Beyond "Industry 4.0": B2B factory networks as an alternative path towards the digital transformation of manufacturing and work

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Abstract. *This article uses theoretical and empirical evidence of variations in digitalized manufacturing to revisit Piore and Sabel's 1984 work on flexible specialization and to criticize the inherent one-sidedness of the Industry 4.0 discourse. This is juxtaposed with empirical findings on platform-mediated business-to-business factory networks, in which flexibility is facilitated by the digital interconnection of a far-flung network of small-scale manufacturers rather than by sophisticated production technology. The effects on work are equivocal; they entail the potential for a craft-like and skill-intensive paradigm of small-scale manufacturing that can upgrade work, but also for a race to the bottom in price-sensitive industries.*

Keywords: *Industry 4.0, flexible specialization, digitalization, platform, global value chains, upgrading, Alibaba.*

1. Introduction

With a series of new digital applications entering the workplace, academic and political discourses on economic strategy and the future of work are rife with the prospects for a new revolution in manufacturing (Sturgeon 2021). The term "Industry 4.0" distils from this the concept of a distinct stage of industrial production, a new industrial revolution that many expect to generate hikes in

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productivity and growth. Since its initial presentation at the 2011 Hannover Messe trade fair in Germany, the Industry 4.0 model has been referenced in countless publications by industry consultants, policymakers and institutions such as the World Economic Forum (Schwab 2017). Yet, catchy as it is, the model must be approached with caution as a scientific categorization of current changes: inherently technology-deterministic, it conveys a very one-sided notion of the way in which digital technologies affect and interact with industrial organization. Industry 4.0, so far, is more a *narrative* than a reality, a stylized projection by vocal stakeholders of how the digital transformation of industries is supposed to come about.

In this article, we highlight an alternative dimension of the digital transformation of manufacturing and work that has so far received very little attention in the discourse on this subject: the "distribution-centred" or "factory network" approach. By contrasting it to the Industry 4.0 narrative, we want to correct the latter's determinism and one-sidedness. As shall be seen, the factory network approach has markedly different characteristics in the areas of production technology and the organization of manufacturing and work. It does not rely on the sophisticated production technologies of "smart factories" in order to maximize productivity and flexibility. Rather, it mobilizes a far-flung network of small and medium-sized enterprises that mainly apply standard production technologies and are integrated via digital platforms that match (industrial) buyers with producers. By contrasting the cornerstones of the Industry 4.0 model as it is presented by its architects in key publications with our own empirical data drawn from case studies of new digitally integrated factory networks in Germany and China, we emphasize the sector- and context-specific contingency of the digital transformation of industries and work.

Acknowledgement of the distribution-centred approach to digitalized manufacturing is not only significant as a critique of the official Industry 4.0 discourse. It also has important practical implications for firms and workers, which is why we offer a detailed empirical analysis of the conditions required for industrial upgrading and the prospects of upgrading worker skills and wages. Except in the Industry 4.0 model, which emphasizes the role of sophisticated technologies, distribution-centred strategies do not necessarily require the individual participants of the network to upgrade, since the flexibility to meet customer demand rests not on a single enterprise but on the network itself. Thus the distribution-centred approach is more pragmatic and achievable – particularly for small and medium-sized enterprises in developing countries – than the investment- and engineering-heavy strategy of emulating the "smart factories" of European- or American-led multinational companies. However, the implications of the distribution-centred approach for social development are equivocal, given that the approach perpetuates small-scale and low-end manufacturing in a digitally updated form and that the business-to-business (B2B) platforms may be its main beneficiaries. What is more, our case studies demonstrate that the factory network approach does not necessarily involve an upgrading of worker skills, which is why it may not lead to a social upgrading of work.

