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3D Printing: What does it offer and for whom?

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Abstract

This paper investigates 3D printing technology in a broad perspective by having a close look at its evolution, current and potential applications, and possible implications in both micro and macro levels. It also discusses existing and possible steps towards reaping the full benefits of this technology. 3D printing can provide valuable opportunities for manufacturing sector as well as in other areas including personal use. While 3D printing promises significant advantages for firms, it also brings about considerable threats for incumbents. Besides, 3D printing may trigger changes in national comparative advantages regarding manufacturing and design activities. By supporting adoption of 3D printing technology, countries can gain new opportunities in a wide range of areas.

1. Introduction

Making things is one of the oldest and major occupations of mankind. While everyone was initially making things for himself; some individuals started to become professional at manufacturing for others and, thus, artisanship and cottage industries have emerged. Later with the industrial revolution, production activities reached a disparate dimension. Throughout this process, as the production became more centralized, quality and variety of manufactured items generally increased along with decreasing costs. On the other hand, as the production moved away from consumers and started to be done in much higher volumes, goods became less personalized.

Three dimensional (3D) printing can be seen as another step of mankind's story of making things as it has a potential to affect the evolution of manufacturing activities. 3D printing technology can enhance both professional and personal production as well as making it closer to individuals and more customized. It can also trigger significant changes from micro to macro levels regarding not only manufacturing and design but also in many other areas where physical objects have a role.

This paper aims to contribute the comprehension of 3D printing technology in a broad perspective. In addition to having a closer look at it by considering current and potential applications, this study also discusses the potential transformative influences of 3D printing and possible steps towards reaping the full benefits of this technology.

Organization of this paper is as follows: Next section investigates different 3D printing techniques in a historical perspective as well as presenting some expectations about the future of this technology. Section 3 browses the prominent 3D printing applications. Fourth section

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includes the recent national efforts related to 3D printing technology. Section 5 analyzes the potential implications of and issues around 3D printing. The sixth section proposes several policy options and the last section concludes this study.

2. 3D Printing from Past to Future

2.1. What is it exactly?

Additive manufacturing or with its more popular name 3D printing is a process of creating physical objects from a digital model by fusing materials layer by layer successively with light, heat or chemicals. These digital models can be formed via computer aided design (CAD) programs or 3D scanners. Then, digital model is sliced into layers by software and sent to the 3D printer for execution.

There are a number of different 3D printing methods yet 3D printers mainly form layers by either squirting the raw material through nozzles onto a build area or selectively fuse liquid, solid or powdered material. While traditional manufacturing techniques like cutting, machining, punching, and grinding are subtractive since they produce final parts by removing some portion of the mass raw material, 3D printing is an additive process as it produces the parts by bonding raw material as needed (Hornick and Roland, 2013). In order to produce the objects, 3D printers use different technologies which can be categorized according to phase of the raw material.

Solid-based 3D printing: 3D printers that use Fused Deposition Modeling (FDM) produces objects by extruding heated material, usually thermoplastic or metal wire, from a nozzle layer by layer. Quite differently, in Laminated Object Manufacturing (LOM) two dimensional adhesive-coated sheets of raw materials including paper, metal, and plastic, are successively cut out by laser. Then this segment is stacked to substrate by the help of a heated roller and fresh material sheet is supplied (Hopkinson, Hague, and Dickens, 2005).

Liquid-based 3D printing: In Stereolithography (SLA) method, a tank filled with liquid plastic (photopolymer) is used. There is a perforated platform on the top of the tank and it leaves a thin layer of photopolymer on the surface. For the creation of each layer, light beam traces and solidifies the some portions of photopolymer on the platform. After hardening of each layer, platform is lowered fractionally and next layer is added by solidification of photopolymer exposed to light. In Digital Light Processing (DLP) technology, light is projected to solidify a complete cross section of each layer at a time. Jetting is another method in which photopolymer liquid is sprayed onto a build tray and then solidified by ultraviolet light by very thin layers (Hopkinson, Hague, and Dickens, 2005).

