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Additive manufacturing – digitally changing the global business landscape

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Abstract

Purpose – Additive manufacturing, that is, layer-based manufacturing technologies, is thought to change supply chain operations from global to local, while also affecting design processes and product structures. As this transformation happens, a power struggle among various actors relating themselves to additive manufacturing has emerged. The purpose of this paper is to discuss and explain the development of additive manufacturing from a power dependence point of view.

Design/methodology/approach – The paper is based on data collected from a number of seminars hosting a total of 620 industry experts representing 102 companies in the area, and reflecting every step of the supply chain.

Findings – The paper points out how measures to deal and create power imbalances occur also related to indirect parties, and how the disruptive character of the supply chain leads to exercised power.

Originality/value – The power struggle provides new insights into how an emerging technology is realised and the effect of protectionism on such attempts. Specifically related to additive manufacturing, the paper illustrates the business side from various actors' point of view, which adds to technological perspectives on additive manufacturing, as well as studies viewing the supply chain from a bird's-eye perspective.

Keywords Power, 3D printing, Supply chain

Paper type Research paper

Introduction

Additive manufacturing, that is, layer-based technologies for the production of goods (e.g. Achillas *et al.*, 2015), is assumed to change supply chains from global to local (Zeleny, 2012), and disrupt operations of several firms along the supply chain (Hoover and Lee, 2015; Kietzmann *et al.*, 2015; Mohr and Khan, 2015; Oettmeier and Hofmann, 2016; Rogers *et al.*, 2016). While the new technology assumes to change the supply chain to a demand chain (Christopher and Ryals, 2014), implying how customers become the core of home fabrication (Rayna and Striukova, 2016), additive manufacturing also wipes out certain activities – and potentially also actors – along the supply chain (Shams and Öberg, 2017). This makes it interesting to understand those mechanisms that come into play as such disruption occurs.

Along the disruptive characteristics of additive manufacturing operations follows, namely, as demonstrated in this paper, how various actors fight to build, maintain and defend positions in the supply chain. Therefore, while the technology as such would be destined to create disruption (Hoover and Lee, 2015; Kietzmann *et al.*, 2015; Mohr and Khan, 2015), its various actors create power struggles along the supply chain, increasing uncertainties and complicating the introduction of additive manufacturing. This is what this

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paper sets to highlight. The purpose of the paper is to discuss and explain the development of additive manufacturing from a power dependence point of view.

Power dependence research reaches back to Emerson's (1962) seminal work on how parties need to depend equally on one another, or they would find solutions to uneven such imbalances. It thereby puts focus not only on power issues but also on how parties try to solve disadvantages of dependencies (Casciaro and Piskorski, 2005). This is in this paper translated to how various supply chain parties create strategies to uneven dependencies, while also potentially trying to create power advantages for themselves. How they go about to do so, along with the reactive steps taken by other parties, is extracted from descriptions by representatives engaging in additive manufacturing, and categorised to shape theoretical understandings for power struggles in a disruptive supply chain. The objective of the paper is to enhance knowledge on individual actors' whereabouts as disruption occurs in a supply chain by specifically highlighting the case of additive manufacturing. The relevance of this study relates to how additive manufacturing constructs a contemporary change of working methods in industry (Jiang *et al.*, 2017), while the observed struggle along supply chain actors indicates a topic not covered in previous research on disruption (Christensen, 2006, Riemer *et al.*, 2017; Kask and Öberg, 2019), yet important as it shapes the conditions of actors during disruption.

The paper contributes to previous research in the following ways: most previous research on additive manufacturing focusses on the technological side of it, while the business side has largely concerned optimisations in production (e.g. Gardan and Schneider, 2015; Paul and Anand, 2015; Zhang *et al.*, 2017). The descriptions of supply chains related to additive manufacturing tend to focus on home fabrication (Rayna and Striukova, 2016) and thereby omit how additive manufacturing may disrupt, for instance, logistics and prototyping. Those studies acknowledging such changes quite factually describe the supply chain changes from a bird's-eye view (Christopher and Ryals, 2014; Oettmeier and Hofmann, 2016, 2017; Rayna and Striukova, 2016), and do not take into account individual parties' perspectives. The power dependence lens is thereby unique to this type of research, while it links to disruption in its creation of uncertainty and act-to-survive orientations. In the broader perspective of theorising about disruption (Christensen, 2006), disruption and power struggles rarely concern supply chains, but focus on industries and individual (dyadic) relationships, respectively. The linking of the empirical phenomenon of additive manufacturing and the theoretical lens of power dependence thereby adds to previous knowledge and does so through the theorising of proactive and reactive balancing and unbalancing attempts of various actors along a disruptive supply chain.