In this article, we outline the contours of the factory network approach to digitalized manufacturing as follows. In the second section we scrutinize the inherent one-sidedness and determinism of the Industry 4.0 paradigm by highlighting the central insights of a classic book on the varieties of industrial organization, Piore and Sabel's *The Second Industrial Divide* (1984). We recall that, beyond the mass production paradigm that has historically attracted the most attention in academic and political circles, there exists the alternative paradigm of "flexible specialization" – conglomerations of specialized small- to mid-sized companies that interact to deliver high-quality goods in a flexible manner. We use Piore and Sabel's insights from the 1980s to frame our analysis of a similar choice of options in relation to the digitalization of manufacturing, which we subsequently describe. In the third section we briefly characterize the smart factory model that constitutes the core of the Industry 4.0 narrative, on the basis of key policy documents. Our aim is not to conduct a comprehensive literature review or to summarize empirical findings on the matter, but to outline the discursive cornerstones of this paradigm, which we then juxtapose with the factory network model.[1] The analysis in the fourth and fifth sections summarizes original findings (20 interviews) from two research projects covering B2B platforms and their manufacturing partners in China and Germany between 2018 and 2020. The analysis describes the main characteristics of production networks that are integrated via digital platforms and considers the implications for manufacturers in terms of industrial upgrading and work. In the conclusion we summarize the main differences between the smart factory and the factory network models and their implications for economic and social development.

2. *The Second Industrial Divide* (1984) revisited

With *The Second Industrial Divide* and its challenges to long-held assumptions about the course of industrial development, Piore and Sabel ignited considerable debate among political economists and industrial sociologists. The book is a useful point of departure precisely because it questioned the one-sided and narrow concepts of industrial transformation that predominated at the time and are being resurrected, in one form or another, under the label of "Industry 4.0". Although the authors argued that industrial change had diverse theoretical trajectories, they also intervened in the political discourse, proposing a departure from the paradigm of mass production and propounding industrial policies and regulatory approaches that could better accommodate flexible specialization, which they considered to be superior and more able to meet the requirements of diversified customer demand.

Piore and Sabel's basic assumption was that the mass production paradigm was neither a natural consequence of economic development nor without

[1] We feel justified in taking this approach because the Industry 4.0 narrative has informed the strategies of governments, enterprise associations, consultants, trade unions and firms and has therefore guided the practice of the agents that are shaping the digital transformation of industries, at least in Germany. The question of the extent to which this discourse matches the actual experience of firms lies beyond the scope of this article, in which we uncover the diverging trajectories of digitalized manufacturing. Good discussions on the matter may be found in, for example, Hirsch-Kreinsen (2019) and Pfeiffer and Huchler (2018).

alternatives. Just like the subsequent approaches to flexible specialization, it had come about through a combination of conscious decisions, institutional peculiarities and accidental findings:

> [T]here is no "natural path" to economic success. … the triumph of a technological breakthrough over competing adaptations depends on its timing and the resources available to its champions – rather than on its intrinsic superiority. In this view, competition guarantees only that the weak must follow the lead of the strong, not that the strong have found the uniquely correct solution to common problems. Progress, we will show, is best described … as a branching tree – yet the limbs of this tree thrive or wither according to the outcomes of social struggles, not some natural law of growth. (Piore and Sabel 1984, 15)

The merit of this emphasis on experimentation and a degree of arbitrariness in the evolution of industrial paradigms lies in a pragmatic view of innovation, which is a better match with the current manner in which Industry 4.0 technologies are implemented than is the stylized concept of a distinct stage of industrial production. This is borne out by various empirical analyses that highlight the contingent and incremental character of current processes of technological change (Butollo, Jürgens and Krzywdzinski 2019; Hirsch-Kreinsen 2019; Kuhlmann 2020). They stress the unexpected and as yet unknown. A perspective that emphasizes the role of experimentalism in economic development thus defies the teleology of the Industry 4.0 model, which assumes that there will be a natural progression towards a distinct and identifiable stage (see section 2). The model of a smart factory responding instantly to customer demand may serve to popularize and substantiate the claim of a fourth industrial revolution, but it rests on the flawed assumption that it is possible to clearly outline the shape of socio-technical systems of the future and that they will naturally evolve out of the properties of technology as such – a notion that has been criticized by sociologists of technology (MacKenzie and Wajcman 1999). Contrary to these assumptions, it is plausible that the broad set of technologies that industrial companies have at their disposal lead to approaches that are more diverse than those suggested by the stylized smart factory model, including some that are very different from the German paradigm of diversified quality production (Sorge and Streeck 1988) underpinning the Industry 4.0 discourse.

But it is not only the emphasis on experimentalism that makes *The Second Industrial Divide* an interesting reference for the discussion of approaches to the contemporary digital transformation of industry. The book's main theme – the tension between (standardized) mass production and networked craft-like production – is in line with the central premise of our article. According to the Industry 4.0 paradigm, with its emphasis on smart factories, industrial mass production can use sophisticated production models to enhance manufacturing flexibility in order to meet customized demand without loss of productivity. Although new digital technologies can indeed, to a certain extent, mitigate the century-old contradiction between high productivity and flexibility, the flexibility of a network of small producers constitutes an alternative and possibly superior approach to this end. We will argue that Piore and Sabel's flexible specialization, rooted "in the networks of technologically sophisticated, highly flexible manufacturing firms" (1984, 17), resembles the contemporary development of a distribution-centred approach to the digital transformation of manufacturing.

