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Does the Digitalization of Manufacturing Boost a 'Smart' Era of Capital Accumulation?

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Abstract: 'Smart Manufacturing' refers to a bundle of recent digital innovations together with the political initiatives that promote them. Public and academic debates indicate a fundamental shift in the socio-economic landscape, or a new era of capital accumulation in the language of regulation theory. A closer analysis of literature on Fordism and Postfordism, however, reveals that a 'smart' accumulation regime is at the most beginning to emerge, while earlier digitalization has already generated considerable impacts. This literature review first considers earlier contributions on digitalization and space that were published from the early 1980 s to the early 2000 s. It then discusses how this can inspire fresh views on Smart Manufacturing today.

Keywords: digitalization, Industry 4.0, inequality, regulation theory, Smart Manufacturing

Zusammenfassung: ‚Smart Manufacturing' steht für ein Bündel aktueller digitaler Innovationen und gleichzeitig für diesbezügliche politische Initiativen. Die mediale und wissenschaftliche Diskussion weist auf eine tiefgreifende sozioökonomische Transformation hin, regulationstheoretisch gesprochen auf einen Wandel des Akkumulationsregimes. Allerdings offenbart eine genauere Sichtung der Literatur zu Fordismus und Postfordismus, dass sich ein ‚smartes' Akkumulationsregime höchstens ansatzweise abzeichnet, während die frühere Digitalisierung bereits erhebliche Wirkungen gezeitigt hat. Diese Literaturschau beginnt mit früheren Beiträgen über Digitalisierung und Raum, die vor allem von den 1980er Jahren bis in die frühen 2000er Jahre erschienen sind, und diskutiert anschließend, inwiefern dies die heutige Sicht auf Smart Manufacturing inspirieren kann.

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1 Introduction

'Smart Manufacturing' is a heterogeneous bundle of digital innovations that predominantly developed in the 2010 s. It specifically stands for cyber-physical systems (or the Internet of Things), i. e. systems based on digital platforms, big data, cloud computing, artificial intelligence and cumulative network integration, moving towards self-organization of increasingly customized production. Within this digital network integration, new machines such as new robots and 3D printers play a key role, as do new features such as digital remote diagnostics. Smart Manufacturing thus brings together virtual data networks with the sphere of material production (Mittal et al. 2019; Thoben et al. 2017).

Recent debates indicate that Smart Manufacturing will transform socio-economic space. Contributions expect a new regime of 'smart' accumulation (Kenney/Zysman 2019; Pickles 2020; Sadowki 2019) and are linked to debates on Fordism and Postfordism, i. e. theoretical concepts developed in regulation theory. But the contours of Smart Manufacturing have so far remained unclear. While the degree to which cyber-physical systems and their components will be adopted by the market is still uncertain, governments support their dissemination. 'Smart Manufacturing' not only relates to ongoing technological change. It is also a political slogan which denotes initatives designed to improve the competitiveness of companies, states and regions. The term 'Smart Manufacturing' is particularly used in the US but has spread across large parts of the anglophone world (NIST 2019). For reasons of readability, this contribution also uses the term, although different countries use different labels for such political initiatives. Smart Manufacturing policies exist e. g. in Japan, China and Korea (Min et al. 2019) and in Eastern Europe (Bogoviz et al. 2018), while 'Industry 4.0', a term that was coined in Germany in the context of industrial policies, has recently become a strategic objective of the European Union (Bailey/De Propris 2019). Policy-oriented contributions for example perceive Industry 4.0 as an opportunity to implement the current cohesion policy of EU. Bailey/De Propris (2019, 68) express the political clarian call thus:

> These are times of radical and disruptive change and inevitably EU regional and industrial policies must move towards having a truly transformative power: this could, for example, render with a heightened attention towards the creation and adoption of Fourth Industrial Revolution (FIR) technologies in different regions.

In line with this quote, many contributions suggest that the world is experiencing a radical revolution in manufacturing. Studies frequently update Kondratiev’s (1935) cycle and emphasize Smart Manufacturing as the latest wave (Thoben et al. 2017; Winter 2017). From that perspective, Smart Manufacturing is necessary to reach or remain at the top in the international competition of high-end innovativeness. At the same time, contributions frequently warn against social polarization on the labour market, seizing on digitalization as a driver of an increasing social divide (“Lousy and Lovely Jobs”, Goos/Manning 2007, 118) and growing international and interregional inequalities (Werner 2019). Barzotto et al. (2019, 15), for example, are concerned that

> “(…) there is a real danger that I4.0 [Industry 4.0] and the uneven distribution of capital intensive manufacturing displacing labour, may unduly favour more dynamic regions and will introduce new layers of socio-economic and regional divides. Indeed, so called digital divides already exist not only between countries, but also between regions in the same country and the rich and poor in society (…).

