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Co-engaging Production in a Multipolar World

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Abstract: *Innovative engineering and powerful ICT (Information and Communications Technology) are changing operational strategy. The result is not only a change in the production of discrete products (Additive Manufacturing), but also a change in the chemical engineering-based production and energy generation. The result will not be limited to changes to centralized production (Industrie 4.0) enabled by, e.g., robotics and 3D printing, but a renaissance of decentralized production. The objective of this paper is to explore the impact of the renaissance of decentralized production on operational strategy and innovation in an emerging multipolar world.The contributions of this paper are (i) the same innovative engineering and powerful ICT can be used in centralized and decentralized production, (ii) the same innovative engineering and powerful ICT cause an evolution in centralized production and a revolution in decentralized production, (iii) decentralized production is not tantamount to individualized products, (iv) Co-engaging Production allows for global value chains, (v) Co-engaging Production is broader than Additive Manufacturing, and (v) the finding that decentralized production allows for a broader foundation in innovation. Further research is required on (i) decentralized production based on the different engineering disciplines, (ii) the dynamics of centralized and decentralized production along value chains, and (iii) the diversification of the foundation of innovation.*

Keywords : *Decentralized Production; Engineering; Innovation; Science; Society*

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I. INTRODUCTION

Operational strategy is on the cusp of profound changes as the result of innovative engineering and powerful ICT (Information and Communications Technology). One of the results is the emergence of Additive Manufacturing. Although the focus has been on centralized production (Gartner et al., 2015; Rylands et al., 2016), Additive Production will also change decentralized production (Steenhuis and Pretorius, 2016).

Additive Manufacturing is focussed on the production of discrete products. This is too narrow an approach to grasp the potential of a renaissance of decentralized production. In addition to discrete products, decentralized production is emerging in the production of, e.g., chemical products and electricity generation. The concept of Co-engaging Production bridges the gaps between the different types of production processes and products in decentralized production. In this article, we explore how the changes made possible by innovative engineering and powerful ICT have impact the development of centralized and decentralized production. We explore the renaissance of decentralized production as Co-engaging Production, and investigate which facets of this renaissance can already be discerned in some industries that we discuss as examples. Our research question is: what is the potential of Co-engaging Production, or a renaissance of decentralized production, on operational strategies and value chains across industries – particularly in an emerging multipolar world?

Decentralization allows for a broadening of the foundation of innovation. Knowledge that has received scant attention in centralized production can be picked up by individuals participating in decentralized production, and with the assistance of powerful ICT such knowledge may come to the attention of other individuals participating in decentralized production and/or potential clients of products based on such knowledge.A broadening of the foundation of innovation increases the cognitive distance (Hée, 2008; Bertrand and Mol, 2013). At the same time, taking advantage of the cognitive distance in innovation requires sufficient absorptive capacity (Bertrand and Mol, 2013; Tortoriello, 2015). Decentralized production makes a broadening of the foundation thus possible, but it is not a guarantee for this. This is also the case for the fluid networks characteristic to Co-engaging Production. Networks can also cement the status quo thus hampering innovation.

Making a broadening of innovation possible allows the mobilization of knowledge that has received little attention in operational strategy in the more recent past. This knowledge includes traditional construction materials and designs which incorporate centuries old experience in particular climates and regions, and traditional medicinal knowledge. This knowledge may be considered traditional non-Occidental engineering and sciences, and folk knowledge.

The objective of this paper is to explore the impact of the renaissance of decentralized production on operational strategy and innovation in an emerging multipolar world.The paper has been organized as follows. In the first section, a few facets of an evolution of manufacturing paradigms in operational strategy across the centuries, have been briefly discussed. The idea of decentralized production's role towards broadening the horizons of innovation has been introduced. In the next section, the importance of a mental foundation of acceptance for innovation in decentralized production processes and products is underlined. Next, the innovative concept of Co-engaging production, bridging the gaps between the different types of production processes and products in decentralized production, is introduced. Finally, it is concluded that as a result of increasing multi-polarity in the world, the combination of the renaissance of non-Occidental societies, the renaissance of non-Occidental engineering and sciences, and the advent of Co-engaging Production will result in greater diversity in innovation.

II. OPERATIONAL STRATEGY COMING A FULL CIRCLE

Innovative engineering of production processes and powerful ICT are fundamentally changing operational strategy. Innovative engineering of production processes incorporates, e.g., robotics and miniaturized chemical unit operations into production processes allowing for increased levels of operational flexibility that can be used for customization and individualization of products. Powerful ICT allows for improved process controls and value chain management. These developments can be used to increase the operational flexibility of centralized large-scale production facilities – the German concept of Industrie 4.0 is an example thereof – or a renaissance of decentralized production.

The precursors of modified centralized production exemplified by Industrie 4.0 and a renaissance of decentralized production reach into the Occidental economic crisis in the 1970ies and 1980ies. The trend toward ever larger centralized production facilities taking advantage of economies of scale and the standardization of products was not feasible in many instances any longer. The solution to the crisis came from Japan. Increasing flexibility in production has been difficult in the Occident. At the beginning of the 1990ies, a dichotomy could still be observed: Large firms took advantage of economies of scale and produced low cost standardized products, and small firms were more flexible (Fiegenbaum and Karnani, 1991). The assumption that low production costs and flexible production were mutually exclusive was about to change.