However, contrary to Piore and Sabel's assumption that the networked small-scale manufacturing approach is per se superior in terms of the innovative capabilities developed by companies and the preponderance of skilled work, we describe the distribution-centred approach as highly ambiguous. The flexibility in market response is facilitated by the network as a whole, rather than by the manufacturers, who may experience economic benefits from a new and professionalized sales channel but no significant upgrading of their products, functions and processes.

3. The smart factory model and its reliance on advanced engineering and skilled work

This section contains a synopsis of the Industry 4.0 paradigm as it is presented in (mostly German-language) key documents by the concept's architects and advocates. The sources were selected according to their origin – the government ministries involved, enterprise associations and research institutions – and their impact on the public discourse. They comprise early high-profile presentations on the issue that are widely agreed to have laid the cornerstones of Industry 4.0.

The term "Industry 4.0" was coined in 2011 by the employers' associations of the mechanical engineering, information technology and electronics industries and supported by the German Federal Ministry of Economics and Technology (BMWi). It purports to present a strategic perspective for German industrial development in the context of heightened competitive pressures. Wolfgang Wahlster (quoted in Spath 2013, 121), a leading researcher in artificial intelligence and one of the concept's architects, argues that Industry 4.0 is prerequisite to a strategy to produce digitally enhanced products of premium quality and in small batches at affordable cost. He also argues that Industry 4.0 technology may become a popular export product that will help the German mechanical engineering sector maintain a competitive edge over its global competitors.

The concept is predicated on the idea of a fourth industrial revolution rooted in technology. It rests on "cyber-physical systems", the connection and dynamic real-time adjustment of products, equipment and human agents. In this technocentric reading of economic history, Industry 4.0 is the successor to three prior revolutions: the invention of the steam engine (nineteenth century), the introduction of the assembly line (early twentieth century) and the application of microelectronics (1970s) (Germany, BMBF 2015, 10). It has raised high expectations in terms of the effects on productivity and growth in gross domestic product (GDP) (Bauer et al. 2014). Critics have pointed out that this makes it a "technology promise" with the discursive function of realigning societal forces behind a shared goal. It is as much a discourse as a socio-technical reality (Hirsch-Kreinsen 2016a; Pfeiffer 2017), or, to put the matter more clearly, it is necessary to separate the stylized version of the model from the day-to-day reality of experimentation by companies with specific technologies. At the enterprise level, Industry 4.0 technologies are mainly implemented in a path-dependent way as incremental adaptations to the dominant production models that have previously shaped the trajectories of enterprises (Butollo, Jürgens and Krzywdzinski 2019; Hirsch-Kreinsen 2019).

The core idea underpinning the Industry 4.0 narrative is industrial mass production. It aims to reconcile high-volume manufacturing (offering high levels of productivity) with the degree of product customization needed to meet increasingly diversified consumer demand:

> In the future under Industrie 4.0, it will be possible to incorporate individual customer- and product-specific features into the design, configuration, ordering, planning, production, operation and recycling phases. It will even be possible to incorporate last-minute requests for changes immediately before or even during manufacturing and potentially also during operation. This will make it possible to manufacture one-off items and very small quantities of goods profitably. (Kagermann, Wahlster and Helbig 2013, 21)

Producers are thus expected to gain competitive advantages over manufacturers of standardized products and to develop the capacity to react flexibly to market volatility, short-term changes in production requirements, fluctuations in the price of raw materials and energy, and supply chain disruptions (Germany, BMBF 2015, 6). Additionally, the data transparency associated with Industry 4.0 is expected to enhance manufacturing quality and delivery reliability (Kagermann, Wahlster and Helbig 2013).

