THE IMPACTS OF ADDITIVE MANUFACTURING ON SUPPLY CHAINS

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Abstract

The main aim of this paper is to point out the increasing importance of using additive manufacturing during production processes and their potential economic impacts on the supply chains. We evaluated the main benefits and limitations of using additive manufacturing instead of traditional manufacturing and also its application in the modern world. Decreasing costs of using additive manufacturing enable consumers to use their own device at home to produce customized products for everyday use. Replacement of traditional manufacturing with additional manufacturing can cause that firms that outsourced some parts of their production process will be able to bring them back to the home country that may significantly influence the national economies and the supply chains, too.

Keywords

Additive Manufacturing, Traditional Manufacturing, Supply Chain

I. Introduction

In the recent years, the increasing research and development in additive manufacturing caused, that firms are using more 3D printers in their production than ever before. This increased usage caused, that the firms have the tendency to bring back some of their outsourced parts of their production process to the home country and for that reason they can reduce transportation costs. This insourcing highly affects the whole supply chain and later may influences the whole national economies. Although with the growing usage of 3D printers, more research papers are issued that are concerning with the economic impacts of the additive manufacturing, it is still not enough and there is still problem with the missing data. This paper is focused on the growing importance of using additive manufacturing during production processes and therefore to raise awareness about this topic. It is necessary in order to capture better its possible economic consequences.

II. Characteristics of additive manufacturing

The birth of additive manufacturing can be dated to the end of the 19th century when it was designed a method for creation patters of topographical relief maps. The method includes continuous stacking and smoothing of wax plates after what they obtained a three dimensional surface that represents the terrain. Afterwards, there were proposed other suggestions for the material used for this purpose. For example, substituting the wax plates with cardboards, transparent plates or photo-hardening materials. The beginnings of the additive manufacturing is also observed in the field of photosculpture in the 19th century, when there was an effort to create a three-dimensional models of any object (Bourell et al., 2009). Although we can consider these methods as the early beginnings of the additive manufacturing, they are similar to the modern form of additive manufacturing just in the procedure of layering. As it is stated in Wohlers Report (2016), the modern version of additive manufacturing can be dated back in the late 1960s, when the laser was used for the first time for creating solid objects from photopolymers. In 1980s, Hideo Kodama was belong to the first inventors creating the single-beam laser curing approach and also his experiments were part of the first evidences of working additive manufacturing techniques in the world. In 1987, the commercial use of additive manufacturing appeared applying process that solidifies thin layers of ultraviolet light-sensitive liquid polymer by the use of laser.

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From this time until the early 2000s, the development of additive manufacturing depended on the pace of the research and development of firms presenting a small oligopoly. Although the price of the machines fluctuated between $20 000 to $500 000, they were used by firms that were looking for rapid prototyping capabilities. Obviously, these machines were not affordable for households in those times yet, so mass production with these machines was not possible (Laplume, 2017).

According to the Mckinsey report (2013) the additive manufacturing represents a process where the objects are built layer-by-layer rather than by molding or machining. This process is also called as 3D printing, because it uses an additive process, where the 3D objects are created by layering materials of different 2D shapes. The expressions additive manufacturing and 3D printing are interchangeable.

The 3D printers work in the following way: in the first step, an image is created by the use of CAD software (computer-aided design) that is sent to the 3D printer. Then the printer prints out the wished product by layering materials on the top of one another.

Nowadays, the development of 3D printing has reached a level, where various techniques are used and the objects can be created from various colors, materials and with various forms. The printed objects can be for example from plastic, glass, metal or ceramics and they can be liquids, powders or sheets. Firms continuously work on the development of 3D printers to be faster, more accurate, more effective and reachable for most of the firms and even to consumers. These improvements lead to lower costs for buying a 3D printer. According to the 3Dinsider the cost of 3D printers has fallen mainly in the last three years. Currently, the price of the cheapest 3D printer starts from $200, the average consumer 3D printers around $700 and the high end consumer ones can cost several thousands.