Critical analysis is therefore not only required of the ongoing digital change with its possible socio-spatial implications, but also of the political attention it attracts – especially since it is difficult to obtain a clear picture from the mix of actual innovation, wishful thinking and nightmare scenarios (Lütkenhorst 2018).

This article briefly reviews economic geography literature and related social science contributions to reconstruct early and more recent narratives of the impacts of digitalization on socio-economic space. Taking up the discussion on technological change within the ‘postfordist’ regime of accumulation (as discussed in regulation theory), the central question is whether smart manufacturing is indicative of a new era of capitalist accumulation, as implied by the political debates surrounding Smart Manufacturing and Industry 4.0.

Contributions have long since perceived technological change in factories (the micro level) as a driver of socio-spatial change on the macro level. This is the view that also prevails in the public discourse. As early as 1964, the German political magazine “Der Spiegel” had a cover picture showing a human-like robot firing workers. In 1978, the cover of the magazine presented a similar robot dismissing workers, entitled ‘The Computer Revolution – Progress Destroys Jobs’. In 2016, the cover once again showed the image of a robot hand firing an employee. Emphasizing the socio-spatial dimension of these developments, a 2013 cover of Time Magazine showed robots (without workers) producing a metal piece with the caption: ‘Made in the USA’, and subtitled ‘Manufacturing is back–but where are the jobs?’ Digitalization has thus been perceived as a driver of labour market dynamics, and a social field of action and political arena for a long time. Such insights on past perspectives shed light on the current debate by revealing stable figures of thought, uncovering utopian visions of technical feasibility as well as dystopian scenarios of social polarization and spatial inequality.

Academia also theorized the digitalization of manufacturing as a challenge for society and political action. Particularly in the 1980 s and 1990 s, many contributions in economic geography and related social sciences viewed the digitalization of manufacturing through the lens of regulation theory, which allowed digitalization to be framed within its socio-economic contexts. Although not all publications from that period followed regulation theory, the social and spatial embeddedness of digitalization was ‘in the air’ then, enabling regulation theory to inspire much of the reasoning surrounding the digitalization of manufacturing and its socio-spatial implications. This article reconstructs the main narratives of regulation theory including later criticism (Bathelt 1994). Rather than raking it up or trying to ‘apply’ it to recent trends of digitalization, the intention is to critically reconstruct its basic assumptions as a former lens to view socio-economically embedded digitalization. Given today’s lack of theoretical notions about digitalization, Smart Manufacturing can be characterized as fairly ‘undertheorized’ reasoning on digitalization in socio-economic space.

The following explains regulation theory as a narrative to understand digitalization and socio-spatial inequality. It shows that Post-Fordism offered orientation in this thematic field in the late 20th century. A critical view on the discourse surrounding Smart Manufacturing and its socio-spatial implications is followed by some central requirements for further theoretical work.

2 Regulation theory as a narrative to understand digitalization and socio-spatial inequality

Regulation theory is one of the most influential conceptual approaches in industrial geography (He/Zhu 2017). Inspired by the French regulation school (Aglietta 1976; Boyer 1986; Boyer 1995), it offers a critical perspective of socio-economically embedded technological change, with a particular view on crisis and stability. Prevailing production technologies, and human labour as part of the production process, shape an 'accumulation regime' which is part of, and itself maintained by, a 'mode of regulation'. Each mode of regulation is characterized by specific social and political (institutional) coordination, as well as particular value chain configurations and consumption patterns. Although the accumulation regime generates social inequalities, the mode of regulation provides the social compromise that stabilizes the particular formation (Fordism, Post-Fordism) for a longer period. Regulation theory accords human labour a key role in this; as such it also considers human labour in the digital reorganisation of manufacturing. In economic geography, such notions relate to the spatial divisions of labour, as well as spatial inequality at the level of society (Sheppard/Barnes 2017).