It is expected that all this will be achieved thanks to smart factories that build on the strengths of German industrial engineering and the application of technological artefacts, especially advanced industry software, autonomous "intelligent" machines, service robots, digital assistance systems and autonomous transport vehicles (Germany, BMWi, n.d.). The strategic orientation towards smart factories thus represents a capital-intensive, engineering-heavy approach to flexibilization in highly automated factories (IG Metall 2016, 5). Apart from investments in equipment (and the associated dilemma of return on investment), the standardization of programming languages and communication interfaces is currently the major bottleneck. Setting such standards requires not only institutional efforts but also considerable data-science expertise within manufacturing companies, including cross-functional abilities of skilled workers that can bridge the gap between data-science skills and practical, domain-specific knowledge (Krzywdzinski and Butollo, unpublished).

Some Industry 4.0 blueprints do expand the idea of a network that enhances production flexibility beyond the confines of the smart factory, emphasizing dynamic connections between resources, intermediary products, logistics, processing machinery and tools. These blueprints have been little explored in practice, however, and the vision of the smart factory as a highly automated and technologically sophisticated mass production unit continues to dominate the discourse on the digitalization of manufacturing.

Just as the smart factory model reflects the engineering-heavy tradition of German manufacturing, projections of the future of work emphasize the important role of skilled workers, who historically have constituted the backbone of this sector's development. Industry 4.0 is expected to lead not to the substitution of work but to the transformation of its nature. In line with the growing sophistication of the technological foundation of production systems, most models envision a further upgrading (or at least no downgrading) of skills as demand grows for skilled workers who work autonomously and perform strenuous tasks supported by technology. The German Minister of Education and Research depicts the role of workers in Industry 4.0 as follows:

> Also, manufacturing workers will experience the use of cyber-physical systems in their working environments as a great help. Production robots, machines and entire plants will be equipped with them. In 2025, people will be working in intelligent production environments in which they will interact directly with machines and exchange information through multimodal assistance systems. (Germany, BMBF 2015, 29)[2]

Such optimistic perspectives call for scrutiny. They are oversimplifications, in which the future of the transformation of work is directly deduced from the characteristics of the technologies applied. Sociological studies, on the contrary, have found that working conditions are contingent on the design of "socio-technical systems", that is, the ways in which technologies, organizations and human work are combined. These may result in work being upgraded, but they may also lead to it being downgraded through the loss of competences vis-à-vis automated decision-making systems or to the polarization of skills and incomes (Hirsch-Kreinsen 2016b).

Future research must therefore not only generate empirical data on exactly how Industry 4.0 technologies shape the production models of firms across industries, but also examine the extent to which the technological upgrading of firms actually implies an upgrading of work. Despite these reservations, it is safe to say that the *model* of the smart factory is firmly grounded in the assumption of additional capabilities that manufacturers need to acquire and also implies that workers will require new and additional skills. The engineering-heavy approach of Industry 4.0 and the emphasis on skilled labour as the cornerstone of advanced manufacturing are closely intertwined (Spath 2013).

4. The factory network model: Flexibility gains through the network itself

What we term the "factory network model", or distribution-centred approach, is a very different approach to digitalized manufacturing compared to the one envisaged in the Industry 4.0 narrative. In this section we describe the model's cornerstones on the basis of 20 qualitative interviews conducted in 2018 and 2020 with platform providers and their manufacturing partners in China and Germany. For both countries, the cases studied were selected from the industry in which the distribution-centred approach was most prominent. The data on the German cases are drawn from interviews with three B2B platforms in the mechanical component manufacturing industry and with five mechanical component manufacturers in Germany, Europe and Asia cooperating with these platforms. The case studies were supplemented with interviews with experts and extensive desk research. In China, interviews and factory visits were conducted at seven garment factories working with Alibaba's Tao Factory platform.

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2 Translations from German are provided by the authors.

The factory network model is a new way of organizing flexible manufacturing networks using digital platforms that function as a matchmaker between industrial buyers and suppliers. In China, the e-commerce giant Alibaba has been particularly agile in exploring such possibilities, linking its original core function as an online directory for industrial suppliers of products and components with the data-science skills derived from its business-to-consumer (B2C) e-commerce business. The Tao Factory platform is deliberately presented as a networked factory supplying small batches of products primarily to e-commerce sellers that operate in Alibaba's Taobao marketplace. One example of this link between e-commerce demand and flexible production is the on-demand business strategy popularized by online celebrities selling their own apparel brands via Taobao. The items being sold are not in stock; instead, they are produced by partner factories after customers place their orders and are ready for delivery in seven to nine days at mass production costs (Zeng 2018). Alibaba is thus accomplishing what the concept of Industry 4.0 ascribes to technologically sophisticated factories – the quick supply of small batches of products to a dynamic and highly diversified market without major losses of production efficiency – but following a very different trajectory.