Evolutionary change in discrete production within the confines of centralized production was suggested and effectuated. The proposed concepts have included Flexible Manufacturing, Mass Customization, Rapid Manufacturing, Agile Manufacturing, Fit Manufacturing, Additive Manufacturing and Lean Manufacturing (Nemetz and Fry, 1988; Kotha and Orne, 1989; Cormier et al., 2003; Ramesh and Devadasan, 2007; Pham and Pham, 2008; Wong and Hernandez, 2012; Secchi and Camuffo, 2016). The German Industrie 4.0 (Sommer, 2015; Sanders et al., 2016; Ganzarain and Errasti, 2016) and in some instances Additive Manufacturing (Rylands et al., 2016) take advantage of innovative engineering (particularly robotics) and ICT, but the increased flexibility occurs within the confines of centralized production. Sun and Venuvinod (2000) discuss another type of manufacturing system – the 'Holonic Manufacturing System' – to cope with increased customer requirements for higher product variety and customizations. There is a tendency to consider that centralized production is superior to decentralized production as shown by the claim that Industrie 4.0 is a threat to small- and medium-sized firms (Sommer, 2015). Similarly, 3D printing has been seen as a way to improve centralized production (D'Aveni, 2015). This focus on centralized production fails to recognize that much of the same innovative engineering and powerful ICT form the foundation of a renaissance of decentralized production (Cormier et al., 2003). Decentralized production is more of a threat to centralized production than the other way around. For instance, design and implementation of a Holonic Manufacturing System from the perspective of 'employee involvement' empowers employees to make decisions at their level in the organization (Sun and Venuvinod, 2000). Decentralized production can increase employees' control over organizational improvement processes, thus enabling an optimal combination of technological and human elements which can be conducive for innovation. In this respect, decentralized production can be deemed superior to centralized production.

Not only innovative engineering and powerful ICT can be the foundation of centralized and decentralized production, but the concepts of Additive Manufacturing and Lean Manufacturing allow for both as well. E.g., insofar Lean Manufacturing has been accompanied with a decentralization of decision-making within centralized production (Secchi and Camuffo, 2016), Lean Manufacturing can be construed to have entailed some tentative steps towards the renaissance of decentralized production.

For large production facilities carrying out centralized production, the question is to which degree decentralized production will replace centralized production. Rayna and Striukova (2016) argue that in 3D printing-based mass manufactured products decentralized production will probably not be feasible. This view is problematic in two ways. First, their argument would suggest that centralized production is superior to decentralized production in the case of standardized products, but as the success of decentralized electricity generation in, e.g., Germany demonstrates, this is not the case (Poesche et al., 2016). This example is particularly instructive, because there exist few products which are more standardized than electricity. Second, their argument would suggest that that there will not be a shift from standardized products to customized and individualized products in spite of decentralized production making it possible – a view that is by no means self-evident.

The literature on decentralized production does not recognize its full potential. E.g., decentralized production using 3D printing sometimes referred to as consumer Additive Manufacturing (Steenhuis and Pretorius, 2016) is only a partial view. Additive Manufacturing does not exhibit economies or diseconomies of scale (Baumers et al., 2016). However, decentralized production can take numerous forms, and is thus not limited to discrete manufacturing as Additive Manufacturing would suggest – this is the key reason why the study on the potential of Additive Manufacturing by Gartner et al. (2015) has strong limitations in recognizing the potential of decentralized production.In this context, the extant literature on operations management is facing challenges. The literature on operations management pays little attention to the idiosyncrasies of chemical processes (Lager et al., 2017) – the same can be said about energy generation. The idiosyncrasies of chemical processes range from complex raw materials over complex production processes to several products being produced simultaneously.

A significant role of decentralized production is not a new phenomenon. Figure 1 contains implicitly a historical development. In the Occident, operational strategy is coming a full circle: Decentralized production (Middle Ages) → Putting-out System (14th century) → Fordism (early 20th century) → Mass Customization (late 20th century) → Decentralized production (Co-engaging Production, early 21st century). The trend was toward more centralized production from the 14th century until the early 21st century. Although Mass Customization introduced some flexibility into operational strategy, it did not challenge the concept of centralized production.

