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Collaboration Moves Productivity To The Next Level

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Abstract

Driven by cyber-physical systems, industrialization is on the edge of its fourth revolution, denominated ‘Industry 4.0’ in Germany. In the past, technological advancements were often only the starting point for productivity gains and had to be translated into organizational innovation in order to foster a pervasive improvement of productivity. According to this, this keynote investigates the role of cyber-physical systems as the technological driver and collaboration as the organizational driver that will enable higher levels of productivity with Industry 4.0. A framework for collaborative practice is portrayed and its constituting components are used to exemplify levers of Industry 4.0 that can increase collaboration productivity.

1. Introduction

Today’s market is characterized by demand volatility, individualized products and increasing competition due to globalization [1]. Key for companies to successfully compete in this dynamic and competitive environment is to continuously strive towards higher levels of productivity, which is particularly essential for companies producing in high-wage countries [2]. While productivity can simply be defined as the ratio between input and output, the underlying drivers behind productivity growth are manifold and include external elements, such as technology, the environment companies operate in, government regulation and competition, as well as internal elements, e.g. production processes, human capital and management. [3, 4]

The working assumption of this paper is that new technologies enable organizational innovations which in turn account for a significant part of productivity growth. Accordingly, this paper examines the introduction of cyber-physical systems as the technological driver and collaboration as the organizational driver, leading to higher productivity in production. [5]

2. Historical view of productivity growth

In each period of industrialization, a few key technological advancements had particular impact on the increase in productivity. BRESNAHAN ET AL. refer to them as ‘general purpose technologies’ (GPTs) that enable new opportunities of productivity growth, but normally do not offer a ready-to-use technical solution [6]. Thereby, three technological advancements had particular impact on the increase in productivity that can be considered as industrial revolutions.

1) In the 18th century, the steam engine embodies the technological breakthrough of the first industrial revolution. With the utilization of steam energy, machines were introduced into production, allowing the general mechanization of the economy. With a high degree of mechanization the economy in general became much more productive. [7]

2) One of the main technological enablers of the second industrial revolution was the widespread utilization of electricity. Electrification was a driver for mass production and had significant impact on productivity of the economy in the beginning of the 20th century [8].

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3) The third industrial revolution is centered around the shift from analogue technology to digital technology and is also referred to as the digital revolution. One technological driver behind the third industrial revolution is the invention of integrated circuits that allow to increase computational power and decrease costs continuously and in an exponential manner [9]. This led to an industry wide adaptation of information technology and has a significant impact on the growth of economic performance till today [10].

2.1. Organizational innovations translate technological advancement into productivity

General purpose technologies, like the steam engine, electricity or information technology are generally associated with productivity growth. Yet often, a significant portion of the productivity gain is realized by the organizational innovations in companies [11]. For example, the steam engine allowed to substitute manual labor with machines, electricity allowed to transfer power to machines without line shafts, making it possible to position machinery much more freely and the invention of the integrated circuit enabled the automation of production [12], see Fig. 1.

Often, the organizational transformation cannot keep up with the pace of technological advancement, resulting in less overall productivity gain than expected [13]. This apparent discrepancy is often referred to as the productivity paradox, which was disclosed by the exponential advancement in computing power and increasing availability of information technology that did not correspond to the relatively slow growth in productivity for the whole economy but also for single companies [14]. The underlying reasons for this paradox are often referred to as the ‘Internet of Things’. With Internet of Things, objects can be uniquely identified and autonomously cooperate and interact with each other in order to reach common goals. [19]

According to a report by ACATECH, cyber-physical systems can be characterized by five constitutive dimensions that lead towards “increasing openness, complexity and intelligence of systems” [20].

- Merger of the physical and virtual world
- Dynamic formation of system-of-systems
- Context-dependent and autonomously operating systems
- Cooperative systems with decentralized control
- Extensive human-system-collaboration

These characteristics illustrate that cyber-physical systems build the technological basis for a fundamental change in how companies and the society are organized today [21].