This approach is not unique to China. Start-ups like Xometry in the United States of America, LaserHub in Germany and Hubs in the Netherlands have also established B2B platforms to match industrial customers with small-scale producers. Unlike Alibaba's network, which gravitates around the garment and light industries, these platforms connect suppliers in the mechanical component manufacturing industry, which has historically been characterized by small-scale production. They are expanding rapidly and increasingly replacing or complementing the established informal ties between industrial buyers and suppliers. Feedback loops on technical drawings were indeed once common and ensured that products matched buyer requirements. However, such adjustments and the inherent advantages of interpersonal interaction have been made obsolete. B2B platforms now facilitate the transfer of production-related data, thus enabling technical drawings to be uploaded and (in some cases) providing automated quality checks of the designs and cost projections. By reducing the need for direct personal interaction with suppliers, the platforms can connect industrial buyers with a large number of suitable manufacturers and provide transparency on prices. Although geographical proximity may still offer some advantages in terms of cost and transport savings, B2B platforms promote the geographical fragmentation of buyer–supplier relationships because lead times and prices depend primarily on the production costs, capabilities and availability of suppliers.

In all of the above cases, suppliers need to provide detailed information about their production processes in order to qualify and their capabilities are evaluated on an ongoing basis in terms of product quality and speed, reliability and price. The results affect the likelihood that they will receive orders in the future. Some of the platforms, which had already collected a wealth of data on production costs and related indicators for the various processing techniques, have introduced instant pricing tools that calculate a binding price for certain items by operationalizing the properties of a technical drawing, the desired materials, the processing techniques, the lead time and the batch size, and comparing this information with automatically generated benchmarks from their vast database. The platform thus more or less dictates prices on the basis of the cost of similar orders in the past and reduces the manufacturers' capacity to bargain. The chief executive officer of one major B2B platform described the additional transparency on production costs and prices created by such platforms as a major advantage. Whereas conventional customers would request quotes for a desired component from only one or a small number of manufacturers, platforms are able to compare large numbers of past quotations for similar components, set an "objective" price by which cooperating manufacturers have to abide, and therefore reduce costs for their customers:

> A [conventional] customer would only get one quote because it just takes him a lot of time to get multiple [quotes]. And that intransparency in the whole process and inefficiency led to the opportunity for factories, I think, to overprice and really charge too much and a customer just simply wouldn't know what a fair price was. Yeah, I think that, thanks to platforms like us, that's becoming a thing of the past.

By recording and analysing such data, the platforms can expand their pivotal role as factory network infrastructure. Future scenarios described by mechanical component manufacturing platforms during the interviews point to even deeper forms of data-based integration of manufacturing. For them, the supply-side Internet of Things plays a key role in connecting the equipment of manufacturing partners directly to the platform, providing real-time information on the status of an order and delays in the production process that can be instantly communicated to customers but also recorded by the platforms. The platforms that facilitate factory networks can thus benefit from a trove of production-related data produced by their vast supplier networks and potentially enhance their market positions.

Alibaba is pursuing a similar vision with its "new manufacturing" initiative, which it piloted at 20 garment factories in Hangzhou. The initiative is exploring how to help factories optimize their manufacturing processes and automate their customer communication. Cameras equipped with image recognition software and installed in factory workshops track the real-time status of an order and automatically communicate it to the factory management and customers by recording and analysing the movements of workers (Schneidemesser 2019). Regardless of whether such expectations will be met and of the obvious data protection issues such initiatives raise, Alibaba's pilot project is a dramatic illustration of the efforts being made to observe, analyse and rate supplier performance using digital means.

The approaches of B2B platforms vary in terms of their main fields of activity, their precise business models and the depth to which they record, analyse and use production-related data. They nevertheless share a number of core characteristics. First, the selling point of B2B platforms is their ability to match suppliers to industrial buyers. This ability depends on the size and capabilities of their manufacturing networks and reduces transaction costs in the process. Second, B2B platforms have an interest in developing and curating their networks by imposing requirements for participation on suppliers, categorizing their capabilities and rating their performance. Third, the efficiency of the platforms' matchmaking function relies on the information that is available about their manufacturing partners; the platforms therefore tend to deepen their insights into the activities of their suppliers and to develop digital tools to facilitate interaction between buyers and suppliers.