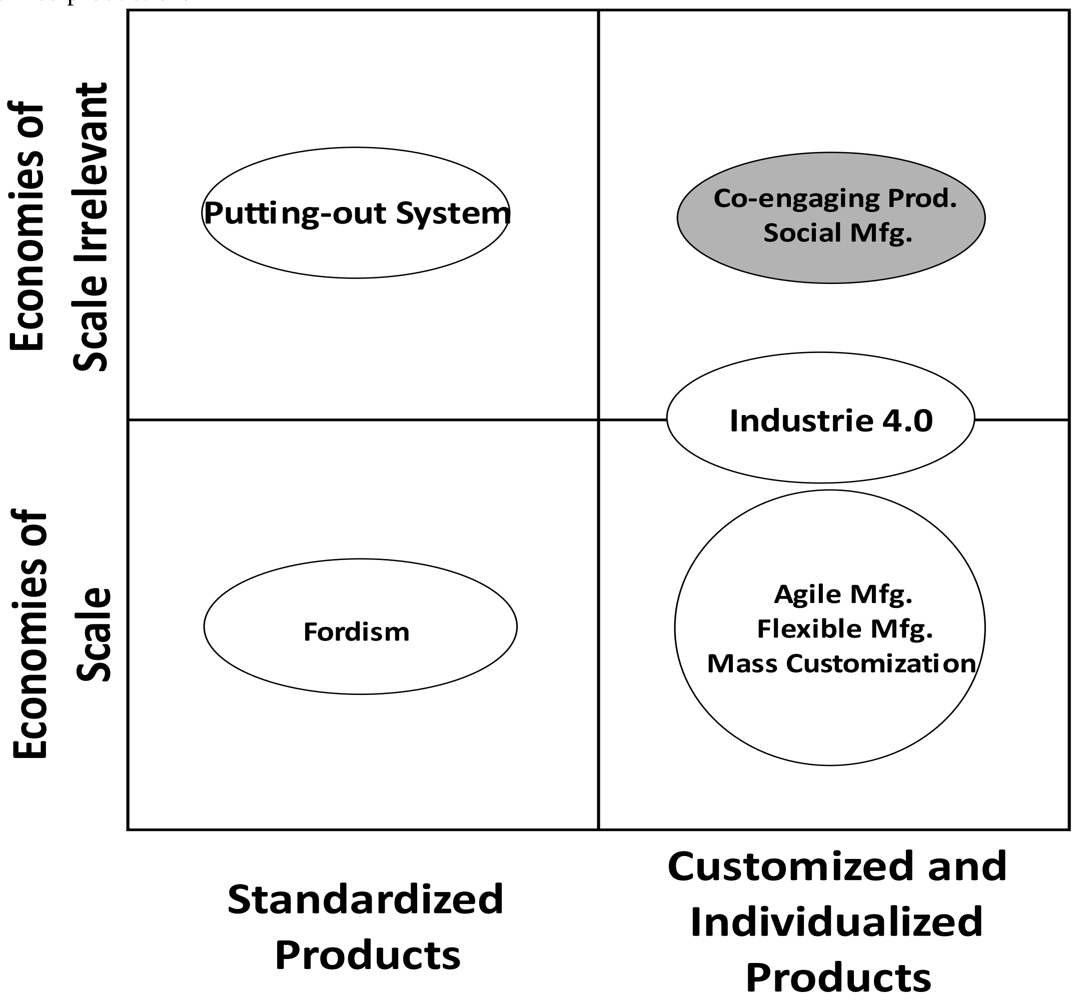

Figure 1: Over the last 700 years, operational strategy has come a full circle (counter clockwise): decentralized production → Putting-out System → Mass Customization → Industrie 4.0 → decentralized production (Co-engaging Production and its cousin Social Manufacturing).

The engineering sophistication of production process engineering and value chain management has increased over the same time period.There may be an inclination to consider a renaissance of decentralized production as a step toward economic decline.The last time there was a major shift from centralized production to decentralized production occurred in the urban crisis in the Roman Empire in the 3rd century (AD). This crisis played an important part in the general economic, engineering and scientific decline in the Occident in the following centuries. There is an important difference in the 21st century: Whereas the move toward decentralized production coincided with an increasing isolation of the production sites in the Medieval Occident, innovative engineering in combination with powerful ICT herald an increasing global engineering and scientific interconnectedness in the 21st century.

The environmental impact of decentralized production remains to be seen. Although there is potential to improve resource efficiency and reduce waste with 3D printing (Despeisse et al., 2017), challenges remain. Materials used in decentralized discrete production pose a significant challenge from the standpoint of resource efficiency. Whereas it cannot be expected that individuals stock a large number of materials to be used in different discrete production runs, it is necessary to have one or a handful materials which can be used in the production of a wide range of products. The properties of each material have to be sufficient for the most demanding product. There will be a similar challenge in decentralized chemical processes-based production. This means that too many resources are used on average, and thus the resource efficiency is unfavourably affected. Higher flexibility per se is not a guarantee for improved resource efficiency and waste reduction. One of the arguments used in favour of Agile Manufacturing has been that it is conducive to shorter product life cycles (Yu et al., 2005). A shorter product life cycle results in more frequent product replacement, and this means more resources being used. It also means more waste generation – if there is not an efficient recycling system in place. Efficient recycling does not fully address the issue of energy consumption during production and transportation. Individualization may address these issues at least partially: The renaissance of decentralized production holds the promise that product individualization translates in a longer product cycle.

III. DECENTRALIZATION AND STANDARDIZATION

Decentralized production per se is not a guarantee of a diversity in production processes and products. History demonstrates this point. Production was carried out by individuals alone and with a few employees during the Middle Age. These individuals formed networks in the form of guilds. The production processes and products were determined by the town's appropriate guild severely limiting diversity of production processes and products. Connections – or networks – spanning significant geographical areas between the appropriate guild and its sister guilds in other towns meant that production process and product standardization occurred across wide geographic areas. Among the formal networks, the medieval Hanseatic League had one of the largest geographical reaches encompassing Northern Germany, the Low Countries and the areas surrounding the Baltic Sea.

The standardization of production processes and products that is observable in Occidental history during the Middle Age cannot be attributed to engineering-related factors alone. Neither can the standardization be attributed to economies of scale in production processes and products. The medieval standardization created a willingness to accept standardization in the Occident, and this willingness created the mental foundation for the acceptance of the standardization inherent to large-scale production facilities taking advantage of economies of scale in the large manufactures in the 17th century and in industrial facilities in the 18th century.

The mental foundation for the acceptance of standardization of production processes and products was not only practiced in the production of products destined for long-distance trade, but it also formed the foundation of the acceptance standardized everyday products bought in small quantities directly by consumers. The degree to which decentralized production will translate in diversity on production processes and products is naturally a question of operational capabilities but also to a great degree it is a question of continued mental acceptance of standardized production processes and products.