Powder-based 3D printing: Selective Laser Sintering (SLS) works very similarly to SLA except using polymer, metal or ceramic powder instead of liquid plastic. In SLS, laser selectively sinters powdered raw material which is spread as a thin layer on the powder bed. At the end of each cycle, powder bed is lowered incrementally and a fresh layer of powder is added. There are a few variations of SLS technology. In Selective Laser Melting (SLM) metal powder is completely melted using high energy laser. Electron Beam Melting (EBM) uses electron beams instead of ultraviolet light. In Direct Metal Laser Sintering (DMLS) metal objects are created directly without any need to further processing. Selective Heat Sintering (SHS) technology fuses powdered thermoplastic thanks to a heated print head instead of laser. Alternatively, in Binder Jetting, print head selectively deposits a binder solution to powder bed and thus bonds powder in line with layered digital model in each cycle. This process is repeated after new layer of powder is spread onto powder bed (Hopkinson, Hague, and Dickens, 2005).

Technologies employed in 3D printing can expand according to different combinations of used raw materials, fusion methods, and binders. Each technology has both advantages and disadvantages and may work better for particular purposes. While some 3D printer technologies can only use a certain type of material, some others are flexible enough to work with different kinds of one material or even several types of materials. Recently, 3D printers have become capable of using new materials like glass, chocolate, and even human cells.

2.2. Historical Background

3D printing technology can be traced back to 1970s. In 1971 French scientist Pierre Ciraud made a patent application which describes a method of manufacturing objects by solidifying metal powder with the help of beam of energy (Shellabear and Nyrhilä, 2004). In the same year, Wyn Kelly Swainson filed another patent application for a system which is similar to SLA and based on production of 3D objects via intersection of laser beams (Bradshaw, Bowyer, and Haufe, 2010). In 1979, Ross Housholder applied for a patent regarding a production process which resembles SLS technology for fusing particles selectively by a laser beam and creating 3D objects layer by layer (Shellabear and Nyrhilä, 2004).

Even though these initial attempts could not be commercialized, in 1984 Charles Hull filed a patent application for an apparatus that produces 3D objects by SLA. Two years later when his patent was issued, Hull established 3D Systems Corporation. In 1986 also, Carl Deckard developed SLS that was described as a method and apparatus which selectively sinters powder layer by layer with the help of computer controlled laser. His academic adviser Joe Beaman and he founded Desktop Manufacturing (DTM) Corporation (former Nova Automation) which would eventually acquired by 3D Systems in 2001 (Shellabear and Nyrhilä, 2004). Furthermore, in 1989 Scott Crump invented FDM and founded Stratasys Ltd (Karp, 2014).

After these initial developments, there have been successive improvements related to different 3D printing technologies. This led 3D printing to find a wide range of application areas in industry especially through rapid prototyping and rapid manufacturing. In fact, these terms have been used interchangeably[2].

[2] Here I use 3D printing as a broader term comprising all additive manufacturing techniques and purposes whilst rapid prototyping is making prototypes by using 3D printing technologies during product development processes and rapid manufacturing is employing same technologies in an automated manner for serial production.

Moreover, thanks to further technological developments, expiring patents, decreasing costs of raw materials and 3D printers, this technology has started to be used by individuals. An open source project, initiated in 2006 and named Replicating Rapid Prototyper (RepRap), played an important role in increasing personal use of 3D printers. RepRap 3D printers can reproduce about 50% of its own parts while remaining parts are designed to be cheaply available (Reprap, 2014). Besides, 3D printing communities, which pursue other open source development projects, share 3D designs or print and deliver requests of others, have started to disseminate. Now, there are a number of 3D printers that are affordable enough for non-professional use, and they are becoming more mainstream day by day.

2.3. Future Prospects

Future expectations about 3D printing vary but they meet on common ground of being quite sanguine. According to a report by Wohlers Associates, global 3D printing market, including all products and services, has reached to $3.1 billion in 2013 by growing 34.9% compared to previous year. They also calculated the 3D printing industry's average annual growth over the past 26 years as 27%. Low-cost personal 3D printers have constituted a significant portion of this growth during recent years (Wohlers, 2014). They expect the 3D printing industry to sustain this strong growth and reach $6 billion in 2017 and $10.8 billion in 2021 (Wohlers, 2013).