5. Flexibility, upgrading and work in the networked factory

As set out in Piore and Sabel's 1984 account of flexible specialization, the flexibility of a large number of small-scale producers that have the capacity to respond to market fluctuations is the core component of the distribution-centred path of the platform-mediated factory network. However, whereas in Piore and Sabel's discussion network flexibility is mainly rooted in the manufacturers' craft-like production methods, this is not necessarily the case in the platform-based factory networks. The responsiveness of a network of small-scale manufacturers, each specialized in the production of a particular component or category of goods, derives chiefly from the network's inherent structure, its sophisticated methods of digitally assisted matchmaking and its sheer size. The global manufacturing partner networks of the German and US mechanical component manufacturing platforms whose representatives we interviewed during our study consist of between 200 and 6,000 suppliers. Alibaba's Tao Factory platform had roughly 27,000 registered factories (in 2018). Industrial customers – assisted by platform matchmaking – are thus likely to find a suitable factory for whatever they need to produce.

The extent to which such flexibility requires the manufacturing partners to have advanced capabilities that may result in industrial upgrading and changes in the work process varies. In the case of the mechanical component manufacturing industry, the use of platforms affects the relationships between firms while leaving the substance of production models virtually untouched. According to our interview data, participation in platform-mediated networks does not require suppliers to have enhanced capabilities for product or process upgrading, nor does it encourage such upgrading efforts. This is underlined by the fact that most manufacturing partners do not engage exclusively with the networks of B2B platforms. Many simply use the demand mediated through such platforms to absorb excess capacity while they continue to engage with regular customers directly. The main effect on the producers is thus an extension of their sales network, a process described as "channel upgrading" in the literature on industrial upgrading (Frederick and Gereffi 2011). One interviewee, located in Eastern Europe but producing – in cooperation with a platform – for customers in Germany, described his previous unsuccessful attempts to enter foreign markets: "We tried [to expand to foreign markets] but a lot of times we tried directly to [find] end customers but we did not have any success." Through platforms, suppliers can easily qualify for contracts with buyers that lie beyond their often geographically circumscribed and informally mediated reach. As all the B2B platforms surveyed have experienced steep growth, suppliers have benefited from the additional demand economically. However, they are increasingly tending to lose the capacity to negotiate the terms of such contracts owing to the platforms' price transparency. Some of the suppliers interviewed reported stronger competition and lower profits for orders received through platforms. This can result in a race to the bottom, competition for supply contracts becoming more intense as the platform model becomes more widespread.

Alibaba's Tao Factory platform represents the contrasting case in which flexibility also depends directly on the capabilities of manufacturing companies. The requirements of flexibility are extended to the shop floor and result in producers having to adjust their production models and work processes. The garment factories of our sample resorted to a craft-like production model, similar to what Piore and Sabel described as a central feature of flexible specialization of production (1984, 17). The small size of e-commerce orders – 50 to 100 pieces per batch – means that it is no longer feasible to organize production along larger assembly lines with semi-skilled workers performing repetitive tasks.

> At the moment I am producing … mostly small orders for Taobao shops. These [orders] have a peculiarity; they are comparatively small … often just 200 pieces or 100 pieces. The orders for brands we did before were 1,000, 2,000 pieces, right? One or two thousand pieces can be produced by more than ten workers together. If it is only 100 pieces this cannot be done by all the workers together; I will give one order to two to three workers – [those] two to three workers finish one order. That is because producing garments is about becoming familiar with it [the style].

As described by the above interviewee, small e-commerce orders are produced end to end. This requires comprehensively trained workers who have completed a three-year apprenticeship or have many years of working experience. During our interviews, factory management explained that only such comprehensively trained workers were able to switch flexibly between different styles and materials while maintaining the necessary production speed.

Among the Tao Factory platform manufacturing partners surveyed, flexibility and responsiveness to market demand were not achieved through a technology-intensive manufacturing process, but by bringing China's vast small-scale manufacturing base online. This approach may rely on traditional manufacturing methods. Processes are not upgraded by acquiring advanced manufacturing technology; instead, the work process is reorganized in a way that requires sewers to have comprehensive skills. The reliance on craft-like organization of production instead of modern production equipment can create possibilities for social upgrading. The supply of experienced workers is pivotal for the garment companies that cater to the Tao Factory platform and such workers are scarce. At the time of our empirical investigations, this translated into wages of up to double the local industry's average for urban employees.