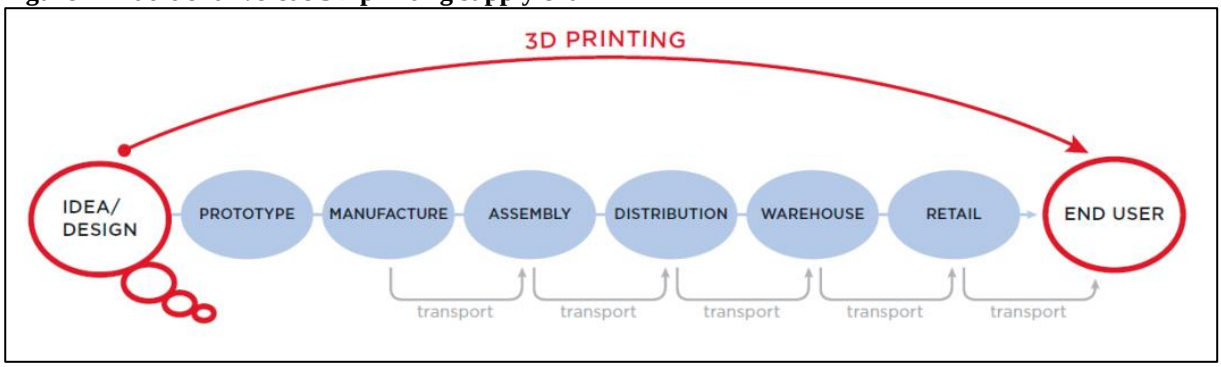
In the recent years, when the 3D printers are more available for the households, the consumers do not have to be engineers to create an image in the CAD software. There are many web pages that provide pre-prepared models that can be downloaded and later printed with their own printer at home.

The importance of using 3D printers mainly by firms is increasingly growing. The reason is, that using 3D printers during the production processes can bring a lot of opportunities and benefits not just for the firms themselves, but also it influences the whole supply chain. The main benefits of using additive manufacturing are the following:

Shorter supply chains

The era of globalization caused, that the production processes of the traditional manufactures are divided into various parts and some of them are outsourced to the countries with cheaper work forces. This was mainly caused by the lower transportation and telecommunication costs. Using 3D printers enables to bring back some parts of the production processes to the home country and to shorten the supply chain also the delivery time of the products to the consumer. This fact is represented in the Figure 1, where it is compared the traditional and the 3D printing supply chains.

Figure 1 Traditional versus 3D printing supply chain



Source: Özceylan (2017)

The traditional supply chain represents the process from the idea/design until the end user. It consists of prototype, manufacture, assembly, distribution, warehouse and retail, during which the product may cross the border many times so the delivery, while the consumer gets his product, takes a long time. In case of 3D printing, the supply chain consists only from two steps. The first step represents the idea/design and the second one the printing and the immediate transport to the consumer.

Shortening the supply chains enables firms to bring back some parts of production process to the home country. Since using additive manufacturing during production shortens the production process, the firm has no reason to outsource their production to the cheaper countries. We can demonstrate it on the following example. Let's say, a firm is producing car parts. These car parts are distributed mainly to the consumers, whose cars broke down and need a new car part. To reduce the production costs, the firm outsourced some parts of the production process abroad. The firm produces a huge amount of car parts abroad that will import back to the home country and keeps them in the warehouses that often located further from the location of sale. In case, that the consumer needs a new car part that is not in the warehouse, he has to wait sometimes a few weeks to get the needed part. But what would happen if this firm would start to use additive manufacturing instead of traditional manufacturing?

After this firm invested to buy a 3D printer to produce car parts, he does not need to have big warehouses anymore. The medium size facilities will be suitable for this purpose. The idea is that in the future, the consumer who needs a new car part just order one and the firm will immediately produce it with the 3D printer and promptly deliver to the consumer. Since these medium size facilities will be closer to the location of sale, the time of transporting will be shorter and there will not be a problem that the car part is sold out and he has to wait to deliver to him from abroad. The unnecessary warehouses, the shorter delivery time lead firms to the reduced production costs as another benefit of using 3D printers.

Lower cost

Shortening supply chain will cause that the firms' total costs will be lower. Since the production is located closer to the end user, the logistics costs will be lower and the delivery will be also faster. Since the firms will not need huge warehouses with lots of spare parts and they will produce only that amount of products that will be definitely used, it will mean that also the inventory costs will fall. Fewer traditional capital goods will be used that will cause that the use of intermediates will decrease so do the import and export costs.

Based on the DHL Trend Research (2016) and taking into account the decreased costs, Figure 2 illustrates the economics of using 3D printing for everyday households items.