The 'transformation' of production, labour and the social context characterizes prevalent formations. These formations do not correspond to distinct phases, but partially overlap (Leborgne/Lipietz 1988). In economic geography, the view on formations allowed a dynamic view of socio-economically embedded production technology to emerge that could also be linked to spatial contexts. The idea of 'transformation' meant that technological change no longer had to be viewed as deterministic cycles, or steps of development. The idea of Post-Fordism offered renewed orientation in the complex situation of socio-economically embedded digitalization, inspiring many contributions (see Bathelt 1994). The main ideas of such contributions were the following.

In the first half of the 20th century until the early 1970s, *Fordist* production meant mass production capable of providing economies of scale. Competencies were centralized at the top of the company hierarchy, and repetitive, monotonous work took place at the assembly line on the shop floor. Products had become affordable for employees, and welfare state policies and strong unions supported such mass consumption. As a result, workers (mostly) participated in this growth mode and thus stabilized it. In the late 1970s and 1980s, this particular formation began to erode because of market saturation and the expansion of liberal policies (Duncan et al. 1993; Krätke 1996). Early contributions on the impacts of digitalization in socio-economic space regarded the introduction of digital production technologies as a way of perfecting Fordist management control over labour in space (Cooley 1972). Hierarchical control as a characteristic feature of economy was a key topic then, with contributions in the regulation approach and in the broader field of political economy, illustrating spatial inequalities between MNC headquarters in metropolitan areas and branch-plant economies in the peripheries (e.g. Clarke 1986; Taylor/Thrift 1986), in particular in the Global South (Ernst 1985; Lipietz 1986). Fröbel et al. (1980) characterized such patters as neo-colonial 'New International Division of Labour' (book title). Similar dependencies between dominant cities and rural regions were analysed as part of inter-regional division of labour within nation states (e.g. Erickson 1980; Massey 1984; Norton/Rees 1979; Savey 1983).

With its open contours, the new formation of *Post-Fordism* obviously affected the division of labour (Altenburg 1996; Peck/Tickel 1992a; Peck/Tickel 1992b; Peck 2000): Globalization, offshoring and outsourcing, economies of scope with lean production and just-in-time delivery became popular business concepts for reorganizing value chains across borders. Flexibilization became a buzzword at the time, with adjustment pressures for the weaker parts of economy and society (Essletzbichler 2003; Gertler 1988; Jonas 1996; Peck 2000). Companies, politicians and consultants saw digitalization as a key to more flexibility in production. Computer Integrated Manufacturing (CIM) was the policy slogan at that time, characterizing the increasingly denser communication between digital divices in production and the direction of technology policy (Kaplinsky 1985). Computer Aided Design (CAD) changed R&D, and new ways of computer work replaced professional work of manual drafting in R&D. CAD also changed international collaboration in R&D. Now, global companies divided the design and test tasks across their various R&D centres and conducted engineering work 24 hours a day. This increased the competition between employees in engineering (Amirahmadi/Wallace 1995). At the same time, CAD was a step towards higher integration of R&D and manufacture on the shop floor, labelled Computer Aided Manufacturing (CAM). A key issue for CAM was that flexible industrial automates and industrial robots increasingly replaced machines that specialized in very specific functions (Fuchs 1992; Fuchs/Schamp 1990). Able to perform a range of functions, machines gradually evolved into general purpose technologies (Leborgne/Lipietz 1988; Malecki/Moriset 2008). CAM meant that the R&D work of engineers virtually flows onto the shop floor, a flow that often also integrates computer-based production planning and scheduling. In sum, the digital technologies substituted simple tasks of human work and required new competencies of engineers, technicians and skilled workers, implying an increasing 'segmentation' of the inhouse (and partially of the local) labour markets (Kern/Schumann 1987). Digital integration continued to develop, connecting more and more steps from R&D to assembly, in some cases even including customers and suppliers (Malecki/Moriset 2008). Such comprehensive digital integration raised critique (Adams/Warf 1997; Edwards/Whitston 1989). The nightmare of digitalized control and massive job loss became popular as the 'glass factory' or the 'factory devoid of humans' (Fuchs 1992).