The remainder of the paper is structured as follows: after this introduction follows a brief overview of previous research on additive manufacturing related to management and business. The theoretical lens of power dependence is then introduced. The research design is presented thereafter. The empirical part of this paper is collected through a number of seminars focussing on additive manufacturing and including 620 industry representatives of various companies engaging with additive manufacturing along the supply chain (mining firms, steel producers, logistics firms, car manufacturers, package manufacturers, etc.). The empirics from these seminars are presented after the research method and outlined to follow the supply chain and struggles among various parties. The analysis is then presented, followed by conclusions including theoretical contributions, managerial implications and ideas for further research.

Theory

This section first provides a brief overview of previous business research on additive manufacturing to narrow the scope of this paper, to then turn to present the theoretical lens of power dependence.

Theoretical background: previous business research on additive manufacturing
As implied in the Introduction, most studies on additive manufacturing (or its synonymous term, 3D printing) concern the technological side: the layer-based technique and how to advance its functionality. In the business and management area, as an emerging field of study, the literature is dominated by research on product optimisation in companies (Öberg *et al.*, 2017, 2018). In that vein of research, additive manufacturing is compared with traditional manufacturing methods to conclude how and when it is most useful (e.g. Gardan and Schneider, 2015; Paul and Anand, 2015; Aboutaleb *et al.*, 2017). While considering business aspects, that research focusses on the internal conditions of a company.

Enlarging the perspective, some few recent studies have concerned themselves with the change that additive manufacturing would bring about for the supply chain. Centring around the supply chain changes, a pull effect from customers is expected, launching the idea of demand chains (Christopher and Ryals, 2014), which is also the centre of much research: home fabrication of customers (Bogers *et al.*, 2016; Rayna and Striukova, 2016; Wang *et al.*, 2016). Rayna and Striukova (2016) described how home-based production will disrupt supply chains, while also pointing to the role of prototyping and tooling, and as stated by Oettmeier and Hofmann (2016, 2017), Sasson and Johnson (2016) and Rogers *et al.* (2016), additive manufacturing could expect to show several supply chain consequences, not only related to the end customer. Oettmeier and Hofmann (2017) described how supply chain consequences impact decisions of firms to adapt additive manufacturing, while more closely studying such supply chain effects in Oettmeier and Hofmann (2016). Li *et al.* (2017) specifically pointed at the effects for supply chains if spare parts are 3D printed, essentially meaning that they become internalised by the manufacturing firm. In line with Li *et al.* (2017), most other effects seem to suggest how make-or-buy decisions are increasingly a matter of making rather than buying as additive manufacturing is introduced, which indeed indicates a core point of this paper: that additive manufacturing may wipe out actors along the supply chain.

But while previous research thus acknowledges changes also beyond home fabrication and localisation of production, it does not recognise how various parties may fight each other off and how the disruptive stage of additive manufacturing (cf. Hoover and Lee, 2015; Kietzmann *et al.*, 2015; Mohr and Khan, 2015) causes power struggles along the supply chain, which is thus the focus of this paper based on those empirical observations inspiring the writing of it.

Theoretical framing: power dependence
Disruption denotes how new solutions replace current ways of acting (Christensen, 1997, 2006; Adner, 2002; Gilbert and Bower, 2002; Danneels, 2004), based on how customers adapt to the new solutions (Adner, 2002). Such adaptation occurs as the consequence of how the new solutions are simpler, reduce costs, increase reliability and are more convenient (Adner, 2002). Disruption, often described as a sector-level change, generally includes how existing companies are replaced by new ones (Cooper and Schendel, 1976; Henderson and Clark, 1990; Utterback, 1994), also implying how the new solutions – often a technology – arise from outside the industry sector. A request for new competences along with within-sector inertia explains these circumstances (Foster, 1986; Moreau, 2013).

While the literature has focussed on how new technologies may bring sectors apart, less is known about the behaviours of those seeing their industries disrupting. The uncertainty is self-evident at this point, which again creates a link to selfish, survival-focussed behaviour (cf. Eyuboglu and Buja, 2007) and for those currently integrating with the technology challenged by disruption, attempts to create positions also following the disruptive stage.