3. Collaboration is key for increasing productivity

The dictionary defines collaboration as “to work jointly with others” [22]. This general definition does not specify
‘others’, but suggests that two or more entities collaborate. The granularity of the collaborating entities can vary and include individuals on a fine-grained level and organizational entities such as companies on a coarse-grained level. Thereby, collaboration strengthens individual function, which in turn strengthen the collaborating companies as a whole [23].

The dictionary’s definition implies that only humans cooperate. However, the technological advancement of cyber-physical systems will increasingly foster the collaboration between humans and machines as well as the collaboration between machines, making it necessary to expand the idea of collaboration [24]. This extended idea of makes it conceivable to have three forms of collaboration on a fine level of granularity: human-human collaboration, human-machine collaboration and machine-machine collaboration [25].

3.1. Creating a framework for collaborative practice

As BEDWELL ET AL., describe collaboration as a superordinate concept that is linked to many subtopics that all represent a more detailed view on collaboration [26]. Characteristically for collaboration is that the collaborating entities communicate with each other, coordinate their activities and cooperate in order to accomplish a shared goal [27]. In particular, larger organizations face the challenge that knowledge and experience is scattered among many employees in different disciplines and consequently all relevant stakeholders need to be involved in many decision-making processes further assigning emphasis on collaboration [28].

![Fig. 3. Framework for collaborative practice](image)

Fig. 3. Framework for collaborative practice

As portrayed in Fig. 3, the framework for collaborative practice proposed here is detailed into three collaborative dimensions: coordination, cooperation and communication [29]. All dimensions consist of two collaborative practices each that in total do not necessarily represent a comprehensive listing, but are meant to facilitate collaboration.

In this context, communication provides the means to share information and enables sense-making [30]. Sharing information is fundamental for all collaborative activities [31]. For example, in supply chain partnerships, mastering information sharing can significantly reduce the bullwhip effect and improve overall productivity [32]. Sense-making on the other hand is the process of interpreting information in order to understand complex situations and assess the consequences of possible measures accordingly [33]. Sense-making is not a solitary activity, but uses the existing knowledge of all the entities in an organization. The result of cooperative sense-making is new knowledge, which is maintained in an organization through the interaction of its members, and, in particular, through effective communication [34].

Coordination is “managing (the) dependencies between activities” [35]. Mastering coordination requires to manage available resources, synchronize tasks and align activities [36]. This definition links coordination directly to productivity: the productivity of the supply chain relies significantly on the efficient coordination of its members, resources and activities by which costs (e.g. excess inventory) can be reduced and throughput time can be shortened. Also, optimizing coordination of cross-departmental activities, e.g. between support activities and primary activities, often results in greater productivity gains than optimizing single departments only. [37] In the proposed framework resource-pooling and goal congruence are the two collaborative practices that are central to coordination [38]. Resource-pooling includes to allocate necessary information, equipment and human resources in order to reach the collaborative goal, to assign tasks and to decide for how much time resources are allocated to activities [39]. One difficulty of resource-pooling is that the collaborating entities compete for limited resources and try to attract as many resources as possible [40]. For resolving the competition for resources, goal-congruence is crucial. Goal congruence describes the mutual understanding and agreement on the overall goal by the collaborating entities. With a high degree of goal-congruence, productivity can be increased, since the objectives and activities of the decision-makers are aligned and do stay in conflict to each other [41].

The third collaborative dimension of the proposed framework is cooperation. Cooperation indicates that the involved entities recognize the importance of the overall goal and consequently work together in order to reach it [42]. Cooperative behavior leads towards better performance of organizations and must be facilitated and encouraged through leadership [43]. For this, the organization system should foster attitudinal factors, in particular commitment to the common goal [44]. Within the framework, cooperation is represented by cross-functional activities and empowerment of employees. These two collaborative behaviors follow the idea that it is desirable to empower decentralized decision-makers and thus giving away control from central entities, but at the same time, to interconnect these decentralizes decision-makers across functions and divisions. The combination of interlinked and decentralized decision-makers allows to utilize local information with global knowledge at the same time for better decision-making and increasing overall productivity [45].