Figure 2 Economics of 3D printing

Items	Retail Price Range	Cost to 3D Print
Shower Head	$7,87 – $437,22	$2,53
Jewelry Organizer	$9,00 - $104,48	$0,70
iPad Stand	$82,84 - $812,85	$10,69

Source: DHL Trend Research (2016)

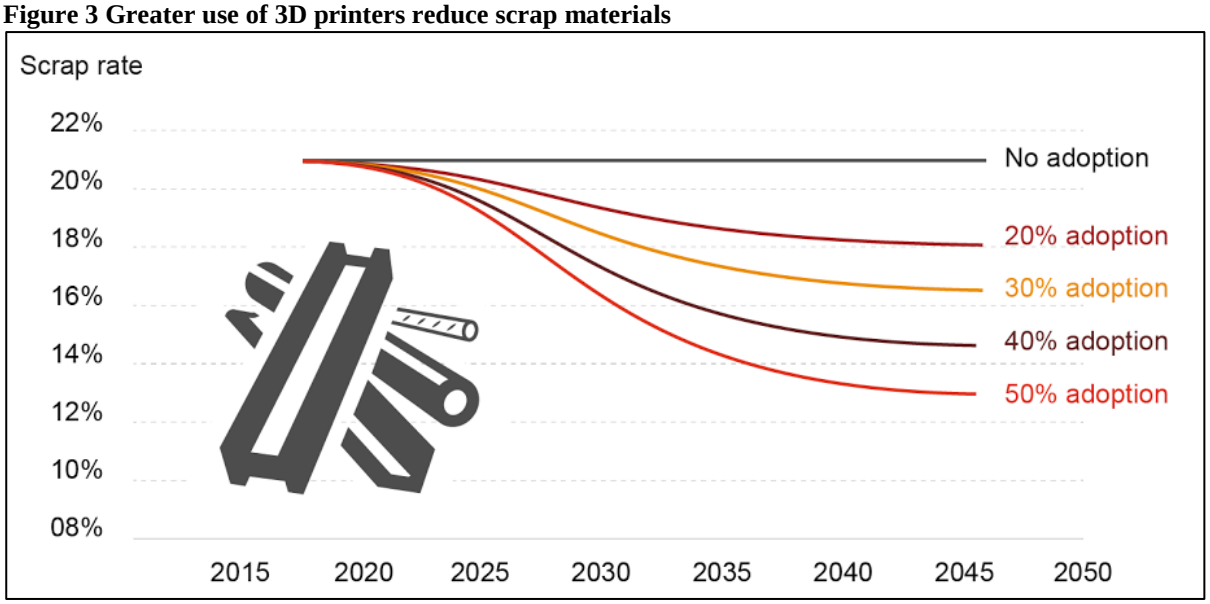
As it is stated in the analysis, these items require some customization, for example jewelry organizer needs to be well-designed for the particular jewelries and an iPad stand needs to be designed to the model's exact size. If these objects would be made by using 3D printers, the potential savings are between 8 to 80 times an equivalent retails price. Product customization enables to produce the exact product that is needed and the firms do not have to make mass production, causing that the spare parts will lay in the inventory for long time.

Lower waste

Based on the PwC analysis (2017), 3D printing can reduce waste in manufacturing. In 2015, the total waste is oscillated around 21 % of the materials that enter a factory floor. Using 3D printing during production processes can lower the level of waste below 10 %.

Figure 3 represents the cases of potential reduction of scrap materials for four scenarios based on different rates of adoption during the next 25 years. If the adoption of 3D printers is higher, the creation of scrap materials will be lower. For example, if the 3D printer does not adapt in the next 25 years, the scrap materials will not be reduced and there is a threat, that this share may be higher than today. If the adaption reach 50 % of all manufacturing, waste may drop to 13 % that represents approximately 40 % below than in 2015.

Figure 3 Greater use of 3D printers reduce scrap materials



Source: PwC (2017)

The general opinion is that using 3D printer can reduce waste creation during the production process. It is because the firm produces less, uses less material and also less energy during their production process. But this statement is not accurate.

According to the OECD study (2017), the largest environmental impacts come from printing energy and material use, but these impacts depend on the printer type, part geometry, machine utilization rate, print set-up and material. It is true, that additive manufacturing produces parts with lower environmental impacts per part than machining, but there are still many exceptions. It is still needed more researches to prove the statement about the environmental friendly printing.