Another study by Grand View Research estimated that the global market for 3D printing was about $2.2 billion in 2012 and will reach $8.7 billion by 2020. According to this report, automotive and healthcare industries will play a key role in this increase. While North America constituted the 42% of global 3D printing market in 2012, Europe is expected to replace it until 2020 (Grand View Research, 2013). Similarly, Markets and Markets' research forecasts a 23% average annual growth for 3D printing industry between 2013-2020 and a total size of $8.4 billion by 2020 (Markets and Markets, 2013).

Gartner expected the worldwide shipments of 3D printers under $100,000 to grow 49% in 2013, 75% in 2014, and 100% in 2015. They also forecasted the consumer and enterprise 3D printer shipments to increase 95.4% from 2012 through 2017 and 3D printer market to reach $5.7 billion by 2017 (Gartner, 2013). In a comprehensive study, McKinsey Global Institute estimated that 3D printing could create an economic impact of $230 - $500 billion per year by 2025. They argue that largest source of this impact would be from consumer uses ($100-$300 billion), direct manufacturing ($100-$200 billion), and tools and mold manufacturing ($30-$50 billion) (McKinsey, 2013).

3. 3D Printing at the Game

It seems possible to utilize 3D printing virtually in all areas where physical objects are used. Most prominent examples include healthcare, manufacturing, education, construction as well as home use.

3.1. Healthcare

3D printing is highly useful in production of biomodels (models of different parts of human body like bones, dental prosthesis, etc.). For this purpose, digital model of particular part of human body is created by using either a series of images of the body or 3D scanner. Then the biomodel is created layer by layer by 3D printing technology. As the anatomy of every patient is unique, 3D printed biomodels provide valuable advantages for surgeons, like better understanding of patient's anatomy and more accurate diagnosis; improved planning, testing, and rehearsal of surgical operations; guidance during the operation and assurance of accuracy and quality; testing new medical methods and technologies; enhanced medical research, education, and training. Similarly, 3D printing is used for design and production of customized implants and prostheses in reconstructive and plastic surgery. 3D printing has also a role in production of specific medical tools like hearing aids, scaffolds, shielding masks, etc. Moreover, 3D printing can be used in fabrication of customized systems, which allows controlled and precise drug delivery, and micron-scale medical devices (Giannatsis and Dedoussis, 2009).

One of the most exciting applications of 3D printing is the production of human tissue and organs, bioprinting. Thanks to this technology, human tissue can be printed layer by layer from bio-ink, which is obtained by special treatment of human cells and other substances. Although there are still serious problems regarding stability and functionality of bioprinted structures, significant advances have been made towards obtaining fully successful human tissue and organs. Bioprinting promises valuable opportunities for drug development, testing treatments, medical research, wound healing, and even transplantation (EU, 2014). Another potential use of 3D printing in medicine may be in pharmaceutical supply chain. Pharmacies or even individuals may print their own drugs from drug compounds by using 3D printers in the future. This has potential to decrease some of the related costs and improve customization of treatment significantly.

3.2. Manufacturing Industry

Quite naturally, the manufacturing industry has been the major user of 3D printing technology. Producing parts with low volumes or complex geometries, obtaining lighter parts, eliminating raw material waste, gaining more opportunities regarding testing and design, and customization are common reasons for employing 3D printing in manufacturing environment. In addition, manufacturers can prefer 3D printing for being able to use cheaper raw materials or to ensure certain physical properties by using different raw materials together. Reduction in complexity of supply chain management due to production of some parts in-house rather than getting them from outside is another reason. As a result, 3D printing may provide opportunity for manufacturers to gain cost advantages, process and product improvements, and swiftness in particular cases.