Channel upgrading also has beneficial effects for manufacturers. By moving their businesses on to Alibaba's online platform, they can establish direct customer relations, cut out some of the intermediaries in China's vast and chaotic subcontracting networks and thereby avoid being merely the appendage of a sprawling e-commerce retail market. As a result, manufacturers are better able to schedule their batches and ensure more stable production; this in turn translates into more stable employment for the skilled workers whom entrepreneurs are eager to tie permanently to their companies.

Wage hikes and more stable employment do not, however, alter other key traits of a labour regime characterized by a high level of informality and precarious working conditions (cf. Lüthje, Luo and Zhang 2013). Workers at some of the companies in our sample had no employment contracts, and many worked excessive hours and were not affiliated to social security schemes. Alibaba has not incorporated these issues, or labour issues in general, into its otherwise sophisticated platform governance mechanisms. Its Tao Factory platform is therefore a peculiar mix of the old and the new: a technologically sophisticated mode of platform governance that relies not on technologically advanced production techniques on the supply side, but rather on traditional forms of garment craft production and labour relations that, while offering high returns to workers, resemble the low standards that are commonplace in China's huge base of garment contractors and subcontractors. It remains to be seen whether the beneficial effects on the suppliers and their workers will last, or whether they represent merely a snapshot of an expanding market in which most manufacturers on the Tao Factory platform are experiencing a surge in orders, resulting in a more stable workflow and economic leeway to attract skilled workers by paying above-average wages. As the Tao Factory platform matures, the opposite scenario could also arise: a deterioration of conditions driven by extreme competition in an overcrowded supplier landscape.

6. Conclusion: Varieties of digitalized manufacturing

The juxtaposition of the Industry 4.0 narrative with data from empirical case studies on distribution-centred approaches to digitalized manufacturing reveals striking differences (see table 1). Both approaches apply digital technologies in order to enhance manufacturing quality and flexibility without compromising production efficiency. But, whereas the smart factory approach is centred on production equipment at the production control and shop floor levels (process upgrading), the B2B platforms take advantage of advanced coordination technologies to improve matchmaking between buyers and suppliers and to reduce transaction costs.

The B2B platforms do not require suppliers in the network to engage much in upgrading their production technologies,[3] but do help them to increase their market reach through channel upgrading – a development that can significantly boost their economic success in terms of volumes and equipment utilization (suppliers on the B2B platforms in the mechanical component manufacturing industry and on Alibaba's Tao Factory report more regular production flows and the opportunity to make available on B2B platforms excess capacities that otherwise would have lain idle). This snapshot of the platform–buyer relationship within expanding B2B networks may nevertheless conceal the long-term effects of such developments, which may involve instances of downgrading or

[3] That does not mean that manufacturing partners in factory networks never engage in process upgrading. The 3D printing of components, for instance, is one process where elements of sophisticated production technology are combined with an industry structure that consists largely of small-scale producers. However, this structure does not conform with the dominant paradigm of Industry 4.0, which is mass production oriented. Furthermore, investment costs in connectivity-enabling equipment and the corresponding software solutions constitute a barrier to the smart factory approach for small manufacturers.

Table 1. Key differences between the smart factory and the B2B factory network models

	Smart factory model	B2B factory network model
Objective	Versatile manufacturing in single enterprises	Versatile distributed manufacturing
Technological driver	Production technology	Coordination technology
Dominant type of upgrading for manufacturers	Process upgrading	Channel upgrading
Worker skill requirements	High (polarization and trade-offs possible)	High to low (depending on product type and production technology)

cut-throat competition as well as platform–buyer relationships of dominance and control. After all, the price transparency on platforms, combined with the potential global reach of their networks, can result in fierce competition once the market environment gets tougher. Currently, the very success of the platforms' business model means that suppliers are experiencing high demand and little competition. This is likely to change, however, if online platforms become the standard sales channel of certain industries. At that point, B2B platforms could turn out to be the main beneficiaries based on the fees they receive and the negotiating power they derive from the acquisition of data (cf. Lüthje 2019).