At the same time, as emphasized by many studies outside the regulatory tradition, digitalization allowed industries in emerging economies to upgrade into engineering activities and link up to global value chains (Fromhold-Eisebith 1999; Fuchs 2003; Hoffman 1985; James 2002). Upgrading was also experienced in manufacturing and work in the former Eastern peripheries of the European Union (Fuchs 2014; Pavlínek/Ženka 2011). Also within nation states, digitalization was perceived as an opportunity for innovation in existing companies and for start-ups (e. g. Bathelt 1991; Berkeley et al. 1996; Morgan 1992; Roper/Grimes 2005; Sternberg/Tamásy 1999). Hence, different to regulation theory, such contributions saw the digital divide as a threat and digitalization as an opportunity to overcome 'lacks' of modernity. Looking back at this, empirically both was the case. Digitalization replaced labour on the micro level of particular jobs and increased management control (see Hirsch-Kreinsen et al. 2012) but also opened windows of opportunity for some regions to modernize (see Fromhold-Eisebith 2018). In the late 20th century, neither CIM nor the the 'glass factory' or 'factory devoid of humans' was in fact typical for manufacturing in general, which is why the revival of such former dystopian views seems somewhat surprising today. In the 1980 s and 1990 s, digital integration was mostly still company based. Digitalization did not yet show the transnational reach it achieved later in the 21st century, and the World Wide Web was only just looming on the horizon.

Still, academic contributions at that time – in line with practitioners such as unionists, works councils and labour-oriented politicians – emphasized the available elbowroom for influencing digital technologies (Kern/Schumann 1987; Leborgne/Lipietz 1988; Piore/Sabel 1985). The pragmatic-empirical argument was that ultimately, it was engineers who designed digital technologies in R&D departments; hence, cooperation between engineers and blue-collar workers could improve the working conditions of the latter, in particular with regard to ergonomics, teamwork, participation and skills. Empirical studies in Sweden and Germany regarded digitalization as a situation of change, which executives, engineers and workers could use to jointly identify common objectives, e. g. to establish more democratic organisational patterns (Fuchs 1992; Ellegård 1983; Ellegård 1989). In contrast to the idea of human subordination to digital technologies, and also in contrast to seeing participatory management methods as a form of occupying workers' minds, studies were now interested in the influence workers could exert. Many authors regarded the labour process as a political arena and digital technologies as tools that can be used to improve or devaluate labour. As Leborgne/Lipietz (1988, 277) put it:

> It may be noted that there is no deterministic relation between technical possibilities and labour relations. Informatics per se does not lead to deskilling or to involvement. The same techniques (microchips) could support many different technological paradigms, depending on the result of social struggles, competition, and political agreements.

Later contributions were more disenchanted. Workers' influence on the organization of labour is limited given the imperatives of efficiency and the practicability of standardized assembly work. Still, theoretical notions and political practices at the micro-level of firms were in fact notable characteristics of the Post-Fordist formation and had lasting effects (see Hirsch-Kreinsen et al. 2012).

Post-Fordist approaches thus explained digitalization at the level of the workplace, within changing frameworks that regulate economic and social relations at the macro-level. Although this close link between micro and macro-level changes is questionable, it still contributed to a grand narrative of digitalization *and* socio-spatial change. Given its broad take on both, and given its increased academic popularity, regulation theory appeared increasingly fuzzy (Bathelt 1994), so that many preferred the term regulation 'approach' instead (Jessop/Sum 2006). Nevertheless, both within academia and practice, the approach contributed to the insight that digitalization is not a given or necessity, but that there is elbowroom for democratization and participation in technological change.

3 Smart Manufacturing – 'undertheorized' reasoning on digitalization in socio-economic space

While the assembly line and CAD/CAM symbolise Fordist and Postfordist production, respectively, cyber-physical systems, a new generation of robots and 3D printers play a key role in the race for high-end innovation today, promising flexible self-organized, customized production. Similar to earlier regulationist narratives, such manufacturing technologies are still believed to play a key role in changing the socio-economic landscape. Yet, unlike regulation theory, Smart Manufacturing is not part of a broader socio-economic conception of society and space. Given its focus on a bundle of digital innovations, and given the discourse on Smart Manufacturing as a political objective within global competition, it is in fact an 'undertheorized' perspective it the sense that it does not systematically explore the role of digitalization in socio-economic space or the political room for manoeuvre at the micro-level in relation to participation and democratization. Most contributions emphasize the possibly growing polarization between skilled and unskilled labour as a critical issue (Frey/Osbourne 2013; Kagermann/Winter 2017). This is in line with former notions on labour market segmentation in Fordism and Postfordism (see Kern/Schumann 1987). Another issue is the increasing pressure on skilled work due to advances in machine-supported decision-making (Loebbecke/Picot 2015). This is partly in line with earlier contributions that saw digitalization as a challenge to professional work, such as CAD and CAM changing the work of engineers and technicians and skilled blue-collar work. Artificial intelligence certainly has high potential to replace knowledge-intensive work in future (Loebbecke/Picot 2015).