4. Levers of Industry 4.0 to increase collaboration

The term ‘Industry 4.0’ expresses that the next industrial revolution, based on cyber-physical systems, is imminent [18]. According to ACATECH, Industry 4.0 is not only a technical challenge, but will particularly change the organizational structure of companies significantly. With no intention of a
comprehensive listing, ACATECH exemplifies five visions for the disruptive change with Industry 4.0 [18]:

- New level of socio-technical interaction: Autonomous and self-organizing manufacturing resources that conduct planning processes in inter-company value networks
- Smart products: Details of the manufacturing process and tolerable operating parameter are known to the product and can be pooled to optimize production
- Individualized production: Flexible reconfiguration allow firms to consider customer and product specific features along design, planning, production and recycling phase.
- Autonomous control: Employees control and configure smart manufacturing resources based on situation- and context-sensitive targets
- Product design controls the product related data: The data related to the product becomes a central resource in the product lifecycle management.

It is apparent that the organizational change towards Industry 4.0 will only be enabled by higher levels of collaboration. For example, self-organizing manufacturing resources need not only to collaborate with other resources, but also with the person who sets the planning parameters. This requires a high degree of collaboration, not only on a coarse-grained level across companies, but particularly on a fine-grained level between humans and machines.

In essence, Industry 4.0 is able to offer productivity gains, because the technological advancement allows to significantly improve collaboration, in particular in terms of the three collaborative dimensions proposed in the framework. In an attempt to anticipate the change in collaboration, the next sections each describe the impact of Industry 4.0 on the three collaborative dimensions. Thereby, Fig. 4 illustrates how the key aspects of Industry 4.0 contribute towards increasing collaboration and thus higher levels of productivity.

4.1. Communication

How poor communication compromises productivity can be exemplified by the planning process: the exchange and interpretation of insufficient and outdated data provoke flawed decisions and limit the scope of action in collaborative efforts, e.g. within supply chains [46]. Thereby, centralized planning approaches are often problematic, because any delay between gathering and interpretation of information result in a discrepancy between plan and reality [47].

Cyber-physical systems offer to close the delay between information sharing and sense-making by fostering decentralized communication, whereas two features of Industry 4.0 are pivotal [48]: Firstly, the omnipresence of sensors will render it possible to obtain information on a new level of granularity with the least possible delay. Secondly, simulation based on real-time data will enable to anticipate the effect of local optimization in the overall context, allowing for better sense-making and employing decentralized control loops.

1) Information sharing: The price for electronics and sensors is continuously decreasing, while the dimensions of sensors are getting smaller at the same time, which allows companies to economically deploy sensors on a large scale and in a multitude of applications, e.g. in logistics and production [49]. By connecting sensors, respectively cyber-physical systems, to local or global networks, the access of information will become arbitrary. Cyber-physical systems enable to inquire information directly by its source. This not only allows to access real-time data for sense-making, but also fosters information sharing among all entities collaborating. [50]

Fig. 4. Exemplified levers of Industry 4.0 in the context of collaboration

2) Sense-making: Often, companies cannot test different conditions and alternative paths of actions, depicting simulation as an attractive method for sense-making, since simulation can help to understand the effect of different input for better anticipating the consequence on real systems [51]. With the advances of computational power, the results of simulation become more significant, since more alternative conditions can be simulated. Bernoulli’s ‘law of large numbers’ implies that the average results of trials (e.g. coin tossing) will tend towards the expected value with greater number of trials [52]. In analogy, it is to be expected that with higher number of performed simulations the average outcome of simulations tends to be the most likely scenario. For example, the landing of NASA’s mars rover Curiosity was simulated hundreds of times in order to take all possible conditions into account [53].

4.2. Coordination

The two collaborative behaviors associated with coordination in the framework proposed are: 1) Resource-pooling as the process of identifying the best fitting resources and managing them in order to collaborate and 2) goal-congruence as the alignment of individual goals towards a common goal.