Among any interacting parties, there would be dependencies of resources and competences causing the power of parties upon which someone is dependent (Emerson, 1962). The dependency follows from how companies become specialised in various areas of knowledge and production, which is also seen in the supply chain idea based on core competences and make-or-buy decisions (Harland, 1996; Nordin *et al.*, 2010). Power dependence denotes the influencing forces where one party can (partly) control and influence another party, as the other party needs those resources or competences held by the first party (Casciaro and Piskorski, 2005). The power may though be mutual, meaning that both parties have influencing power over one another, and if in balance, their dependence on each other is equal (as is their power). Again, an imbalance would imply that someone depends more on the other party than the reverse. The ideas of power dependence (Emerson, 1962) lay the ground for resource dependence (Pfeffer and Salancik, 1978), emphasising how dependences occur as the result of resource specialisations, but also implying that parties strive for balance in their interactions.

While Emerson's (1962) work indeed discusses how balance can be obtained, it does not set to focus on that parties really want to achieve balance. Rather, they may well strive to have power advantages over counterparts (cf. Casciaro and Piskorski, 2005; Drees and Huegens, 2013) and connections between parties may well remain imbalanced (Kumar, 1996; Hingley, 2005). Any strive for power advantages, or aims to deal with power disadvantages or dependency, would cause dynamics in the connections between firms. More precisely, those being highly dependent in disadvantageous power connections would try to minimise the role played by the other party or strive to strengthen their own situation. Emerson (1962) presented four strategies to deal with imbalances: decreased engagement or withdrawal by the more dependent party; changed structures on network levels through diffusion of dependency into new relationships; the dependent party achieving status recognition; and the dependent party forming coalitions to on the group level meet the more powerful party. Similar strategies would also be used by a party trying to strengthen its power even further.

Most research adopting a power or resource dependence lens has focussed on connections between two parties. A supply chain constructs a flow including multiple parties (MacCarthy *et al.*, 2016) and thus describes structures where multiple parties contest for power advantages or attempt to even powers. This creates a dynamic that occurs in parallel among different supply chain parties. Theoretically, this is the issue that this paper tackles using additive manufacturing as the empirical phenomenon under study. Disruption, as introduced in this section, would be the antecedent causing uncertainties, potentially changing power structures, but also leading to selfish behaviours as a result of perceived challenges and threats to current positions and parties in the supply chain, while behaviours of actors would create or attempt to even imbalances created. Figure 1 summarises the relations of concepts as an analytical tool.

Figure 1 points at how additive manufacturing could be regarded as the technology that disrupts current structures, while power imbalances and attempts to regain balance would follow from those changes and uncertainties created among the actors in the supply chain as they see their current positions challenged by the new technology and by how other parties adapt to it.

Research design

The inspiration for this paper was a number of seminars with the author as one of those arranging the seminars, and with the broad focus on the seminars being the

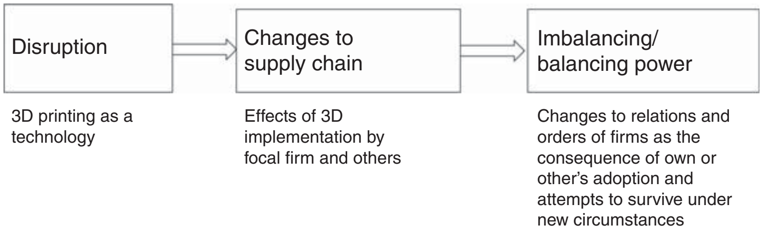

Figure 1.
Analytical tool (order of argument)

business side of additive manufacturing. These seminars also constituted the main source of data collection.

Data collection

The seminars included how the author and two co-researchers presented some early thoughts on additive manufacturing and changes to businesses, how company representatives described steps taken by their firms, ideas on further developments in relation to additive manufacturing and how the audience debated their ideas, questioned current propositions and helped to create understandings for the development. As such, the research design resembles an action research approach (Whyte, 1995; Greenwood and Levin, 1998; Reason and McArdle, 2004), which suggests being suitable when the phenomenon studied is in a state of flux. Studying additive manufacturing at this stage was also fundamental for capturing the ongoing power struggles among parties, which would not be as easily captured in retrospect (Huber and Power, 1985).