Product design/feedback from consumer

Against traditional manufacturing, additive manufacturing enables firms to customize their products. Firms using 3D printers can customize more efficiently and at lower costs than during mass production, where customization is often impossible. The typical example is producing shoes. The firm produces few hundred sometimes thousand identical shoes. Although they may have different size, it does not mean that it will fit for every consumer. Everybody has a little bit different type of foot, so customization means to produce shoes that will fit perfectly for the particular consumer. When firms produce on demand, it brings them closer to the consumer so it means, that the consumers can give quicker, more detailed feedback that will incite firms to produce better products.

The benefits of 3D printing indicate that using additive manufacturing during production process gives lots of opportunities for the firms. But the increased usage of additive manufacturing brings also new risks that they have to face with. We can divide these risks in the following way (ING Economic and Financial Analysis, 2017):

High speed production

In many cases, traditional manufacturing is still cheaper than 3D printing mainly because of the mass production. High speed production still can not be done with the most common 3D printers so in case the firm needs to produce huge amount of products, it will still use the traditional manufacturing.

Recapturing costs of investments in traditional capital goods

When the firms want to replace traditional manufacturing with additive manufacturing, they need to think about the gains and losses, because 3D printers involve high fixed costs. Also if the current machines are older, then switching to 3D printers will be more economical.

Expensive raw materials

The raw materials market used for 3D printing is characterized with few suppliers, monopoly pricing power that lead to higher variable costs of the firms.

Lower wages

Substituting traditional manufacturing by 3D printers will cause lower wages and decreased prices in this sector. This will slow down the process of adoption of the 3D printers.

Slow adoption

Slow adoption mainly by the businesses caused by the lack of knowledge.

Quality of the printed products

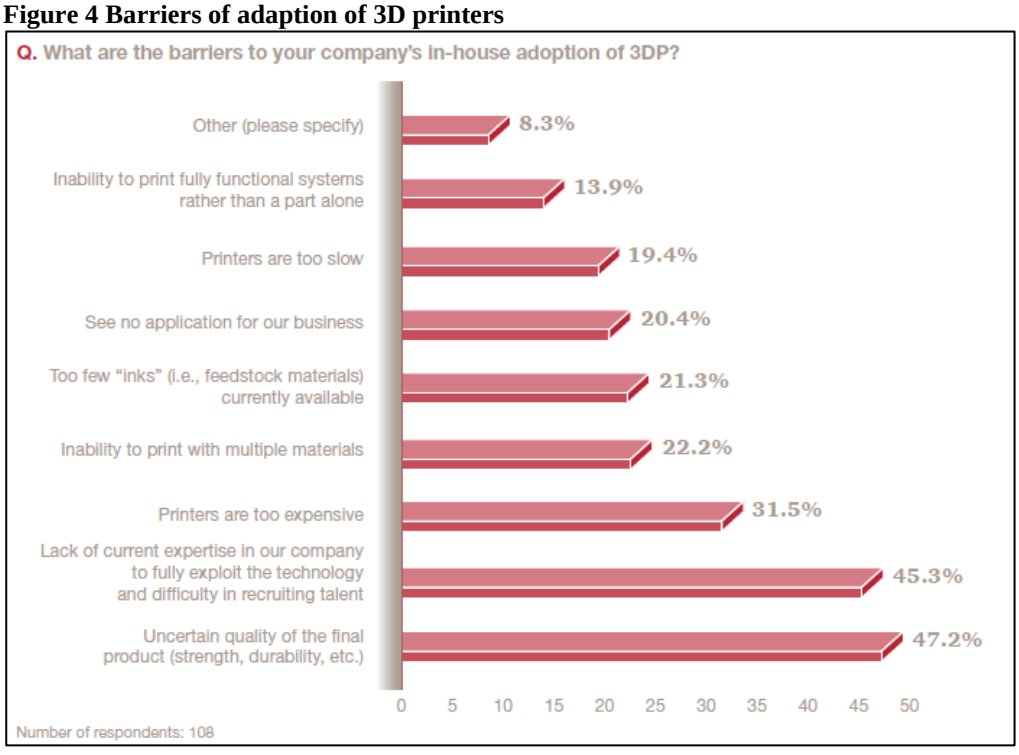
Since the 3D printing is still evolving, there may be some shortages in the product quality.