Today, digitalization is often related to Foucauldian perspectives (e. g. Foucault 2008), which are used to explain digital control (Ford/Graham 2016; Ettlinger 2016) and the asymmetries of power that have come to be institutionalized in digital infrastructure (Zuboff 2015). The conceptual approaches taken by these contributions offer ways of understanding the new dimensions of digitalized control, which go far beyond fears of the 'glass factory'. But these new contributions hardly relate to manufacturing; they are more concerned with services, click-workers, the World Wide Web and large internet firms (Graham 2019a).

There is no comprehensive view of digitalization in manufacturing as part of a socio-economic formation. Recent studies on the adoption of Smart Manufacturing ask whether it will spread to the degree suggested by policy-related contributions. However, its antecendent, CIM, only manifested itself as a direction of technological change in manufacturing and not as an all-encompassing reality (Hirsch-Kreinsen et al. 2012). This raises a fundamental question, namely whether Smart Manufacturing is a driver of a new regime of accumulation at all. The following explores the potential of smart key technologies.

The process of increasing digital integration is supposedly changing towards *cyber-physical systems* based on digital platforms, big data, cloud computing, artificial intelligence and further network integration. Self-organizing and customized production is the new direction, i. e. the Internet of Things not only processing data but also processing substantial things. Remarkably, many plant managers are still reluctant to introduce or expand cyber-physical systems on the shop floor. Companies worry about the safety of their data. They often prefer not to change their existing organization or make themselves dependent on (often foreign) providers and data servers. Probable hacker attacks are indeed a challenge for manufacturing companies (Del Casino 2016; Strange/Zucchella 2017); moreover, there are cost reasons. Unlike private households, investments in digitalization do not follow design fashions but have to amortize. Up-to-date, smart applications and devices in factories are rarely general purpose technologies but need to be adapted to particular functions, which is an expensive procedure. Especially smaller companies hesitate to take such financial risks. As a result, cyber-physical systems are often limited to renowned pilot companies, frequently accompanied by (governmentally funded) research (Mühl et al. 2019). The gap between the professed visions of digitalization in manufacturing and its current reality raises the question whether Smart Manufacturing will remain an island solution at the level of pilot projects and early applications, or whether a more fundamental digital transformation is imminent which will change socio-economic patterns.

Contributions that address the socio-spatial implications of e. g. new industrial robots with increasing artificial intelligence, 3D printers as an 'additive' process of moulding, and digital remote diagnostics are still rare. All are key technologies of cyber-physical systems in that they create, shape and process the 'physical' dimension of cyber-physical systems, in other words the 'things' of the Internet of Things. Caruso (2018) for instance analyses *robots* that are increasingly becoming part of cyber-physical systems within factories, i. e. the advanced integration of the virtual web with the material spheres of production. Robots have gained considerable flexibility through numerous sensors that continuously collect data about their environment. With this kind of big data, learning algorithms and enhanced artificial intelligence, robots can improve their own performance (i. e. they are learning) and (partly) control other steps in the production process (Caruso 2018). They do this by having a repertoire of solutions stored in their software and choosing the correct procedure depending on the situation. Industrial robots support the handling, assemblage and processing of materials and parts, but since it is only now that a new generation with such comprehensive self-learning ability has been developed (Albu-Schäffer 2019), the potential impacts on labour still are open. Focusing on existing robots, Carbonero et al. (2018) show that they have a statistically significant negative impact on worldwide employment which is weak in the core economies and strong in emerging economies. The World Economic Forum (2016) illustrates that beyond the cores of the world system, dynamic areas in emerging countries can become attractive locations for such new robots. Richardson/Bissell (2019) thus call for fine-grained attention to the various ways in which robots could affect work. Obviously, robots do not simply replace human labour and intelligence in the sense of replacing experienced workers, but they do have the potential to substitute various tasks beyond routines (Loebbecke/Picot 2015).