A total of 620 individuals participated in the seminars, representing 102 different companies. The companies included sub-suppliers to manufacturing companies, raw material refining companies, large and small manufacturing firms, consultancy agencies and representatives of companies manufacturing 3D printers with the aim to thereby cover the entirety of a supply chain. They represented different industries, such as car manufacturing, steel production, mining and the packaging industry, while being there to discuss an interest for metal-based additive manufacturing (cf. Ren *et al.*, 2008; Asnafi *et al.*, 2018). Covering various positions of the supply chain allowed for the capturing of the different firms' adoption and consequences, while representatives from different industries enabled comparative analyses (Eisenhardt, 1989). The seminars were held at different locations in Sweden. The seminars and estimated number of participants are listed in Table I, as well as companies having representatives there for talks.

Participants held such roles as CEO, researcher, production manager and similar in the companies they represented. In addition to the talks and informal discussions, various representatives were also approached individually for follow-up questions and deepened discussions (Sarantakos, 1998). These discussions included descriptions about what the companies were to do next, challenges in connection with other parties and whether and how present ideas challenged current structures. Several company visits were also made to participating companies.

Data analysis

While the main scope of the data collection was not that of power struggles, this emerged as a relevant perspective based on the descriptions at the seminars. In the analysis of data, notes from the seminars were first sorted to represent various companies along the

Date	Location	Participating talks	No. of participants (approx)
30 May 2017	Örebro	Uddeholm, Region Örebro	110
8 June 2017	Gothenburg	Volvo Cars, Lasertech, Chalmers Tekniska Högskola	80
14 June 2017	Östersund	AIM Sweden, Handelskammaren Jämtland, Mittuniversitetet	80
29 August 2017	Olofström	Techtank, Olofströms kommun	110
14 September 2017	Luleå	Swerea, IUC, Luleå Tekniska Högskola	110
20 September 2017	Värnamo	Acrom Formservice, Campus Värnamo, MetPrint, Jönköpings Tekniska Högskola	110
25 September 2017	Lund	Tetra Pak, AlfaLaval, Lunds Tekniska Högskola	20

Table I.
Seminars

supply chain. If companies in the same position acted in different ways, these were all included for the particular position. Descriptions were thereafter produced based on the notes and targeting current developments for the particular supply chain position, along with the parties' view on the development at other places in the supply chain (Pratt, 2009). This latter aspect was particularly important since the power dependence could best be recognised and understood in comments on other parties (Casciaro and Piskorski, 2005), their ways to behave and proactive and reactive steps to meet challenges caused by others. Furthermore, the descriptions allowed for the capturing of whether and how the parties experienced any power imbalances, let alone tried to create them.

The activities of firms were classified, using iterative coding of empirical instances (Eisenhardt and Graebner, 2007; Pratt, 2009), to see how they behaved to create power balances or imbalances. The empirical codes were thereafter categorised as proactive or reactive, and as attempts to regain balance or create power advantages, meaning that in the second round of coding (Pratt, 2009), empirical notes were theoretically categorised with the means to better understand the power struggles of firms. The four codes (proactive, reactive, regain balance and create power advantage) were compared among firms based on their various supply chain positions to grasp the overall understanding of power dependencies as the consequence of additive manufacturing. Meanwhile, the empirical codes of activities were synthesised to create understandings for how power was created among the parties. This was done in several steps of reduction of codes to theorise these aspects.

In the last step of the analysis, findings were compared with previous research on power dependencies and parties' behaviours (Emerson, 1962; Pfeffer and Salancik, 1978; Casciaro and Piskorski, 2005), while also linked to the supply chain order and disruptive character caused by the additive manufacturing technology. This helped to narrow down the research gap and define the more exact theoretical contribution while also link it to the empirical setting.

Empirics

In the following paragraphs, the findings are described per position following the supply chain downstream. For each type of actor, they are briefly introduced, followed by how they handled the introduction of additive manufacturing and the power dependence consequences of this way of acting.

Manufacturers of 3D printers

Firms manufacturing 3D printers are dominated by some few international companies, mostly with a European foundation, and with two of the larger companies being owned by General Electric. Most of the companies have been founded as separate start-ups for the sake of manufacturing the printers. These companies, being launched or established to address the need for 3D printers, obviously try to drive this development, while also creating advantages for themselves.

As a means to create market share and uphold revenues, the companies have ensured that their printers only work with a specific type of powder. This has created niches in the 3D printing markets and means that manufacturers (and the sub-suppliers, see below) need to buy specific, often quite expensive powder once they have acquired a printer. This way of handling the market allows for power positions relative companies buying printers and powder, while it would also mean that the further spread of use is actually constrained. Prices of printers are kept at a high level as a consequence, while the individual printer manufacturers create silos in the market directing their printers at certain customers and thereby minimising competition among the manufacturers of printers.