The importance of mentality is shown in Figure 2. Although decentralized production has the capability for diversity – and Co-engaging Production has an explicitly stated aspect of producing individualized products – without the corresponding mentality decentralized production will result in standardized products being produced with standardized production processes in a small scale. As the example of the guilds show, cross border networks do not prevent this. Standardization is a valid possibility in decentralized production – and in some instances like decentralized electricity generation standardization is even a necessity. Decentralized production opens the door to individualization, and innovative engineering and powerful ICT make individualization feasible in numerous instances. The critical issue will be mentality.

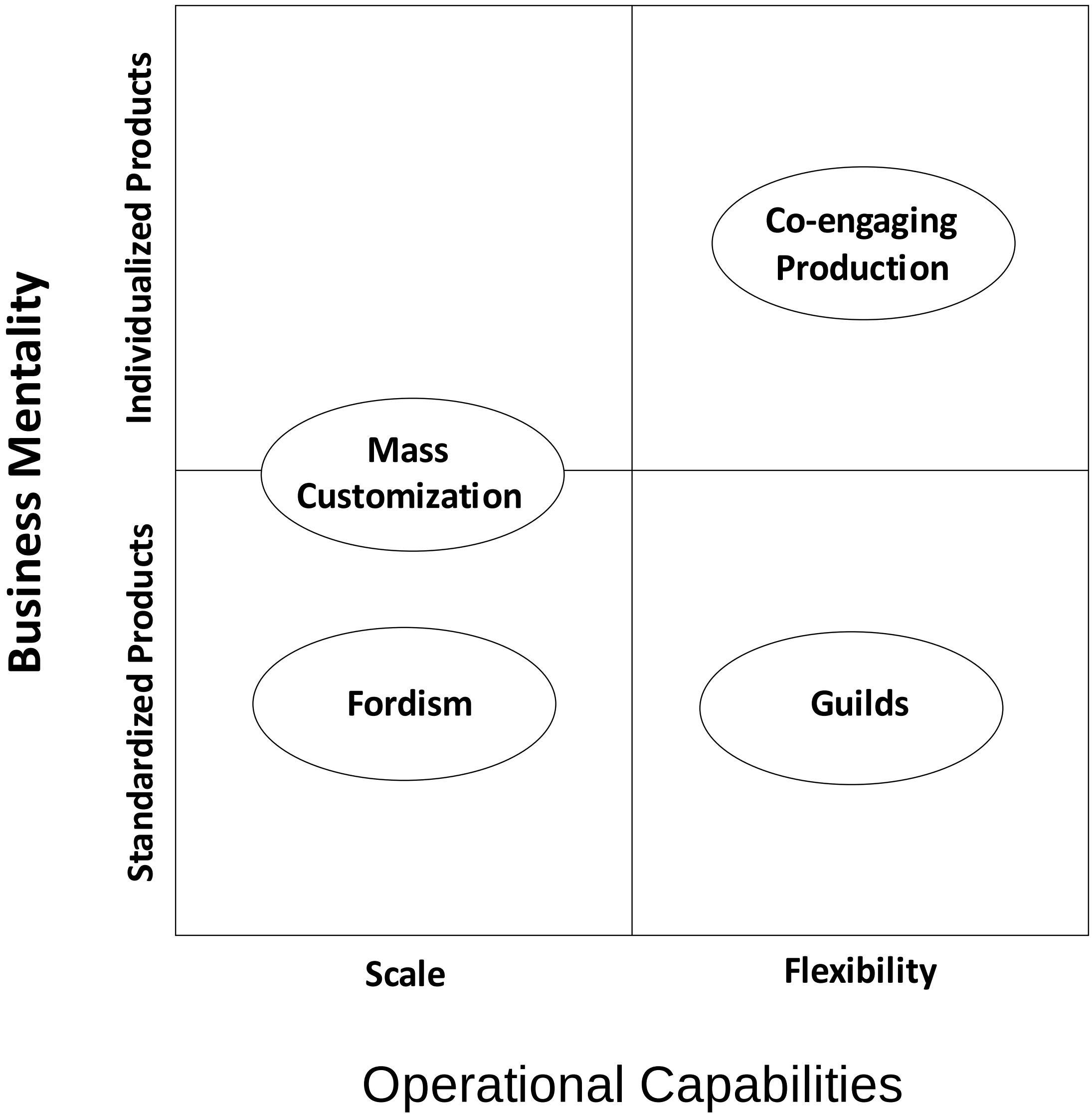

Figure 2: The Medieval producers belonging to guilds would have been capable of operational flexibility, but this was prevented by the mentality of the guilds: Production processes and products were standardized. Although this may occur in Co-engaging Production as well, the likelihood is smaller as a result of the producers being simultaneously the consumers. Customization is less than individualization, because the customization options are limited.

Innovative engineering and powerful ICT can be combined in different ways. A suggestion thereof is that they form the foundation of more flexibility in centralized production and a renaissance of decentralized production, but there are hybrid forms as well. Powerful ICT makes it possible to perform centralized operations management of decentralized and geographically dispersed production facilities – a simultaneous centralization and decentralization. Mass customization can be interpreted an embryonic form of centralized production directed by decentralized operations management empowered by powerful ICT.

Co-engaging Production – the present-day iteration of decentralized production – entails a change in mentality by explicitly calling for diverse production processes and products to the degree feasible for the production processes and products in question. Co-engaging Production goes further than Additive Manufacturing, because Co-engaging Production is applicable in discrete manufacturing, in chemical processes and products, and in energy generation.