Digital remote diagnostics is another feature of cyber-physical systems. It comprises digital predictive analysis, maintenance and (often additionally) repair of machines. The producers and providers offer their service over considerable spatial distances. Machines abroad analyse their own status and immediately report problems to the centre so that they can be solved rapidly. A key technology is the ‘digital twin’, which is a digital representation of things. In the central R&D and planning departments employees analyse the digital twin of an object abroad and navigate an avatar (remote sensor) that solves the particular problem there. Evidently, such central-peripheral patterns may generate spatial dependencies (see IGM/IMU 2018), but digital remote diagnostics can also be useful for improving labour conditions as digital devices can perform tasks that pose high risks to human health. For example, workers now use monitors with avatars and sense gloves to maintain and repair machines in dangerous (nuclear, chemical) environments (Del Casino 2016).

Another feature of Smart Manufacturing is the *3D printer*. 3D printers are machines that build products in line with a digital model, thereby introducing another (‘additive’) method of production up and above e. g. injection moulding or ‘subtractive’ procedures such as digital milling. Until recently, 3D printers were mostly used for constructing models and batch production and rarely for larger series. This is a small but dynamic segment of the economy and employment (Gress/Kalafsky 2015; Mühl et al. 2019). Esch (2019) illustrates the selective use of 3D printers for automobile industries. Busch et al. (2020) discover hybrid modes of urban production in start-up firms combining engineering work (R&D) and manual craftwork. While in principle, machines can decentrally ‘print’ parts somewhere in the world – which could restructure regional and global value chains and thereby displace established suppliers (Winter 2017) – many contributions have remained skeptical with regards to increasing manufacturing opportunities in rural and marginalized regions in the foreseeable future (Gress/Kalafsky 2015). They stress the relevance of supportive infrastructure, skilled engineers and workers, reliable suppliers and logistics for high-road production and application of 3D printers, which generally can only be found in the core economies. Gress/Kalafsky (2015, 47) write:

> While 3D printers may indeed be doing more and more of the ‘work’ associated with production, there will still be an inexorable link between the worker and the machines themselves. Technicians, troubleshooters, repairpersons, and perhaps even programmers will be required to work in conjunction with a printer or battery of printers, and industry favors proximity for the suppliers of these functions (…).

Such a fine-grained view on issues of Smart Manufacturing is in line with earlier contributions that are critical of broad-brush views of digitalization as a means of economic growth and social development. Today, in particular a cautious view is relevant with regard to backshoring labour from the Global South to the North (Bailey/De Propris 2014; Kinkel 2012). Until now, there are few indications that confirm the hypothesis of “premature deindustrialization” (Rodrik 2016, 1), i. e. that digitalization might cause the Global South to lose manufacturing industries before industrial penetration is comparable to the North because capital-intensive production substitutes cheap labour and is relocated back to the core economies (Dachs et al. 2019).

4 Conclusion and fields for future research

This contribution critically reconstructed the basic assumptions of regulation theory as a formerly widespread approach to analysing socio-economically embedded digitalization in the late 20th century. One the one hand, it illustrated the persistence of narratives surrounding digitalization as challenge for workers, for instance related to job security, skilled work and control, and spatial inequalities. This leads to the question whether there are any indications of a radical shift in the mode of capitalist production. Obviously, both the media and science are concerned about the socio-economic effects of Smart Manufacturing, suggesting that it might not have unfolded its full potential to engender structural and regional change. On the other hand, existing studies in the field of new ‘smart’ technologies reveal that visible effects have been limited up to now. Overall, while the digitalization of manufacturing obviously seems to promote a ‘smart’ regime of capital accumulation, the contours of a new formation have so far remained hazy. As a result, the article does not provide a fully formed and sophisticated new theorical framework, nor does it offer a ‘Post-Post-Fordist’ perspective. Instead, it suggests five fields for future reseach that would allow a critical perspective on Smart Manufacturing to emerge.

1. Only few publications investigate how Smart Manufacturing (and the constituent parts of this bundle of digital innovations) affects socio-economic space. Given the technological potential of Smart Manufacturing, and the massive political support it enjoys, *empirical studies* are necessary. Particularly the speculative statements of policy-oriented contributions, as mentioned in the beginning, illustrate the need for a solid empirical basis. Thereby, a comprehensive view of digitalization in manufacturing is necessary, in other words a perspective that also includes business strategies as customization and value chain reorganization, and the role of unions and works councils. Moreover, a clear picture of digitalization as part of the neoliberal economy is necessary (Cockayne 2016). Aoyama et al. (2011) stress that digitalization affects possession and title over resources, which is an emerging research field in economic geography. Powerful economic actors such as large companies and states frame this arena in that they influence how digitalization takes place.