Raw material producers

The raw material for additive manufacturing in metals consists of fine-grained powder, or the printers use metal threads to build surfaces. In the production, the raw material is heated to melt as the layers or threads are built by the printer.

One of the raw material producers in the study focusses on various types of metals. The company decided to add powder to its product portfolio, which is also how those other producers of the raw material seem to have entered this production niche: they are presently producing steel or metal powder for other uses. The reason for entering into the production of 3D powder (or threads) is to meet competition based on how the demand for metals currently sold by the companies may be challenged by additive manufacturing requiring powder. The powder is then niched to advanced, complex applications, thus also potentially constructing an additional niche of metal solutions to be offered to manufacturing companies; that is, 3D powder would either replace some current raw materials of the firms or add to their current product portfolio.

As a means to meet the lock-in effects caused by manufacturers of 3D printers, the studied raw material producer has decided that its powder would work in any printer, thus trying to decrease the dependence on 3D printer manufacturers not only for itself but also for sub-suppliers and manufacturers. Again, this means challenging the power advantage created by the manufacturers of 3D printers, while also thereby potentially increasing the scope of the market for the raw material producers. Here though, some other raw material producers rather work to meet the requirements of a specific manufacturer of 3D printers, constructing also a struggle among the raw material producers for the specialising or not of powders.

Sub-suppliers specialising in additive manufacturing

Sub-suppliers in the supply chain would generally be characterised as any (often small-sized) company manufacturing parts or pre-producing materials for firms assembling them into sellable products. These latter companies are typically large-scale production units, surrounded by the sub-supplying specialists on parts and materials to be used in their final products.

If home production, or increased in-housing of production, was to follow as manufacturers (and customers) increasingly adhere to additive manufacturing, these sub-suppliers could well be out of business. As a means to break against this trend, some sub-suppliers have decided to offer additive manufacturing as part of their production methods. This means that the products – or components – are still manufactured by the sub-suppliers (and thereby transported to the manufacturing firms). This again means that the sub-suppliers attempt to build a position of competence and production capacity to maintain their position in the supply chain.

The high price of 3D printers means that for a piece of machinery to be profitable, it needs to be run more or less continuously, and this is the niche that the sub-suppliers currently try to cover: how it would be too expensive for manufacturing firms to own their own 3D printers. Various sub-suppliers collaborate to develop their business proposition, while the companies often work closely with universities (that may own their printers) as testbeds for production methods. Thus, the sub-suppliers attempt to create some advantages over their customers – the manufacturing firms – based on competence creation and more efficient use of printers. Several of them, however, work against time and the potential price drop on printers in this regard.

Logistics firms

Logistics firms are any company specialised in the transportation of other parties' goods and end products. They would traditionally operate between any position in the supply chain, transporting raw materials (and machinery) from those mining or producing it to those using it and again delivering goods from manufacturing firms (and among these) to retailers and consumers. As such, logistics firms are challenged by two developments: the more general trend of retailers taking on their own transportation routes; and the risks of home fabrication, and internalisation of production, decreasing the number, value and length of transports.

Being specialised in transportation, additive manufacturing would at its core of home productions cause a considerable threat. As one logistics firm plans, it wants to create a position of a fab lab, a 3D printing house that prints products for end customers. This would mean placing fab labs or shops close to end customers or airports so as to minimise transportation while maximising printer use. Sketches would be wired to these labs and printed for customers on demand to advocate the customisation trend enabled through the printing. Again, and similar to the sub-suppliers, the logistics firms would take advantage of printers being too expensive to become everyone's property, but then especially relating this to home fabrication and close-to-customer printing. In this regard, the logistics firms try to defend their current position through creating a partly new one, but then also mostly adhering to the trend of home fabrication and less so to the internalisation of production by manufacturing firms.

Manufacturing firms

Manufacturing firms, like sub-suppliers, engage in the production of products. The difference between the parties would largely be that the sub-suppliers do so while mainly relying on designs from the manufacturing firms, and furthermore, the sub-suppliers focus on components rather than ready-to-use products. Traditionally, the manufacturing firms would be large-scale production sites, while the sub-suppliers are small- or middle-sized companies highly dependent on the manufacturing firms as customers.