IV. CO-ENGAGING PRODUCTION

Co-engaging Production entails several modifications to traditional decentralized production. Co-engaging Production is characterized by innovative engineering and powerful ICT (Information and Communications Technology). Five important aspects of Co-engaging Production are:

(i) Prosumers: Individuals (or very small firms) unleash their capabilities, competences and creativity being concomitantly producers and consumers (prosumers);
(ii) Dynamism and Fluidity: Co-engagement is dynamic and fluid, and the value chains change from time-to-time and from product-to-product;
(iii) Self-selection: Every prosumer decides who is invited to co-engage in the fluid networks that is the value chain;
(iv) Individualization: Co-engagement allows for product individualization and thus better product performance from the viewpoint of the individual user; and
(v) Convergence: The same prosumer takes all production-process- and product-related decisions thus eliminating the divergence of ethics and production that is inherent to centralized production.

To reiterate: The renaissance of decentralized production is not the only possible outcome of the innovative engineering and powerful ICT. The same or similar innovative engineering and powerful ICT make it possible to make centralized production more flexible. The German Industrie 4.0 concept (Sommer, 2015; Sanders et al., 2016) is an example thereof.

Conceptually, the changes made possible by innovative engineering and powerful ICT are an example of a situation in which the same innovative engineering and ICT impacts the development of production – evolution versus revolution – differently. This situational relativity has not been sufficiently recognized in the literature on innovation. In the case of Co-engaging Production, the confines of currently dominant centralized production are broken, and the innovative engineering and ICT result in a revolution. In the case of Industrie 4.0, changes occur within the confines of centralized production, and the innovative engineering and ICT result in an evolution.

A co-engaging individual – or a very small firm – is a prosumer who can take decisions regarding all stages of the value chain as shown in Figure 3. Co-engaging Production exhibits some of the same characteristics as decentralized Additive Manufacturing in moving value-added activities from centralized production to decentralized production, and in involving the consumer directly in productive and value-adding activities (Bogers et al., 2016).

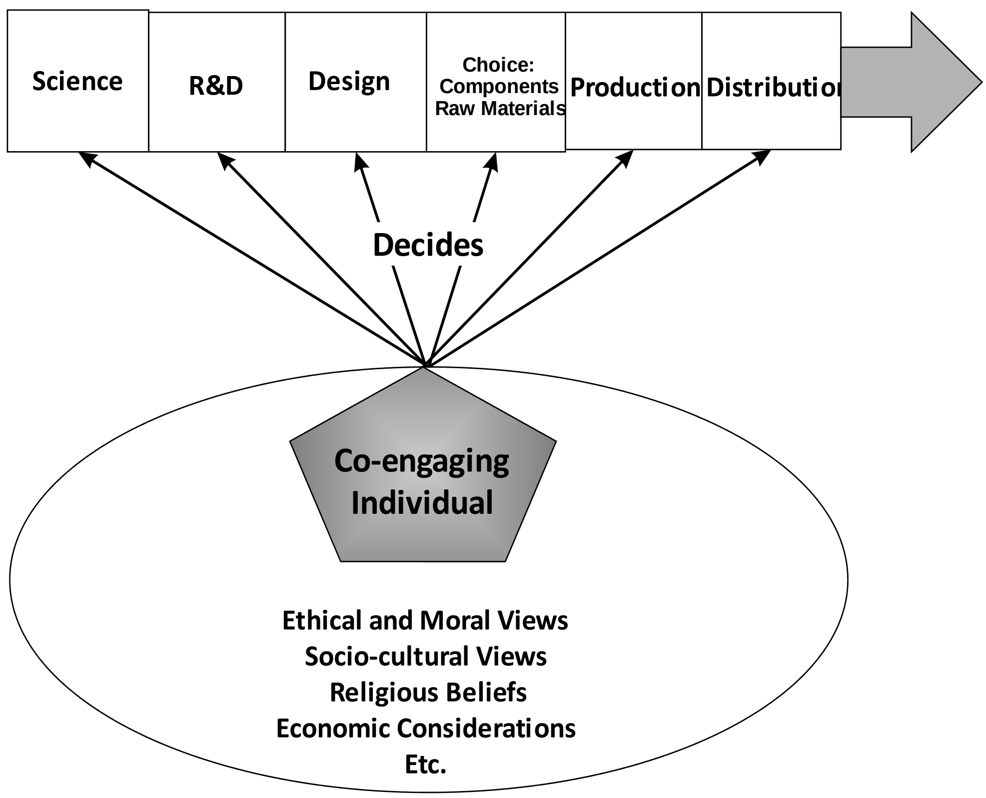

Figure 3: In Co-engaging Production, the co-engaging individual takes direct decisions along the entire value chain, from choice of the science used in R&D to production and distribution. This allows the co-engaging individuals to bring their personal ethical and moral views, socio-cultural views, religious beliefs, economic consideration, etc. to bear throughout the value chain.

At the science stage, a co-engaging individual may contribute to science, but a co-engaging individual decides the scientific foundation of innovation in the R&D stage of the value chain. This may happen within the confines of the currently globally dominant Occidental science, but it may also entail the choice of another science, e.g., (traditional) Indian science or (traditional) Sino science. In medicine, e.g., the foundation of Co-engaging Production may be Occidental pharmaceuticals or Sino traditional medicine. In this respect, Co-engaging production varies significantly from traditional decentralized production. Typically, during the R&D stage of the value chain in traditional firms, the sources of innovations are human capital (internal), or through market, consumer and supplier research (external) (Chen et al, 2011). In a way, the foundation of innovation in firms is constrained by the existing mindset deep in their organizational culture. Co-engaging production can help remove this constraint by virtue of the diverse outlooks and backgrounds that participating prosumers bring in. In a multipolar world, one of the manifestations of this diversity may be a renaissance of non-occidental science and engineering as the foundations of innovation in industry.