Lack of skilled working force

Insourcing some parts of the production process back to the home country because of the increased adaption of 3D printers can create new job opportunities. These jobs are mainly for high skilled labor force that are capable to operate those 3D printers.

Based on the PwC analysis *2014 Disruptive Manufacturing Innovations Survey*, Figure 4 represents the surveyed manufactures' opinions about the barriers of adopting 3D printers in their firms.

Figure 4 Barriers of adaption of 3D printers



Source: PwC (2014)

As the Figure 4 illustrates, the biggest challenge in adopting 3D printers in the firms are the uncertainty of the final product quality, lack of skilled working force and in some cases the price of the printers is still too high. The larger adoption of the 3D printers in the firms will be able only in that case, when these limitations will be eliminated.

III. Application of 3D printers

3D printers are mostly used in the following ways:

Medical tools – additive manufacturing are highly used in the medical profession. The printers are used mainly for printing dental appliances, specifically dental prostheses. There are many 3D printing firms that produce personalized dental crowns, bridges that will fully fit for the patients. The additive manufacturing is used also for producing orthopedic aids. Nowadays, the 3D printers are also used for producing prosthetic hand or different implants that can be implanted inside the body.

Industrial machinery – many industrial manufactures start to use 3D printers during their production process that means that they are not just a competitor to the additive manufacturing. 3D printers are widely used mainly for prototyping and fabricating tools of specific machines parts. It indicates, that the firms use 3D printers to make their machines more productive rather than produce products.

Automotive industry – in automotive industry the 3D printers are mainly used to produce car parts like car engines, the body of the car or panels. But there are other utilization of the printers in this industry. The start-up company Local Motors has designed the world's first 3D printed electric car, called Strati. The car is printed from carbon-fiber-reinforced plastic, a strong and relatively cheap material, the production took approximately 40 hours and cost about $5 000 (Popular Mechanics, 2015).

Aerospace industry – the first mover of the 3D printing was aerospace industry. The reason is that it was needed to produce new products that were much lighter than existing with lower costs. Based on the Wohlers report 2017, General Electric Aviation uses 3D printers for producing thousands of nozzles annually for their machines. Airbus also uses 3D printing during his production process. The reason why Airbus started to use additive manufacturing is, that he needed to produce a small batches of components and the traditional manufacturing was not fit for this purpose. The 3D printers enable them to produce just components they are needed with lower costs, so the whole production is much cheaper compared to using only traditional manufacturing.

Consumer use – the decreasing prices of 3D printers caused that more consumers are able to buy their own printers in order to use them at their own home. They are printing not just only small gadgets but also a wide variety of meaningful products. The consumers can print different types of jewelry to differentiate themselves or own headphones that are customized to their ears and style.

IV. Analyses of additive manufacturing

Recently, there are only a few economic analyses dealing with the additive manufacturing. Even in the time of increasing usage of 3D printers, economist do not deal with this problem very much, so the analyses are mainly technological based. In this part of the paper, we would like to give a closer look about the current state and the future of the 3D printing from the economic point of view.

McKinsey (2013) global institute analyzes in his research the potential economic impacts of the growing use of 3D printers by the year 2025. They estimated that 3D printing could generate economic impact between $230 - $550 billion per year in 2025. The 3D printers will be used mainly by consumers followed by direct manufacturing using them for producing finished goods. Just the consumer use of the printers will generate potential economic impact of $100 - $300 billion per year. This increased usage by consumers will be caused mainly by reduced cost and the value of customization. The prediction is that the needed product printed at home will be cheaper than buying it through retailer and that most of the consumers, if not all of them, will have a 3D printer or will have an access to one of them, so they can easily print out the needed products. The analysts are aware

that not all of the products will be able to print out, but additive manufacturing will have a potential to increase the productivity of the injection molding processes by shortening setup times, eliminating tooling errors and producing molds.

In 2014, PwC surveyed over 100 industrial manufacturers to get a closer look at using of 3D printers in the firms. The sample represents small firms and also big multinational ones. During the surveying, two-thirds (66,7 %) of the manufacturers are already using 3D printers in some way, 24,7 % of the firms are planning to use them in the future in some way and only 8,6 % of the firms are not planning to use 3D printers ever. Most of the respondents stated that 3D printers will be adopted by more than a half of the US manufactures in the next 3-5 years.