For manufacturing firms, additive manufacturing would allow for the change of product design and also the replacement of solid materials for more advanced surfaces. While being so, the manufacturing firms have somewhat lagged behind in that regard and focussed more on the production technique than the design of products. Several of these firms have also had difficulties to make additive manufacturing a management concern, and discussions have largely been suppressed to production management levels.

One of the manufacturing companies in the study has decided to take up the production of spare parts for its own machinery by 3D printing such parts. Rather than buying spare parts from suppliers and having them shipped to the production sites, this would mean that each production site would have CAD drawings for the spare parts and produce them locally on demand. Some other manufacturing firms have focussed on prototyping, meaning that they use printers to test early ideas of innovation as real products, and yet some other firms have started using additive manufacturing for tool production.

This development challenges any supplier to the manufacturing firm, be it a supplier of spare parts or a sub-supplier manufacturing tools based on CAD files from the manufacturing firm. Again, this creates a power advantage over the sub-suppliers, let alone the logistics firms, while the power advantage would be challenged by the expensive printers and powder, meaning that the development is restricted for monetary reasons. At the current stage, the manufacturing firms could be regarded as holding an advantageous position when it comes to the introduction of additive manufacturing. Them being slow in adopting the technology and the high price of printers has, however, created several of those loops that firms at other supply chain positions try to use to create or regain some power.

Customers

Additive manufacturing is said to be customer driven, or allow for increased customisation, shorter series of production, and indeed that the customer (consumer) manufactures the products himself/herself. While the latter may be the case for additive manufacturing in plastic materials, it is quite a long reach before customers would do the same for metal-based products.

In the shorter run, the customers rather only become more active parties for customisation purposes, influencing what is manufactured and when. The dependence on others to manufacture these products remains high, while the influence of customer specificities creates disruption in production techniques among manufacturing firms. Again, customers create a pull effect for additive manufacturing but are constrained in their requirements based on the lack of knowledge on what is really possible to manufacture and how. In the longer-term perspective, and given more dispersed knowledge and a decreased cost of printers – as seen for plastics – customers may well take on activities currently performed by the manufacturing firms, while also decrease or even erase the need for fab labs.

Societal support

The social support for additive manufacturing consists of how universities and municipality representatives sponsor and bring knowledge to the regional development and adaptation of the technology. There has been a tendency for such organisations to work with sub-suppliers – representing ownership interest in two of the three sub-suppliers focussing on additive manufacturing in Sweden – while sponsoring the 3D printers at the last sub-supplier. The organisations, in return, use these sub-suppliers to run tests of various kinds, also potentially contributing to the knowledge of the sub-suppliers. Their role, thereby, is basically to foster the adaptation to additive manufacturing, while their way of acting creates power advantages for the sub-suppliers. While this may be seen as initiatives to the help local sub-suppliers and extending general knowledge on additive manufacturing, these parties thus also play a part in constructing imbalances along the supply chain.

Analysis

Table II summarises the various parties described above, and in dimensions of proactive and reactive activities, and aims to create a power imbalance or even current imbalances (cf. Emerson, 1962; Casciaro and Piskorski, 2005). This way of analysing the data – proactive, reactive, imbalance and regain balance – followed from the theoretical perspective of power dependence (imbalance and regain balance) and the more empirical idea of parties either doing so in response to others (reactive) or so as to achieve their own advantages (proactive) at a stage of disruption.

Looking first at the table from the various actors' point of view, it seems quite evident that there are those whose position would be strengthened (or at least not harmed) by additive manufacturing: The manufacturers of 3D printers would benefit from a demand for printers, manufacturing firms could increasingly internalise production and customers would both be able to push for increased customisation and take on more production through home fabrication. This again indicates some initial things: disruption, albeit as a technology with several adopters along a supply chain, would not cause as severe an effect for all parties along the supply chain. And, although most research on disruption implies that disruption replaces current actors with new ones (Christensen, 1997, 2006; Adner, 2002; Gilbert and Bower, 2002; Danneels, 2004), some parties may actually persist and drive – or be able to drive – the further development of the new technology.

But while it could be assumed that those parties – the manufacturers of printers, the manufacturing firms and customers – would be those proactively gaining power as the supply chain disrupts, the empirical data for this paper tell a different story: both those potentially benefitting from and those being challenged by additive manufacturing acted proactively to create power advantages for themselves. Sub-suppliers acted to build a position of competence, for instance, while raw material producers took on the manufacturing of powder.