It is conceivable that a co-engaging individual either on his/her own accord or on the basis of interactions in a fluid Co-engaging Production network decides to combine different sciences, e.g., Indian traditional medicine and Sino traditional medicine. Stepping outside of the science a co-engaging individual knows requires an ability and willingness to syncretism in addition of absorptive capacity (Cohen and Levinthal, 1990; Reagans and McEvily, 2003; Tortoriello, 2015) and integrative capabilities (Low and Ho, 2016). Because syncretism is higher in China than in the Occident, the challenge is not the transfer of Occidental engineering and science from the Occident to China discussed by, e.g., Tsang (1994), but the transfer of traditional Sino engineering and science from China to the Occident. Cognitive distance (Hée, 2008; Bertrand and Mol, 2013) suggests that a broader foundation for R&D results in improved innovation as a result of the lengthening of cognitive distance by the use of non-Occidental engineering and sciences.

At the R&D stage, a co-engaging individual decides the performance characteristics of a product to be produced. This allows a better fit with the local circumstances where the product will be used. Such an optimization of the product also allows for the elimination of performance characteristics of little or no practical use in the local circumstances thus reducing product complexity and production costs.

At the design stage, a co-engaging individual decides the design of a product. This allows for products to be individualized according to the needs and preferences of a specific prosumer. The potential of customers being involved in the design phase of products through crowdsourcing, whereby solutions to internal innovation problems are sought externally, has been examined in industries such as the fashion industry where there are rapid fluctuations in demand due to changing trends (Mehtala et al, 2016). Co-engaging production can also allow for designs to be adopted which correspond to the local traditions.

At the stage of the choice of raw materials and components, a co-engaging individual decides which raw materials and components are being used. Such decisions are subject to economic, engineering and operational considerations, and they may, e.g., reflect local traditions. The respect of local traditions may improve performance, because local traditions are based on experience spanning millennia. The case of social manufacturing of bamboo bikes for Africa (Ras et al, 2016) proved that using crowdsourcing for getting new ideas produced more designs in a shorter amount of time than a traditional design method. Involvement of local communities and global communities in the design process enhanced the innovation process.

At the production stage, a co-engaging individual ties together all the decisions of the previous stages of the value chain. A challenge may be in the materials being used in production. Whereas it is possible to use numerous materials in a large-scale production facility, for a co-engaging individual – particularly in remote areas – a large number of different materials is not feasible. Co-engaging Production promotes some standardization of materials. Prosumers from diverse backgrounds and with diverse product needs participating in co-engaging production wield higher control over the production process than consumers who participate in crowdsourcing or open innovation (in this case, the production process is controlled by the firm which had undertaken the crowdsourcing or open innovation initiative in the first place). Therefore, it can be expected that co-engaging production will enhance the innovation process to a higher degree than crowdsourcing or open innovation.

At the distribution stage, a co-engaging individual decides on the way the product is distributed. Although Co-engaging Production focuses on a prosumer producing for own consumption, there may be instances of small quantities of product being produced for other consumers. In such situations, some distribution will be necessary.

Throughout the value chain, a co-engaging individual can take decisions which are congruent with the individual's economic considerations, ethical and moral views, religious beliefs, socio-cultural views, and other considerations important for the individual. This reverses a trend in operational strategy. The growing importance of centralized production led to a divergence of business, engineering and operational decision-making on the one hand, and ethical, moral and socio-cultural decision-making on the other hand. The concentration of decision-making in the hands of a prosumer means a convergence of all aspects of the value chain.

The fundamental approach of co-engaging production has been applied to assessments concerning the production of chemical and discrete products (Poesche and Kauranen, 2016). The approach of Co-engaging Production may also be applied to situations which do not allow for the application of all aspects of Co-engaging Production. One example would be decentralized electricity generation (Poesche et al, 2016). The rigid engineering definitions of electricity required by electrical engineering of machinery using electricity effectively prevents product individualization, but other aspects of Co-engaging Production are still applicable.

There are similarities and differences between start-ups and Co-engaging Production fluid networks. While the two most striking similarities are that both are small and young, the most obvious difference is growth. Whereas start-ups have the intention to grow and thus require resources for growth (Gils and Rutjes, 2017), co-engaging individuals are not out to establish a large enterprise prima facie. When science-based innovation is required – this is required in, e.g., chemical processes and products – there may or may not be a difference. As a rule, start-ups in the realm of chemical processes and products are science-based (Gils and Rutjes, 2017). In Co-engaging Production, the situation is less clear. Co-engaging individuals may resort to existing engineering and scientific knowledge, but they may also co-engage to create new engineering and scientific knowledge

V. GREATER DIVERSITY IN INNOVATION – A DISCUSSION OF THEORY

Although Cheng and Yiu (2016) wrote about the business opportunities associated with customizing products for the Sino market, they did not address the issue of the foundation of this. Should the foundation be Occidental engineering and science, or traditional Sino engineering and science? It is noteworthy that the monoculture of Occidental engineering and science found in Europe and North America is not considered a problem and the potential of traditional Sino engineering and science is not considered an opportunity by, e.g., Tung (2016).

The exposure to Occidental engineering and science in the domestic market has been identified as a cause for international expansion of Indian firms (Stucchi et al., 2015), but the question of the strategic pitfalls of adopting Occidental engineering and science has not been addressed. The "reverse innovation" argument of Chittoor and Aulakh (2015) does not address the engineering and scientific foundation thereof – it is not traditional Indian engineering and science but Occidental engineering and science.