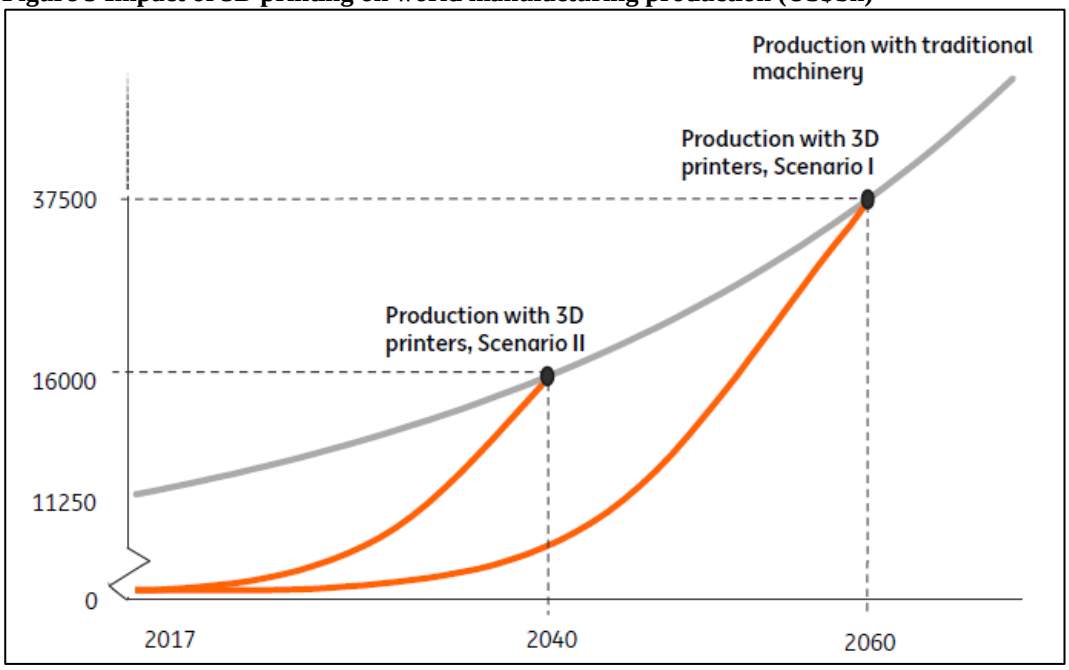
In 2015, worldwide 3D printer shipments was approximately 250 000 units and it is expected to grow between 2016 and 2019. The estimated value will be $5,6 billion and demand will increase not just by the manufacturers, but also by private consumers, start-ups and learning institutes (Rehnberg – Ponte, 2017).

Study based on ATKearney (2017) suggests than in the United States in the following 10 years, 3D printing will affect around 42 % of production in industries, automotive, consumer products, healthcare and medical devices and also aerospace. 3D printing is also expected to triple its market value to more than $26 billion by 2021 and create 3-5 million new skilled jobs.

According to the ING analysis (2017), the annual growth rate for investment in 3D printing has been 29 % over the past five years and in traditional machines 9,7 %. This indicates the raising importance of 3D printers. In this study, two scenarios are suggested about the impacts of 3D printer on world manufacturing production and they are illustrated in Figure 5.

In Scenario I, the annual difference in investment growth will be 19 % on average for the coming decades and the stock of 3D printers will equal the capital stock in 2060. In Scenario II, they took into the account that the technological development could boost revenues from producing with 3D printers that will cause investment acceleration in additive manufacturing. In the second scenario, the size of the capital stock of 3D printers will be equal to capital stock of traditional machinery in 2040. They are assuming, that in both scenarios the mass production of printers will be possible during the studied period.

