic change have highlighted the cyclical nature of change. Specifically “long wave” and neo-schumpeterian theories provide an account of how previous technology change typically happened. This occurs through the emergence of niches, which become adopted through the wider economy, eventually facilitating major change in industrial structure (Bernard et al. 2014, Köhler 2012). The source of disruptions in these accounts, however, rarely comes from incumbent actors who tend to be resistant to change. Rather it is entrepreneurs and new entrants who produce niche and new products (Hagedoorn 1996).

The important point here is that this account of radical change departs from common Industry 4.0 accounts. Disruptive change comes from *outside* rather than *inside* the existing system of production and is not associated with existing firms and supply chains. This account also questions the outcomes of disruptive change and whether it should be limited to current capitalist paradigms, as is typical in Industry 4.0 visions. Alternative outcomes have been suggested, including ones centred on abundance of digital goods and new types of post-capitalist production; or alternatively new hyper-capitalistic societies with capital increasingly intertwined with everyday lives (Mason 2016).

Technological change

The emphasis placed on industrial and technological breakthrough in Industry 4.0 disguises questions of how technological change intersects with societal transitions. While technological innovation is important, studies of industrial change have highlighted a broader interplay of scientific, economic, political and cultural (and in some readings natural) developments during periods of change (Köhler 2012). For instance, the emergence of the computer and digital networks can be linked to high level of investment in research and development post-World War II (Mason 2016). Such social factors may not necessarily be key in the future, but such literature highlights that disruptive innovation arises through the interplay of broader socio-political developments, rather than isolated technical advances.

Important insights on technological change are also offered in the literature that explores social practices. Here routine domestic life is the foci of analyses rather than the political-economic system. The literature on energy and water demand, for example, illustrates clearly how social

and material changes associated with previous industrial revolutions have shaped institutions and everyday life; changes to labour and domestic life shifted the social contracts of urban provisioning, altered the moral geographies of mundane practices such as laundry, showering and commuting, and introduced new material elements to systems of resource provision (e.g. Kaika 2004, Kuijter & Watson 2017). There are many socio-technical theories (such as theories of social transitions, practice and innovation) that would provide insight to unravel the processes, outcomes and resistance to Industry 4.0 more broadly. Their contributions to the literature on Industry 4.0 are as yet fragmented however, and are yet to counter the prevailing focus on technological change and economic systems.

Summary

Exploring the terminology surrounding industry 4.0 highlights important critical questions that are worthy of further research. For example: Are the changes associated with Industry 4.0 disruptive, and in what regard? What are the wider societal impacts of innovation and disruption in spheres of production? What are the paths by which change emerges in the economy? What are the outcomes that might emerge?

3) Methods: What are the challenges in researching a revolution in progress?

Issues concerning speculative critical research

Core to the study of Industry 4.0 is future-oriented research. Much existing research looks to discuss opportunities and challenges that may emerge in the future, based upon present and emerging trends. This speculative orientation should prompt us to consider more deeply the methodological challenges concerning extrapolations of future society, particularly in a field associated with innovation and disruption.

Firstly, far from the tame picture conveyed by numerical models, processes of socio-technological change include crises, disruption and uneven development. These dimensions are problematic as they pose questions for how to best undertake speculative enquiry (Sharmina et al. 2019). Secondly, the distributed nature of change – particularly concerning the spill-over effects from spaces of production into wider society – are difficult to capture and represent. While technology changes within a smart factory may be analysed – such as the application of robots and artificial intelligence in a production line – the broader implications of these

developments, for example, on family life (given the associated possible changes to working hours and incomes) are more difficult to trace. Similarly, the flows of knowledge and technology from spaces of production to systems of provision and spaces of consumption are unpredictable, heterogeneous and difficult to attribute to specific developments. For example, it is unclear how industrial developments concerning the internet of things could affect energy and water use in people's homes or the possibilities for demand management.

Speculative critical research will make an essential contribution to understanding Industry 4.0 and the possibilities for directing change associated with its emergence. Though there are undeniable limits to extrapolation, this need be no more restrictive of social science research than any other discipline and more extensive effort to understand the possibilities, relationships and implications is needed. In particular, discussion regarding the potential for, and alternative pathways toward, just and sustainable industrial transformation is vital. There are existing methods that might be adapted to this task, including augmented scenario methods for example, enabling better understanding of how people, practices, and politics contribute to processes of change.