The issue of international R&D activities innovating in different locations and even different countries within the same firm has been addressed in innovation literature by, e.g., Teece (2014) and Cantwell (2017), but the issue of the engineering and scientific foundation of the innovation has not. If innovation is seen as a recombination of existing components (Schumpeter, 1939; Petruzzelli and Savino, 2014), then the issue becomes which existing components are considered in the context of recombination. Because of cognitive reasons, it can be expected that firms and individuals will use components known to them. The result is that firms and individuals knowledgeable about Occidental engineering and science will be unlikely to venture to one or several non-Occidental engineering and sciences. The example of haut cuisine used by Petruzzelli and Savino (2014) is instructive: A chef has to operate within the confines of what is considered acceptable food by the clients.

Although local knowledge of subsidiaries has been identified as a source of competences for multi-national enterprises (Andersson et al., 2014; Athreye et al., 2014; Mudambi et al., 2014), the scope of such local competences has not been expanded to the abandonment of Occidental engineering and science in favour of one or several non-Occidental engineering and sciences. The silence in the literature on non-Occidental engineering and sciences can be observed in the criteria used in the research into product vision. Although the research criteria consider market-related issues in broad terms (Benassi et al., 2016), the impact of non-Occidental engineering and sciences on all parts of the value chain is not addressed.

The combination of the renaissance of non-Occidental societies, the renaissance of non-Occidental engineering and sciences, and the advent of Co-engaging Production will result in greater diversity in innovation. Currently, operational strategy in industry is characterized by large production facilities (centralized production) producing products for Occidental markets. As shown on the left in Figure 4, the products have to correspond to the expectations in Occidental markets, and this effectively means that the products and the associated innovation are based on Occidental engineering and science – even when the production occurs in non-Occidental production facilities. Even in non-Occidental markets, products based on Occidental engineering and science have been commercially successful as the Occident has been associated with sophistication chic, performance and sophistication.

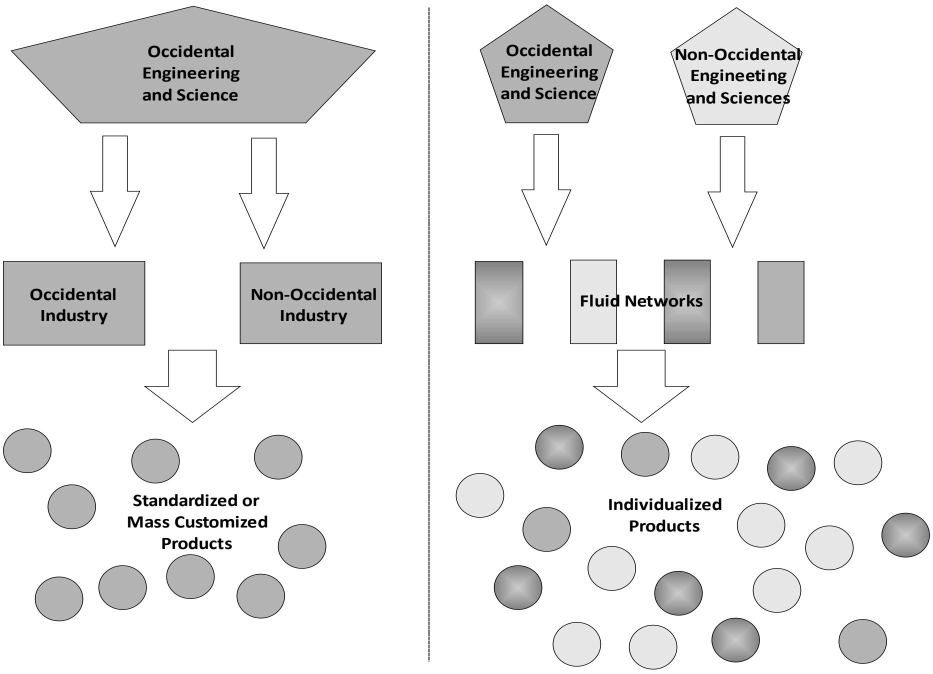

Figure 4: Production processes and products are based on Occidental engineering and science that is used by Occidental industry and non-Occidental industry alike in the late 20th century (see left). The products are either standardized or mass customized. Co-engaging Production fundamentally breaks with the status quo (see right). First, the mobilization of different foundations for innovation made possible by Co-engaging Production holds the promise of a greater diversity of products. Second, Co-engaging Production with no economies of scale allows for an individualization of products without economic disadvantages. Third, the fluidity of the Co-engaging Production networks reduces the propensity of path dependence reducing the innovation potential.

The renaissance of non-Occidental societies is likely to result in a rise of pride in their traditions, including their respective traditional engineering and science. This will impact the ethical justification of engineering and science: E.g., Crowley (2017) has argued that society is an ethical system. Whereas Nature is always right, science – and hence science-based engineering – is not, because science is only a description and interpretation of Nature. The same Nature can be described and interpreted validly in different ways. The renaissance of non-Occidental engineering and sciences offer alternatives or complementary foundations for innovation as shown on the right in Figure 4. Diverse knowledge is conducive to innovation: Explorative search means increasing the breadth of search allows for novel combinations of distant and diverse knowledge (Katila and Ahuja, 2002; Eriksson et al., 2016). Co-engaging Production can also take advantage of traditional folk knowledge relating to production processes and products insofar traditional folk knowledge is not considered part of engineering and sciences. Traditional folk knowledge includes the choice of construction materials and the lay-out of buildings based on centuries old experience. The delineation between traditional folk knowledge on the one hand and non-Occidental engineering and sciences on the other hand may be ambiguous in some cases. The growth story of an Indian consumer goods company, which has brought a health revolution in the country with the integrated approach of traditional Indian knowledge and sciences like Yoga and Ayurveda, suggests a widespread acceptance of and belief in traditional practices in India (Kumar et al, 2013).