In addition to purposes like testing, design, prototyping, and production of certain parts and some special assembly tools, the automotive industry has tried to utilize 3D printing to manufacture complete cars. In fact, a car named Urbee, which has a 3D printed body, has already been produced (Hornick and Roland, 2013). They have been working on increasing the number of 3D printed parts in Urbee, with the ultimate goal of achieving great reductions in fuel consumption.

Electronics industry is one of the early adapters of 3D printing technology. 3D printers have been used for production of complex special parts from different materials as well as styling work in this industry. 3D printing is also perfectly suited to the fashion industry, where personalization is critically important. 3D printed custom jewelry and clothes are becoming popular (Forbes, 2013).

Aerospace industry is another eager customer of 3D printing technology. Increasing number of aircraft parts, especially those with complex shapes or assembled from different parts, have been produced by 3D printers. This brings about significant advantages regarding tooling, inspection, maintenance, assembly, and inventory. Moreover, 3D printed parts enable some performance improvements like fuel saving thanks to being lighter (Wohlers, 2011). Similarly, defense industry also uses 3D printing for special manufacturing purposes, quality improvements, and cost savings. In addition to production of customized, complex, and low volume products, 3D printing has a distinct advantage for defense industry in terms of allowing fast and on demand replacement. Thanks to 3D printers, certain parts can be produced quickly whenever needed, even in battlefield (UK MOD, 2013). And after plastics ones, a metal 3D printed gun that works properly has been produced by a custom manufacturing company (Solid Concepts, 2014). Apart from these, US National Aeronautics and Space Administration (NASA) has been utilizing 3D printing technology to produce some special parts for spacecrafts. Furthermore, NASA has been working on printing objects in the space.

3D printers, or more precisely 3D food printers, have been at work for producing different kinds of food. While almost anything that has liquid or powder ingredients can be printed, chocolate and other candies are among the most popular supplies in this regard. NASA has also been working on printing food in space. Similar to human tissue printing, 3D printers are expected to be used for meat production, with a hope for offering a solution to humanity's nutritional needs (L'Atelier, 2014).

3.3. Education

In addition to medical training mentioned above, 3D printing can also be used for other educational purposes, especially regarding science, technology, engineering, and mathematics (STEMS) skills. By utilizing 3D printers, students can design and produce objects in classroom environment and, thus, find a valuable opportunity for testing ideas and learning by doing. This increases fun, teamwork, and interactivity in class as well as supporting creativity, computer skills and three- dimensional thinking ability of students. Thanks to 3D printing, students can see engineering concepts prior to higher education, and university students can comprehend the content of technical courses better. In addition to these, teachers can produce fit-for-purpose 3D objects and use them to visualize concepts or conduct experiments in the classroom (Murray, 2013).

3.4. Architecture and Construction

One of the most amazing examples of 3D printing applications comes from construction sector. Although it is in a very early phase, there have been multiple successful efforts to construct buildings by using gigantic 3D printers. Most popular materials for building printing are plastic, concrete, and sand. If it measures up, building printing may bring about improvements in terms of quality, speed, costs - especially labor costs, flexibility, modularity, work safety, and environmental effects. Furthermore, there are some thoughts on employing 3D printing technology to construct buildings on the moon (Wired, 2013). 3D printing technology can also allow for more creativity, customization, and customer involvement in architectural design.

3.5. Home Use

As the cost of 3D printing technology diminishes and it becomes easier to use this technology, 3D printers start to penetrate into homes. Desktop 3D printers provide an enormous opportunity for individuals to produce whatever they wish and at their own places, within the dimensions allowed by a desktop 3D printer and raw material possibilities. Hobby items, toys, utensils, ornamental objects are just some of the first examples coming to mind.

Thanks to desktop 3D printers, individuals can design and produce objects for their unique requirements and this paves the way for the ultimate point in personalization. This doing by yourself opportunity enhances creative and innovative potential of people. Moreover, home 3D printing relieves individuals from some of the constraints posed by traditional supply chains.