Party	Activities related to additive manufacturing	Proactive	Reactive	Regain balance/create imbalance
Manufacturers of 3D printers	Manufacture printers	Creating silos of lock-in effects through requesting specific powder for each printer		Trying to rule the market through specific powders (create imbalance)
Raw material producers	Complement product portfolio with powder	Powder to avoid future competition	Powder that can be used in various printers	Manufacturing of powder to meet competition (regain) Powder not for specific printers to decrease such dependence between manufacturers of printers and sub-suppliers/ manufacturers (regain)
Sub-suppliers	Manufacture components for manufacturing firms; creating around-the-clock production	Utilisation of printers	Avoid risk of being outperformed by manufacturing firms' home fabrication	Avoid risk of manufacturing firms (customers) doing the production themselves (regain balance, partially)
Logistics firms	Create fab labs for local printing		Risk that less transportation is needed	Balance decreased use of transport (regain)
Manufacturing firms	Produce prototypes, spare parts, etc.	Home fabrication of spare parts. Changed design or products. Increased customisation		Increase home fabrication (create imbalance towards sub-suppliers; regain from customers)
Customers	Potentially manufacture goods themselves. Demand of customisation	Demand for customisation	Home fabrication	Home fabrication and customisation (create imbalance)
Societal support	Support and test technologies	Trying to advance additive manufacturing use		Sponsor sub-suppliers with printers (no attempt to create or regain power, but affects the balance in the supply chain)

Table II.
Summary of findings

The difference, however, relates to reactive behaviours, where, again as seen in Table II, those being challenged by additive manufacturing are also those to act reactively to it. Therefore, two mechanisms occur more or less simultaneously: a proactive aim to reposition the firm based on new activities, and a reactive aim to deal with those issues caused by how parties at other positions in the supply chain adapt to additive manufacturing. To exemplify, raw material producers acted reactively towards manufacturers of printers through starting to offer powder usable in various types of printers, while they also acted proactively to create a niche of manufacturing powder. Sub-suppliers, in a similar manner, acted reactively to avoid being wiped out by manufacturing firms' internalisation of production, while proactively attempting to build a knowledge hub and provide efficient use of printers.

As for the regaining of power or attempts to create imbalance (Emerson, 1962; Casciaro and Piskorski, 2005), there seems to be an upstream pressure to create imbalance, and a downstream one to regain power. To exemplify, manufacturing firms tried to create a power advantage to sub-suppliers, while regaining power from customers. Meanwhile, there is the link between regaining power and acting reactively and creating imbalance and acting proactively, though influenced by such upstream and downstream pressures. The pairs of imbalances and proactivity and balancing and reactivity seem quite natural and are in line with how Casciaro and Piskorski (2005) argued that companies do not only attempt to regain balance but also actually create imbalance. However, reactive steps may thus aim to create imbalance and links to the disruptive characteristics of the supply chain as well as the upstream/downstream focus on power.

Compared to previous research on power dependence, this paper highlights how the changes to power dependencies arose from the "outside", being driven by the disruption caused by additive manufacturing, but even more so important: how power balancing/unbalancing occurs beyond dyadic connections. More precisely, companies' proactive and reactive whereabouts focussed on balancing/unbalancing connections also to parties that the company only had indirect relations with. To exemplify, raw material producers attempted to balance the power imbalance created by 3D printer producers and did so with the attempt to create sounder conditions for sub-suppliers and manufacturers. Logistics firms tried to balance the general imbalance created by manufacturers and, in the end, customers, about the decreased demand for transportation.

Previous literature has either argued dependence from a power point of view or linked it to resources (Pfeffer and Salancik, 1978). Viewing such resources broadly and including knowledge and competences (Penrose, 1959; Eisenhardt and Martin, 2000) in the definition of resources, this present paper seems to suggest that the resources are a means to create the power advantages: the sub-suppliers use knowledge to regain a power balance with manufacturing firms, while raw material producers reconfigure current resources to be able to produce powder. While this suggests being the case, it is thus not the resources as such that create the dependencies. This, again, is based on the state of flux caused by the ongoing disruption. At the current stage, the various companies act quite independently from one another from a resource point of view. This is so since the rules of the game, manifested through standards and dominant design, are yet to be decided, as seen in, for instance, the different types of powder and printers for various such variants currently being launched. Again, this indicates how resources are reactive, while power positioning may be proactive along the supply chain.