Williamson (1999) as well as Low and Ho (2016) separate firms which are legal constructs on the one hand, and organizations which are stable exchange systems allowing for the transfer of capabilities, competences and knowledge on the other hand. Economic organizations include social networks (Kogut, 2000; Low and Ho, 2016). The fluid networks in Co-engaging Production are short-term legal constructs. The fluid networks may be exchange systems. Their stability is questionable even at high aggregate level, because the fluid networks may entail of co-engagement across societal borders. The existence of numerous fluid networks in Co-engaging Production entails an advantage vis-à-vis a few large industrial firms characteristic of centralized production. The existence of numerous fluid networks is less conducive to the emergence and perpetuation of a path-dependent dominant foundation of innovation, because the co-engaging individuals – and thus the represented knowledge of engineering and sciences – are frequently switched. Large firms can be expected to be more status quo- oriented because of the relative stability of the employees. Additionally, contrary to firms, there is not enough time in fluid networks for the emergence of organizational cultures which would cement one set of engineering and science. Thus, the foundation of innovation in fluid networks can be any set of engineering and science, or a combination of several sets of engineering and sciences. The greater diversity of the foundation of innovation results in a greater diversity of products – a greater diversity that is needed in an increasingly multipolar world.

Path-dependence is not completely banned in fluid networks. Path-dependence can be found in the co-engaging individuals and society at large. For instance, the Connect and Develop innovation model adopted by Procter and Gamble (Huston and Sakkab, 2006) helped the company identify novel ideas around the world and apply them to create better and cheaper products using the company's internal resources. In this case, fluid networks have been used to conceptualize new or improved products, but there is still a dependence on the relatively stable foundations of the company's resources to create, develop, market and purchase the product. Such kind of an open innovation practice by companies using an 'open innovation process' but a 'closed innovation outcome' (and hence a path dependence on the company's internal resources) has been termed as a private open innovation practice (Huizingh, 2011). Whether the ICT platforms used in Co-engaging Production will entail path-dependence remains to be seen.Firms which have operated within the confines of Occidental engineering and science must have the dynamic capabilities to expand their foundation for innovation into one or several non-Occidental engineering and sciences. A problem with the literature on dynamic capabilities is that such an expansion has not been addressed by, e.g., Teece et al. (1997), Teece (2007) and Dixon et al. (2014). Some scholars have argued that absorptive capacity is a component factor of dynamic capabilities, e.g., Wang and Ahmed (2007), but even here the question of breaking the confines of Occidental engineering and science has not been explicitly addressed.

A problem in the innovation literature is superficial neutrality while alternative foundations for innovation are not explicitly addressed. E.g., the use of terms like "different frames of reference" (Goepel et al., 2012) in the assessment of obstacles to innovation have the benefit of sounding neutral and thus scientific. This can also be seen in research on the country-level sources of innovation are silent on the importance of other engineering and scientific platforms than Occidental engineering and science (Arenius and Minniti, 2005; Choi and Phan, 2006; Colovic and Lamotte, 2015). Terminological neutrality can thus in itself become an obstacle to innovation, because it does not allow for the formulation of corrective action.

VI. CONCLUSION

Innovative engineering and powerful ICT make a renaissance of decentralized production in the form of Co-engaging feasible. This is a renaissance, because decentralized production has played an important role before, but its role was diminished by the rise of centralized production. The emerging renaissance of decentralized production will have wide-ranging implication for production.

The contributions of this research are:

(i) The same innovative engineering – encompassing, e.g., 3D printing and robotics – and powerful ICT – used in value chain management and production – can be used to change centralized production (Industrie 4.0) and in the renaissance of decentralized production (Co-engaging Production);
(ii) The same innovative engineering and powerful ICT results in evolutionary change in centralized production and a revolution in decentralized production;
(iii) Decentralized production does not necessarily result in production process and product individualization – it may also result in production process and product standardization;
(iv) The renaissance of decentralized production does not require a localization of value chains, but decentralized production is conducive to global value chains as the result of the use of powerful ICT in value chain coordination;
(v) Co-engaging Production is broader than Additive Manufacturing, because Additive Manufacturing is limited to discrete production, and Co-engaging Production includes discrete production, chemical production processes and energy generation; and
(vi) The renaissance of decentralized production enables a diversification of the foundation of innovation in a multipolar world.

Weaknesses of this research, and some aspects which require further research are:

(i) Research on decentralized production has been fragmented along the characteristics of the production processes, and a synthetization of the phenomenon of decentralized production irrespective of the production processes being discrete production, chemical production processes or energy generation is needed;
(ii) The dynamic role of centralized production and decentralized production along value chains need to be identified; and

(iii) The dynamics of a diversification of the foundation of innovation in a multipolar world needs to be better understood.

The renaissance of decentralized production as Co-engaging Production can already be discerned in some cases, e.g., 3D printing by individuals, microbreweries and decentralized electricity generation. The potential of Co-engaging Production is larger, and it may significantly alter value chains in discrete production, chemical production processes and energy generation in the coming years.

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