Emergence of online 3D printing platforms has an important role in dissemination of desktop 3D printers. In these online platforms, people can exchange knowledge, ideas, designs, and 3D printed objects. For example, Thingiverse allows people to download 3D printing designs freely from thousands of options as well as uploading theirs. On the other hand, Shapeways is an online 3D printing marketplace where people can buy and sell 3D printed objects. This provides opportunity for people to monetize their 3D printing capacities as well as enabling some people, who do not own 3D printers, to take advantage of others' resources.

4. 3D Printing on the National Agendas

3D printing technology has been attracting attention of several governments. Strengthening the manufacturing industry and utilizing for educational purposes are the most popular focus of government interest in 3D printing. In this section, I present prominent examples of government positions related to this area.

4.1. US

President Obama mentioned 3D printing as having "the potential to revolutionize the way we make almost everything" in his 2013 State of Union Address[3]. In fact, support of US

[3] State of Union Address is the annual speech that is given by the president of US to the Congress and that outlines upcoming legislative agenda.

government to 3D printing goes back to several decades. For example, SLS technology was developed at the University of Texas under sponsorship of US Defense Advanced Research Projects Agency (DARPA) (3D Printing, 2014).

In abovementioned speech, president Obama also touched upon National Additive Manufacturing Innovation Institute (NAMII) or with its rebranded name "America Makes". NAMII was established in 2012 as a public private partnership with the aim of accelerating 3D printing technology for the US manufacturing sector and thus increase its competitiveness. In this regard, NAMII promotes research, development, and implementation efforts; facilitates collaboration among companies, universities, and non-profit organizations; and supports education and training activities related to additive manufacturing. In 2014, NAMII would provide $9 million to applied research projects which have a total budget of $19.3 million with project owner contributions. Thus, total public and private investment in additive manufacturing within the scope of NAMII project supports would reach to $30 million (US, 2014).

National Science Foundation (NSF) is one of the major supporters of 3D printing in the US. NSF has been providing funding for research projects regarding additive manufacturing. In addition, NSF supports knowledge exchange activities and educational programs designed for students. NSF has provided $200 million (2005 dollars) for 3D printing technology between 1986 and 2012 (NSF, 2013).

Department of Defense (DOD) has also been supporting 3D printing actively and consistently through its different agencies, especially DARPA and Office of Naval Research (ONR). While NSF mostly focuses on basic and early stage research, DOD is more interested in 3D printing implementations. Furthermore, other US government agencies which have involved in 3D printing technology includes NASA, Department of Energy (DOE), Department of Commerce (DOC), National Institute of Standards and Technology (NIST), Armed Forces Institute of Regenerative Medicine (AFIRM), and National Institute of Health (NIH) (McNulty, Arnas, and Campbell, 2012).

4.2. China

While many people see 3D printing revolution as a threat to China’s advantage in manufacturing sector, China has been trying to take advantage of it quite ambitiously. In 2012, China included 3D printing technology to National High-tech Research and Development Program of Ministry of Science and Technology. In this context, Chinese government would provide $6.5 million (40 million Yuan) funding for research focused on 3D printing technology (3ders, 2013). Asian Manufacturing Association, which is a government supported chamber for manufacturing in China, has initiated the China 3D Printing Technology Industry Alliance in order to support 3D printing industry. And this alliance is planning to build 10 3D printing innovation centers in different cities of China by investing $3.3 million (20 million Yuan) for each of them (Global Times, 2013).

Moreover, in June 2013, Chinese government committed to invest $245 million (1.5 billion Yuan) in 3D printing technology during next seven years (TCT Magazine, 2013). China launched the 3D Printing Research Institute in the same year, which would receive about $33 million (200 million Yuan) initial government funding. Collaborating with academia, this institute will carry out research on 3D printing technology as well as work on commercialization and deployment activities (NOST, 2013). China also opened the world's first 3D printing museum in Beijing in 2013.