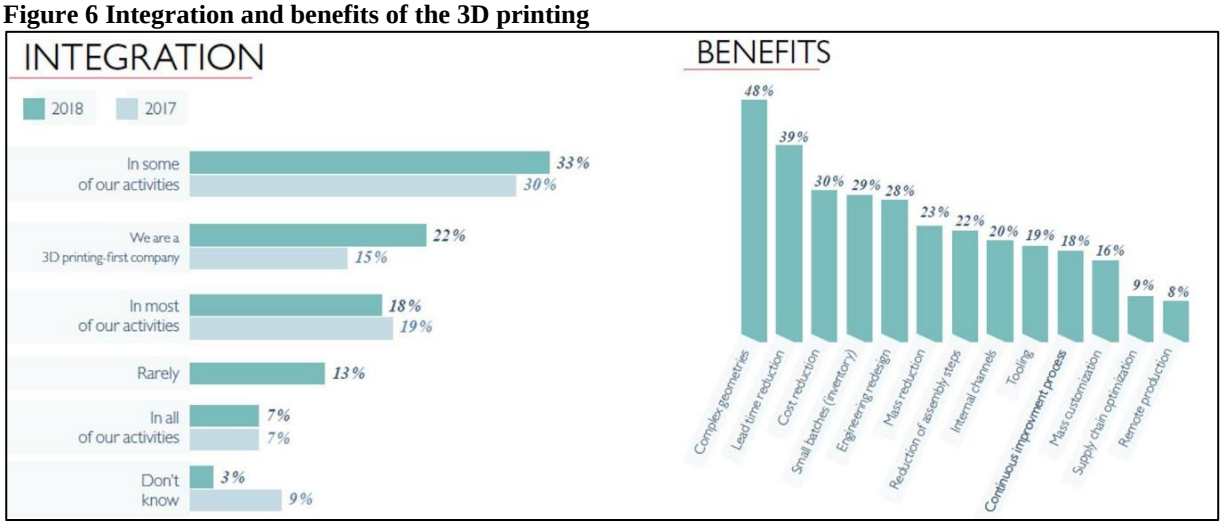
Figure 5 Impact of 3D printing on world manufacturing production (US$bn)



Source: ING Economic and Financial Analysis (2017)

The most famous analyses about 3D printing are issued by the Wohlers Associates. Every year they issue the Wohlers Report that is an annual worldwide progress report on the additive manufacturing and 3D printing state of the industry. The latest report was issued in 2018, where it was pointed out that the sale of metal additive manufacturing system in 2017 increased by nearly 80 %. The industry of additive manufacturing exceeds $7,3 billion that represents growth of all additive manufacturing products by 21 %.

Figure 6 Integration and benefits of the 3D printing



Source: Forbes (2018)

The Sculpteo's 4th edition study about the 3D printing (Forbes, 2018) also contains some interesting facts. In 2018, 93 % of surveyed firms that are using 3D printing are able to gain competitive advantage and 70 % of them have increased their investments in additive manufacturing (in 2017 it was only about 50 % of the firms). For almost 40 % of the firms using 3D printers, the highest priority is to accelerate product development. Figure 6 illustrates the integration and the benefits of using 3D printers during production processes. The more integrated the additive manufacturing is, the more benefits will the firms gain. In 2018 the integration of 3D printers has increased compared to the previous year. The main benefits arising from using additive manufacturing are complex geometries, lead time reduction, cost reduction, small batches and engineering inventories.

Comparing above mentioned analyses that were issued in different years, the usage of 3D printing is continuously growing and takes more important place in the firms' production processes. Nowadays, the additive manufacturing is applicable in the various fields of production and more and more products are printed by 3D printers.

V. Conclusion

The main aim of this paper was to point out the growing importance of using additive manufacturing during the production process. Although additive manufacturing still has lots of limitations, few of them were eliminated by the growing investments in research and development. The quality of used materials, print quality, print time has enormously improved and also the price of the printers were constantly falling and caused that printers are more affordable for the consumers, not just for the manufactures. Many aspects of the 3D printing have highly improved in the past few years and caused that more and more firms adopting 3D printers in their production. The increased adoption of the printers may cause that the character of the supply chain will continuously change. By replacing traditional manufacturing with additive manufacturing, firms will be able to insource some parts of their production process back to the home country and lower their production costs. This may change the general look on the global value chains and the issue of outsourcing.

The major limitation of this topic is the missing data. Lots of analyses exist on the topic of additive manufacturing, but they do not deal with the economic impacts of the 3D printers. There are only few

firms that deal with the economic point of view of 3D printing and provide data about the usage of the printers. This paper provides information about the benefits, limitation of using 3D printers and potential economic implication on the supply chain. Although the 3D printers will never fully replace the traditional manufacturing, its influence is continuously growing and its impact on the national economies and supply chains are becoming noticeable. The adoption of additive manufacturing in the production processes is mainly depend on the future research and development in this field and also on the cost of the printers and materials used.

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