2. Empirical studies need theoretical frameworks against which to analyse the mixture of political objectives, utopian and dystopian visions and real world applications surrounding Smart Manufacturing. Regulation theory has been criticized because of its increasing openness and fuzziness (Bathelt 1994); it has recently drifted into the background of the academic discourse. Obviously, there may be sound reasons for wanting to overcome the limitations of existing theories; it is also acknowledged that views on research topics will shift over time due to intellectual fashions and the pursuit of novelty as well as paradigm shifts (see Kuhn 1962). Regulation theory, however, remains a starting point for *overcoming the ‘undertheorized’ view of Smart Manufacturing*. It allows the deterministic notions of cyclical succession and technological revolution, with their poor conceptualization of the socio-economic contexts of digital change, to be criticized (Bathelt 1994). Moreover, views inspired by regulation theory can allow technology to be understood as part of socio-economic formations and help to frame change and spatial inequalities. Analysis is thus sensitized to the influence of politics – be it technology policy designed to promote digitalization or the use of digitalization to support participation and democratization. Regulation theory helps to see Smart Manufacturing as *driven* by policies as well as a *driver* of social change and spatial (in-)equality.

3. Smart Manufacturing (*driven by policies*) can contribute to overcoming spatial inequality if it is sensitive to the digital divide (modernization) as well as the division of labour (dependencies). With regard to the former, it has to be acknowledged that politically driven approaches that seek to foster digitalization as an engine for growth are limited. Given that political initiatives to produce ‘silicon somewheres’ have often failed (Hospers 2006), academia and practitioners should be cautious with respect to simplistic efforts to generate ‘somewheres’ in Smart Manufacturing. With regard to the latter, *Smart Manufacturing as a driver* of social change relates to both the micro-level within companies and the macro-level of society. It is acknowledged that micro-level changes of labour within manufacturing firms do not simply ‘represent’ general trends on the macro-level, and vice versa (Krzywdzinski 2017). Still, research should improve the binuclear micro and macro-level perspective in order to arrive at a comprehensive understanding of socio-economic change and windows of opportunity for democratization and participation. Polarization of labour markets, regional inequalities and related cognitive patterns (othering) are critical for democratic societies (Storper 2018). In whatever direction, society and policies shape digitalization. With its immanent spatial view, economic geography can contribute to issues of regional change, cross-border interdependencies and the role of societal and political actors in ‘place-making’ (Fuchs 2019).

4. Digital technology offers elbowroom for *democratization, participation and work according to human needs*. This relates to the field of co-determination in the manufacturing industries, where trade unions and works councils are influential (Hirsch-Kreinsen 2018). There is an increasing number of start-up firms and self-employed digital nomads, such as crowdworkers. While some may benefit from more self-determined work and a flexible work-life balance (Lange/Bürkner, 2018), others suffer through technological change as they work in vulnerable

positions (Cockayne 2016; Graham/Anwar 2018; Richardson 2018). Graham et al. (2015) argue for new contracts and institutional regulation to increase the bargaining power of digital workers, including also workers employed outside of smart factories. A range of suggestions are put forward: laying the foundations for fair work, further internationalizing union activities, building up digital freelancers' unions, introducing labels for socially acceptable work (certified by trustworthy organizations), and improving regulation in Europe and the US where many headquarters of internet firms are located.

5. Last not least, research needs to focus on digitalization *beyond factories*. Fordism and Post-Fordism particularly refer to US and European automobile manufacturers and related industries. Recent studies on digitalization broaden the perspective beyond manufacturing (Ettlinger 2016; Graham 2019a) by including the interface of manufacturing and services (Bailey/De Propris 2019). The financial sector increasingly plays a role in the ‘new economy’ (Boyer 2000; Zeller 2003), and e-commerce is changing work in the Global North and South (Graham 2019b; Krone/Dannenberg 2018). Moreover, there is the need to differentiate between large-scale manufacturing in factories and small-batch production in workshops and crafts; both are changed by digitalization (Busch et al. 2020). There is a need for fine-grained analysis that covers various sectors of economy and identifies those kinds of digital production and labour that are relevant for the new ‘smart’ regime of accumulation.

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