4.3. UK

In early 2014, the UK Chancellor announced that they will establish a national center for 3D printing by investing about $25 million (£15.3 million) (BBC, 2014). In fact, this is the last step of an ongoing effort. In June 2013, Technology Strategy Board (TSB), which is the UK's innovation agency along with three research councils, introduced a support program. This program envisaged a $13.9 million (£8.4 million) government support for private companies that will make investments to develop manufacturing solutions using 3D printing technology (UK, 2013). Previously in 2012, TSB launched a competition named Inspiring New Design Freedom in Additive Manufacturing. This competition was designed to provide a total of $11.5 million (£7 million) funding to collaborative research and development activities in 3D printing area (3D Printing Industry, 2012). Department of Education is also interested in 3D printing technology. In 2012-2013, a pilot project was carried out in 21 schools to examine potential use of 3D printers in STEM education. This initiative was later expanded to include 60 more schools allowing them to purchase 3D printers and train their teachers (The Telegraph, 2013).

4.4. Japan

Japanese government is among those which have realized the importance of 3D printing technology. Japan Revitalization Strategy, which was adopted in June 2013, embraces the 3D printing technology and reveals the aim of encouraging private investment on it besides other leading edge technologies (Japan, 2013). Recently, Japan's Ministry of Economy, Trade and Industry (METI) announced a plan to support the use of 3D printers in schools. METI will be subsidizing 3D printer purchases of several universities and technical colleges. This subsidy is planned to be extended to include selected middle and high schools later. In addition, METI allocated about $44 million (4.5 billion Yen) in its 2014 budget in order to support research and development activities related to using 3D printing in metal manufacturing (3ders, 2014).

5. What is at Stake?

There is a general optimism about transformative effects of 3D printing technology. The potential implications of 3D printing are being compared with those of printing press, steam engine, industrial revolution, internet, etc. While it is still quite ambiguous how profound those effects could be, it is highly probable that technical developments related to 3D printing technology and its diffusion to different areas will go hand in hand. In this section, I discuss major foreseeable issues around 3D printing technology.

5.1. Implications

Manufacturing is the primary area that is being affected from 3D printing. While 3D printing cannot completely replace traditional manufacturing, 3D printers will certainly take over some tasks that are most suitable for them similar to what robots have been doing so far. Again like in the case of robots, scope and scale of those tasks that are performed by 3D printers can enlarge as time progresses. 3D printing will also make it possible to design and produce in ways which are more efficient but were not possible with traditional manufacturing techniques. These changes can bring about efficiency and quality improvements.

3D printing may pose a threat for incumbent firms in certain industries. 3D printing lowers barriers to entry by providing opportunity to manufacture products without bearing high fixed costs, in low volumes or for niche segments. Thus new and smaller firms can try to compete with incumbents (McKinsey, 2014). As a result, not only manufacturers but also other firms that were previously involved in any phase of traditional supply chains like raw material procurement, sales, marketing, delivery, retail, etc. might be affected. In this regard, we may expect more resistance towards 3D printing in countries where big incumbent firms are very strong like in the US.

On the other hand, firms can be more flexible and responsive by taking advantage of 3D printing technology. First, firms can obtain prototypes faster and with more customer involvement (McKinsey, 2014). This will give them new possibilities to design more customized products. 3D printers can also contribute customization by allowing manufacturing of more specialized products. In addition, 3D printers can let firms to produce those customized products with costs that are not much higher than mass produced ones. Apart from these, in some instances, consumers will start to produce some goods with their own 3D printers and this basically represents the highest level of customization.

Thanks to 3D printing, make- to- order approach will be much easier both economically and technically. Firms or even consumers themselves will be able to efficiently produce products just when people want them and with desired properties. This can significantly decrease wastage arising from overproduction. Moreover, due to the nature of additive manufacturing, raw materials are added as needed to produce a part and therefore are not wasted. Hence 3D printing can help diminishing losses in manufacturing.

3D printing may change the position of production in supply chain by bringing it closer to consumers. It may promote local manufacturing instead of concentration of manufacturing in big central factories or certain countries (Atlantic Council, 2011). As production becomes closer to consumers, transportation requirements of products will decrease. Furthermore, necessity for holding inventories of finished and intermediate goods may significantly decrease since 3D printing enables production only in case of need and sometimes without intermediate goods. These will decrease costs, bring about energy savings, and benefit environment.