Issues of extrapolation and generalisation

As innovation policies have blossomed so too have innovation studies. Many of these studies aim to tease out the ingredients to successful innovation in order to transfer insights to other locations and sectors. Yet, as Pfothenauer and Jasanoff (2017) describe, efforts to reproduce innovation pathways "have regularly led to frustration, with the import seldom living up to the promise of the originals". These links to the impact of "exogenous constraints" (sometimes referred to as path-dependency) includes differences in culture, politics, historical development patterns, wider material geographies and actor relationships that complicate the dynamics of innovation. Though positioned as exogenous to the practices of firms and institutions, if innovation is entangled in these socio-technical particularities, then further understanding these relationships is needed to enable appropriate discussion of innovative directions.

One method used by innovation scholars to integrate such considerations are case study approaches. They allow for the rich representation of the multiple dimensions and dynamics of change. Case study analysis, for example, enables the insight derived from numerical models to be combined with interpretive research that unravels the particularities of Industry 4.0 emergence and implications. Case study research is also an effective forum for transdisciplinary

research, with the potential for reciprocal methods which embed learning that might direct transition towards justice and sustainability benefits. However, case study research is inherently messy, with evolving research questions, methodological surprises and contentious findings compromising the validity and reproducibility of the research (Clark et al., 2007). Attempts to use such research outputs to inform policy and management may encounter resistance in a research landscape that celebrates universalism and generalisability (Sharmina et al. 2019).

Yet arguably it is messy research that is most needed to grapple with the critical questions being asked of Industry 4.0 and provide context-sensitive insights. There is considerable room for social science research which pushes the importance of heterogeneity of innovation processes, within and between sectors and locations allowing understanding of local needs and socio-cultural particularities to inform Industry 4.0 developments.

Integrating data and the digital into research

Industry 4.0 expands the sites and approaches to observe human-machine interactions. For example, smart meters and other devices enable flows of materials and resources to be traced with greater accuracy, specificity and granularity than ever before. Similarly, digitalisation of goods movement enable analysis of interactivity throughout the supply chain, with the potential to yield insights on governance, accountability and responsibility. In addition, advances in big data analysis, machine learning and other (non-AI) digital methods offers further potential for inquiry into a broad set research questions.

Yet questions regarding these methods, the skills needed to exploit them in the social sciences, and their ethical considerations are yet to mature. This is a challenge that has begun to be taken up by more critical data scientists, who through experiments, data extraction and analysis of compiled datasets have been able to provide important inputs into social science studies that incorporating such data (e.g. Bors 2018). Further work on how such methods support Industry 4.0 research, including ethical use, creation and sharing of appropriate datasets are important directions forward.

The process of Industry 4.0 research

In addition to these concerns, there are practical challenges associated with undertaking Industry 4.0 research. How to secure physical access, given that innovation processes are core to the competitive advantage of innovators, and obtain rights to publish research findings are timely questions. Moreover identifying emerging innovators is not an insignificant challenge,

particularly given the time and resources required to establish a trusting and reciprocally beneficial relationship.

Exploring Industry 4.0 as a global phenomena is vital, and this should emphasise the importance of research partners who are geographically spread and have different socio-cultural understandings. For researchers this brings forth familiar challenges for research into sustainability and justice, not least the justification for of overseas research given the environmental impacts of flying (e.g. Glover et al. 2018), and social justice issues surrounding colonisation of emerging research fields. These challenges are not unique to studies of Industry 4.0, but a new dimension to these discussions emerges given the centrality of digital technologies and the possibilities this afford for tele- and co-research

Summary

Some questions that might inform discussions on methodological concerns in this field include: How can researchers and research users actively participate in shaping the research landscape so as to enable understanding of the particularities of Industry 4.0 (including pushing towards justice and sustainability)? What are the onto-political concerns for empirical research pertaining to industry 4.0 – for example, how do specific research methods and traditions shape what is (and is seen to be) possible and plausible? What questions and lessons are opened and foreclosed by existing methodological practices?

4) Outcomes: How do we integrate justice and sustainability?

There are innumerable effects that Industry 4.0 could have on society. For the authors, those related to justice and sustainability are particularly interesting, and thus far have been paid limited attention.

Justice

Justice, broadly defined, concerns the fairness, rights and privileges that individuals or groups are able to experience. For Industry 4.0, the social science literature has explored some aspects but remains quiet on others. The negative impacts of Industry 4.0, particularly consequences for labour, have been widely discussed. Analyses have highlighted how changes associated with Industry 4.0 can lead to injustices where deployment of automated technologies leads to unemployment, routinisation and/or deskilling of jobs (Butollo et al. 2018, World Bank 2018). There are also concerning spillover effects, including increasing competition for work as it

becomes scarce, wage reduction, and impacts on organised labour (Acemoglu & Autor 2011, Edwards & Ramirez 2016). The literature has also begun to explore the approaches by which such injustices might be mitigated including reformulation of policy to shape the future of work, such as worker skills and forms of social security (Chandy 2016, ILO 2019). There is also emerging activism intended to challenge some of the worst excesses of automation, such as in the “gig economy” (Graham & Woodcock 2018).