When it comes to the implications for work of both paths towards digitalized manufacturing, the results underline the interrelationship between technology and social upgrading. The stylized model of Industry 4.0 very much conforms to the corporatist traditions of the German model, with its emphasis on skills, comprehensive training and work quality. Although it seems reasonable to assume that more complex production systems will go hand in hand with higher skill requirements on the shop floor, the smart factory narrative largely overlooks the possible negative effects in terms of deskilling, work intensification and loss of autonomy. As with prior instances of technological change, the effects on work will definitely depend on the design of socio-technical systems, for example through the intervention of workers' representatives in the processes of technology implementation (Hirsch-Kreinsen 2016b).

Our case studies on the B2B factory network model show diverging effects in terms of "social upgrading" that depend heavily on how the production of small batches modifies work processes. In both cases the B2B networks connected industries that consisted of a large number of small-scale producers even before they were connected by platforms. Production system flexibility is a matter not so much of the organization of processes and work routines as of the scope and diversity of the network itself. What is more, in both industries adaptation to customized demand has historically played a significant role, be it in the form of small-scale component manufacturing that tended to take place in geographical proximity to important buyers or of small garment workshops in China that persisted alongside large industrial manufacturers (Chu 2018). In the case of the mechanical component manufacturing industry, the supplementary demand mediated through B2B platforms does not affect work routines, since the production process is largely automated and the routines barely differ between the production of large or small batches. Such is not the case, however, in the garment industry, where the production of small batches requires skilful and experienced workers and the dismantling of an industrial division of labour, since individual workers control the production of entire products in a revival of craft-like production. The working conditions at the small-scale suppliers of the Tao Factory platform bear the birthmark of the informal and exploitative conditions of the Chinese subcontracting industry from which they emerged; however, amid a widespread labour shortage, the economic expansion of the Tao Factory platform and the predominance of more regular production flows, the distribution-centred path could bring enduring prospects of social upgrading. As discussed in relation to the economic upgrading of suppliers, however, further prospects for work depend on whether these systems will suffer from overcrowding and price competition as the B2B production networks mature.

In sum, our findings concur with the general perspective of Piore and Sabel (1984) about the varieties and the openness of industrial trajectories. The findings illustrate that the digital transformation of production and work does not necessarily correspond to the strand of process upgrading that is sketched out in the stylized model of Industry 4.0, and that it can flourish in other forms. The flexible specialization of distribution-centred factory networks, as pioneered in the Chinese garment and the international mechanical component manufacturing industries, is a possible alternative; indeed, the exploitation of a network's flexibility may in some cases constitute a more suitable option than the engineering-heavy approach associated with Industry 4.0. We are nevertheless cautious in interpreting the factory network approach as a superior path towards industrial transformation and the upgrading of work. In this sense, our analysis differs from that of Piore and Sabel, for whom the instances of flexible specialization that they observed represented a normative alternative entailing significant innovation and a social trajectory that rested on workers' skills and their participation in economic gains. Our case studies, on the contrary, underline that the distribution-centred approach to digitalized manufacturing does not necessarily go hand in hand with better conditions for workers. There was a positive correlation in the garment industry cases of our sample, where manufacturing flexibility rested on advanced skills, but not in the mechanical component manufacturing industry.

So what does this discussion tell us about the trajectories of digitalized manufacturing in the future? Does the factory network offer a better approach that will supersede the smart factory despite the latter's technological sophistication? Recent frictions in the implementation of Industry 4.0 indicate that the real development of manufacturers may not live up to the bright future heralded by government and business representatives. In particular, there is an inherent danger that processes will be over-engineered as companies invest heavily in technology without reaping sufficient returns. At the same time, B2B platforms remain a marginal phenomenon. Even the 27,000 small-scale producers reported to operate on Alibaba's Tao Factory platform are dwarfed by the immense volumes of Chinese industrial output through conventional means. What is more, the factory network may be applicable in some, but not all, industries. It is a good match for the small-scale structure of the Chinese garment industry and the on-demand mechanical component manufacturing industry, but remains a relative mismatch for large-scale automotive or electronics manufacturers, for whom the Industry 4.0 path may offer better prospects.

The COVID-19 crisis will affect the spread of both models. It has reshuffled economic relationships and forced companies to adapt to an insecure market environment. At many head offices, it has deepened the commitment to innovative approaches and strategic decisions, although the conditions for making major investments are tightening up in the current difficult macroeconomic environment. For the engineering-heavy approaches of the smart factory model, this may spur the digital transformation of industries but may also give rise to financial constraints. B2B platforms, however, could turn out to be the big winner: in many cases their platforms have experienced high demand precisely because of the economic disruption of regular supply chains.

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