As 3D printers find more places in the manufacturing environment, new qualifications and skills will gain importance while some of the old ones become obsolete. 3D printing related skills can also gain popularity among individuals as 3D printers become widespread. Similar to internet cafes did in the past in some countries, online and physical 3D printing shops may play an intermediary role for large number of people to experience this new technology. Furthermore, as a result of this proliferation, both 3D printer and printing material industries can grow substantially and promise new business opportunities.

Besides these, 3D printing technology may trigger changes in global political economy by altering comparative advantages in manufacturing industry or via promoting new players that can achieve breakthroughs in this area. 3D printing can eliminate some of the labor requirements from production processes. These may harm the position of countries which have emerged as manufacturing centers by especially leveraging their low labor costs (Atlantic Council, 2011). On the other hand, those same countries have been facing with serious problems in capturing sufficient value through manufacturing supply chain in part due to their lack of design capacity. 3D printing technology can lend a helping hand to developing countries by promoting their design and prototyping capabilities and, thus, enabling them to climb up in manufacturing value chain.

3D printing can also cause cultural transformations by changing the ways people shop and consume. Finally, it is worth mentioning once again that 3D printing may conduce to solution of some of the vital problems of humanity if efforts towards printing human tissue or synthetic meat succeed.

5.2. Regulation

3D printing can have profound impacts regarding intellectual property rights (IPR) since it allows recreating objects or materializing designs. Firms may have serious difficulties while other firms and even individuals can easily replicate their products by using on hand design files or 3D scanners. CAD files of objects, which are assumed to be under IPR protection, can be shared with the whole world immediately thanks to online 3D printing platforms. It may be quite hard for both users and competent authorities to distinguish which 3D printing practices contradict IPR. Conscious IPR violations may become easier since flexibility offered by 3D printing technology enables circumventing IPR regulations. Furthermore, it can be very difficult for firms to follow and determine any violations to their IPR once 3D printers become widespread (Hornick and Roland, 2013).

3D printing will also have important implications in terms of national security. Due to similar concerns regarding protection of IPR in firm level, 3D printing can heighten conflicts over protection of national economic interests. In addition, as 3D printing technology facilitates distributed manufacturing, it is not only nice and useful things to be produced. Manufacture of other items like weapons, whose production is normally subject to control, will also reap the benefit of 3D printing. Those products can become cheaper, more accessible, and more easily concealable by help of 3D printing technology (Atlantic Council, 2011).

5.3. Limitations

Although it has been continually improved, 3D printing technology has still some way to go. First of all, 3D printing is quite slow for high volume production. In addition, 3D printing materials need to be cheaper while becoming more diversified in the meantime. Advancements regarding strength of 3D printed parts, growth of supporting ecosystem, improvements in design software, and adoption of 3D scanners are other major issues that can affect the fate of 3D printing (McKinsey, 2013).

6. What can be done?

Since 3D printing is an emerging technology, it could be a good time to move for nations in order to take the best advantage of it. In this section, I propose some policy options which can help countries to accelerate their development journeys by utilizing potential benefits offered by 3D printing technology.

- **Promoting manufacturing and design activities:**
  - ✓ In order to reinforce the manufacturing industry, adoption of 3D printing technology can be encouraged. Besides financial supports, technical assistance would be critical for this purpose, especially in developing countries. Governments can directly help creation of initial technical expertise and human capital pool in the country. Then these should be disseminated via educational and promotional activities, pilot applications, and technical guidance services.
  - ✓ Countries can choose to pursue a strategy for becoming a service hub in design and prototyping activities by leveraging advantages offered by 3D printing technology. This could open new windows of opportunity for countries that can facilitate sufficient technical and human capital capacity even if they did not have any particular advantage in manufacturing previously.
  - ✓ Countries that have already significant advantages in manufacturing but are not able to capture sufficient value due to their lack of design capacity can catch up on this by utilizing prospects offered by 3D printing technology.
  - ✓ On the basis of potential changes in comparative advantages related to manufacturing, nations can also try to become a regional production hub. 3D printing may change the decision mechanisms for where to produce by decreasing share of labor in inputs and increasing importance of customization.
- **Ensuring effective R&D support:**
  - ✓ As it is the case for other emerging technologies, 3D printing industry involves risks that might be too high to incur for private firms, especially those in developing countries. Therefore, governments can have a hand in research activities related to 3D printing technology. Support for research activities should be complemented by initiatives towards implementation and commercialization.
  - ✓ Research and development support should focus on creating 3D printing techniques that are distinct in certain respects or specialized for particular purposes.