1) Resource-pooling: the allocation of resources, including the identification, prioritization and controlling of these, is
particularly challenging in interdependent work settings when multiple entities compete for limited resources [54]. Thereby, the key characteristic of cyber-physical systems being able to form ‘system-of-systems’ corresponds directly to the collaborative behavior of resource-pooling. The idea of the system-of-systems approach is that multiple cyber-physical systems interconnect with each other in order to combine their individual abilities to create a temporary new system with enhanced functionality for solving complex tasks [55]. In this way, cyber-physical systems will enable new possibilities for quickly identifying the relevant resources and interlinking them ad-hoc in order to foster collaboration [56].

2) Goal-congruence: Two key implications for high levels of goal-congruence are well harmonized goals that are coherently based on each through the organizational hierarchies and to introduce common and transparent reporting tools [57, 58]. Both implications are facilitated by the broad introduction of cyber-physical systems: Since the vision of Industry 4.0 depicts that diverse cyber-physical are meant to interconnect autonomously and across organizational boundaries, standardizing design and interfaces are absolutely necessary to develop [59]. With high degree of standardization, the individual goals can be easily surveyed for integrity over all levels of hierarchy and across organizations. Also, a common reporting schema will become much easier to implement, once cyber-physical systems are introduced.

4.3. Cooperation

As described in the previous section, the identified collaborative behaviors for cooperation are 1) fostering cross-functional activities in organizations for a dynamic collaborative process and 2) the empowerment of decision-makers in order to decentralize the decision-making process.

1) Cross-functional activities: With cyber-physical systems, the significance of cross-functional activities will further increase. In the future, interlinking of intra-company activities and collaborating along the supply-chain will be crucial for attaining high levels of productivity. Even today, supply-chain management optimizes the “interaction between information, materials, money, manpower, and capital equipment”. [60] Yet, the interaction between things will further increase with the concept of the ‘Internet of Things’ as described previously above. In the vision, all objects can be located instantly, can be identified unambiguously, are aware of their past, present and future state and autonomously cooperate with machine tools, storage areas and other resources for piloting through the production processes self-dependently. With the Internet of Things physical objects as well as real processes have virtual representations, enabling collaboration between processes and objects without any limiting restrictions of the physical world, like proximity and time, enabling more and quicker cooperation between functional areas. In this manner production systems will be directly interlinked with the relevant business management processes and externally connected to all partners of the supply chain. [18]

2) Empowerment of decision-makers in order to foster accountability for work and to facilitate decentralized forms of leadership and control is central to the dimension of cooperation. The importance of humans deciding will not at all become less important, but will only gain more significance, since employees will set up the determining factors of production, design, install and maintain complex cyber-physical systems and define the rules for production, e.g. determining the best fitting optimization criteria. In a more interconnected world the function of employees will shift away from simple operators towards decision-makers that are actively involved in the decision-making process, which focuses not on selective optimization but also considers the overall context. [61]

By unburden employees from simple and routine activities, like information gathering and pre-processing of data, cyber-physical systems play a significant role in empowering the decision-makers [25].

5. Conclusion

The working assumption of this paper is that new technologies enable organizational innovation which in turn can account for significant part of productivity growth in producing companies. Accordingly, this paper examines the introduction of cyber-physical systems as the technological driver and collaboration as the organizational driver that will enable higher levels of productivity in production.

This paper first surveys the past three industrial revolutions in terms of the technological change that induced organizational innovation. In analogy to the past, the characteristics of cyber-physical systems are shortly introduced and implications for organizational innovation are suggested. Secondly, in reference to BORGHOFF ET AL. [29], a framework for collaborative practice with the three dimensions communication, coordination and cooperation is proposed, and is further developed by allocating six collaborative behaviors to each dimension. It is then examined how each collaborative behavior facilitates higher productivity. Lastly, the impact of Industry 4.0 on each element of the collaborative framework is exemplified and suggested how cyber-physical systems can play a pivotal role in increasing productivity.

References