Conclusions

This paper discusses and explains the development of additive manufacturing from a power dependence point of view. The theoretical framing was selected based on how the empirical material for this paper proved to include many controversies, uncertainties and parties aiming to build or (re)gain positions along the disrupted supply chain.

The paper points at how power dependence is not dyadic, but how the unbalancing and balancing of power may occur *vis-à-vis* parties that the company is only indirectly connected to. What is more, and in addition to such works pursued by Casciaro and Piskorski (2005) and Emerson (1962), an external force or disruptive stage may lead to how previous balances become imbalanced, and also to how parties aim to exercise powers to an increased extent when the supply chain disrupts. In addition, the uncertainties created suggest that parties attempt to create imbalances and advantages to a higher extent than before. This would be linked to increased selfishness in decisions among parties and struggles to stay alive among the companies, and is specifically noted when proactive attempts are made to create imbalances, yet also when reactive activities aim to lead to such imbalances. Figure 2 summarises the various dependencies as outlined in the empirical part of the paper.

Theoretical implications

The paper's foremost theoretical contribution consists of how it discusses power dependence in a supply chain setting. This extends previous knowledge mostly focussing on dependencies between any two parties only (Emerson, 1962; Pfeffer and Salancik, 1978; Casciaro and Piskorski, 2005; Hillman *et al.*, 2009), and it introduces the idea of indirect and direct dependence by pointing at how one firm may act to balance or imbalance powers *vis-à-vis* a party only indirectly connected to the firm. Furthermore, the paper notes how imbalance or balancing may occur towards a set of parties, not just a single actor.

The link between disruption and changes to power dependencies is denoted in the paper and indicates foremost how the disruption causes changes in the power dependencies, but furthermore: how it awakes behaviours of exercising power and selfishness caused by uncertainties and fights for survival.

Empirically, the paper makes a contribution to research on additive manufacturing, and specifically to business studies on additive manufacturing. While the interest for supply chain disruption has lately emerged related to the technology, it is often with a bird's-eye perspective on the supply chain and more rarely captures changes and how individual parties drive and respond to these.

Managerial implications

For managers, and regardless of which position their companies hold in the supply chain, this paper points at the importance to recognise activities pursued not only by direct business parties but also by all parties along the supply chain. This introduces the notion of carefully "picturing" (Öberg, 2012) the activities of others in the supply chain and keeping track of their current whereabouts. Scenario analyses and other tools would help to understand the consequences of other parties' activities.

When it comes to additive manufacturing and looking at positions that would be especially difficult as the consequence of additive manufacturing, sub-suppliers and logistics firms would need to really consider their long-term development, whether to try to build positions on their own or ally closer to manufacturing firms, for instance. Questions to address would include what core activities additive manufacturing consists of, how this would change current ways to operate, risks for changes related to make-or-buy decisions as well as resource needs and what core activities would also be needed in the future.

Limitations and ideas for future research

The empirical part of this paper evolved from the seminars, capturing real-time problems and scenarios for the future for various parties along the supply chain. Still, those represented did so in a specific country setting – Sweden – and while they represented different industries, the scope of the empirics would still be constrained to those specific industries and the geographical setting they acted in. For further research, it would, therefore, be interesting to explore similar phenomena in other countries and industries. This would help to validate those results presented regarding proactive and reactive power balances and imbalances. Following companies over time would in addition to this help to

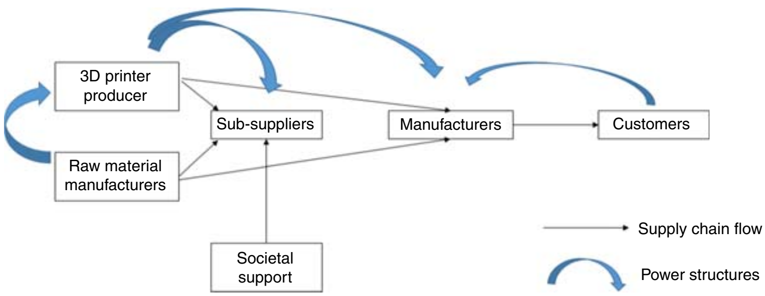

Figure 2.
Power dependencies along the supply chain

see short- and long-term effects and what happens as dominant designs and ways of acting emerge, for additive manufacturing, but also with those power struggles currently marking the disruptive stage.

The idea of disruption causing uncertainty and power struggles would be worth investigating in other settings, and additive manufacturing would be interesting to study related to different materials (plastics, metals, etc.) and compare different settings.

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