- ✓ Research and development activities can also focus on 3D printing materials with the prospect of obtaining superior materials in terms of cost or performance as well as finding novel 3D printing materials.

- **Creating their own 3D printers:**
  - ✓ As patents related to 3D printing are expiring, there is a great opportunity to tinker on this technology. Existence of an open source culture around 3D printing can also be encouraging for such intentions. Governments can promote creation of local 3D printer brands. In addition to direct economic advantages, this would also help wide scale adoption of 3D printers by lowering domestic costs which are normally high due to importing and scarcity of suppliers.
- **Enhancing social development:**
  - ✓ While abovementioned efforts for promoting economic activities related to 3D printing technology might result in direct benefits in the near future, repercussions of wide scale adoption of 3D printing will occur more indirectly and in the longer term. As 3D printers are started to be used by many individuals, this would reinforce national competencies related to 3D printing and related areas like design and computer skills as well as creativity and innovation. With this understanding, adaption of 3D printers by public can be supported via educational and promotional activities.
  - ✓ 3D printing can be used as an effective tool to improve educational practices, especially those related with STEM. Similar to providing schools with broadband access, computers, tablets, smart boards, etc., governments can distribute 3D printers to schools. These 3D printers will not only enhance educational activities in other areas but also lay a foundation for accumulating knowledge on 3D printing technology. These could be supported by teacher trainings and related curriculum creation.
- **Carrying out balanced regulation:**
  - ✓ As I mentioned in the previous section, government intervention becomes a necessity as a result of implications arising from 3D printing technology. Since 3D printing has a potential to create profound impacts, it is normal to expect that some of the economic agents would turn out to be losers while some others would rise as winners in the course of events. In this regard, while maintaining legal rights on the one hand, governments should take brave steps in order to reap the full benefits of 3D printing technology. They should pay great attention to ensure that their interventions do not disrupt innovation which is expected to be promoted thanks to 3D printing.
  - ✓ Governments should take effective precautions to prevent illicit usage of 3D printing technology. Thus those illicit usages would not constitute an impediment for employing this technology in wider scale.

7. Conclusion

3D printing is a promising technology that has a great potential to bring about significant improvements to manufacturing sector, particularly regarding design, customization, and flexibility. 3D printing also provides valuable opportunities for almost all areas by enhancing design and creation of objects in different ways. Furthermore, wide scale adoption of 3D printers by individuals seems to be on the horizon, which would crucially empower people to make things.

In the micro level, while 3D printing promises significant advantages especially in terms of efficiency, flexibility, and responsiveness for firms, on the other hand it also brings along considerable threats for incumbents by lowering the entry barriers and making the protection of IPR more difficult. In the macro level, 3D printing may trigger changes in comparative advantages regarding manufacturing and design activities. A number of developed countries have already started to take remarkable actions in order to take the best advantage of 3D printing technology.

By supporting adoption of 3D printing technology, countries can enhance national manufacturing capabilities as well as fortifying their design and prototyping capacities. Leveraging on these, new strategies aiming at achieving superiority in design or manufacturing could be pursued. These intentions should be reinforced by financial, technical, and operational support mechanisms as well as constructive regulations.

Since 3D printing technology has a very wide application area, opportunities and issues around its usage in different fields should be studied in more detail. In addition, because each country has different endowments and advantages that can affect the best utilization of 3D printing technology, appropriate strategy, policy, and actions should be analyzed case by case.

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