While there has been growing focus on these *injustices*, less research has examined how Industry 4.0 might support the expansion of *justice*, and how to bring about these changes. For instance, limited work has highlighted the potential role of automation in reducing unsafe and mundane aspects of work. These are core issues connected to global justice for low paid workers, and further work could particularly benefit production in the global south where such types of low value work are often outsourced to (Bajpai & Hickok 2018, Huang & Sharif 2017).

More broadly, and following the overarching narrative of Industry 4.0 being fundamentally a disruptive process, more imagination is needed into how future configurations of production and economies might benefit human values and needs. This aligns with Sen-ian visions of justice, where justice is argued to be embedded in the choice and expansion of capabilities of individuals and communities in line with their values and goals (Sen 1999). At the margins of Industry 4.0 such visions have been articulated: in post-capitalist literature in the visions of increased leisure time and improved work-life balance that challenge fundamental beliefs about work (Richardson 2018, Williams & Srnicek 2015); and in consumer-oriented perspectives on production that highlighted the democratising power of automation in making previous professionalised, and expensive services available more widely to the population (Susskind & Susskind 2015). Further work on integrating such visions into mainstream thinking is important.

Thus for justice, we need to continue to ask questions about the potential injustices that emerge from industry 4.0, and how these might be identified and mitigated through policies and practices. More than this, how and under what circumstances could Industry 4.0 contribute to global justice in production through making repetitive, dangerous work a thing of the past? How might new values of work-life balance and accessible services become a stronger focus of Industry 4.0?

Sustainability

There is increasing consensus that current modes of production and consumption are unsustainable. Rising demands for energy, water and land combined with increasing levels of emissions, growing inequality and volatile weather are of growing concern to businesses, policy makers and the public. Urgent and radical changes are required to address sustainability objectives. Unlike the literature on justice, Industry 4.0 has commonly been interpreted as an opportunity for sustainable transformation (e.g. Herweijer et al. 2018), promising vast improvements in operational efficiency, sensing and control over systems, the extended application of smart technologies, and demand management processes. Each has potential to contribute to sustainability objectives.

To date this body of research focuses on the direct, upstream sustainability benefits of technical innovation. Wider sustainability implications of Industry 4.0 are less commonly discussed. Given the potential wider reaching effects of Industry 4.0 on society, the indirect impacts are worthy of more extensive consideration. For example what potential do Industry 4.0 technologies, platforms and business models have for unsettling unsustainable systems of provision commons today (or reaffirming them) (Carolan 2018). Alternatively, how do new objects and configurations in homes interact with the emergence of new routines and/or norms and expectations regarding everyday consumption?

It is therefore vital to understand how Industry 4.0 might most effectively contribute to realizing global sustainable development objectives. With global sustainable development commitments such as the Paris Agreement framing the current discourse on climate change adaptation it is important to understand what a fit-for-purpose Industry 4.0 might look like with consideration of the appropriate modes of governance, equitable access and adoption. Questions need to also be situated in a broader discussion concerning responsible digital transformation: What are the implications of Industry 4.0 for everyday geographies of lifestyle and labour? How does the automation and digitization of industry spill-over into domestic practices? and; What are the associated impacts for the ways in which resources used and wastes produced?

Summary

In sum, the acknowledgement of justice and sustainability issues emerging with Industry 4.0 suggest that better linkages between social sciences and engineering/business research would be beneficial. At present, social science research has strongly focussed on the challenges of

automation and begun to formulate approaches for potential mitigation. Such work needs to be more strongly integrated with the practices and requirements for engineers to consider, and needs to increasingly challenge the overarching visions of what Industry 4.0 should be. Future visions of ways by which Industry 4.0 will transform society and might be pushed to improve justice and sustainability outcomes has been explored by social scientists but this has often been fairly speculative. It is here that demonstrators and prototypes built by engineers can offer more ground considerations and visions that can be supported by social scientists.

5) Conclusion

The social science literature has yielded a number of important discussions related to researching Industry 4.0, and technical change more broadly. Exploring definitions of Industry 4.0 has highlighted the need to unpack the broader macro-level processes of change, and the merit of linking to historic accounts of technical, social and disruptive change. Analysis of methods in Industry 4.0 emphasises the importance of a more transparent engagement with ethics and processes of researching Industry 4.0. Exploring outcomes from a justice and sustainability perspective, highlights how Industry 4.0 research can move beyond the narrow concerns of efficiency and economic gain. These discussions, and the questions posed in each section, highlight valuable new research directions. But more than this, they should challenge researchers to more actively shape research agendas of Industry 4.0 – and to become more attentive to how they might support equality, engagement, and inclusive change in society.

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