



Dematerialised and re-dematerialised economy – 3D printing as a key technological and environment-friendly innovation¹

Lukasz MAMICA

**Department of Public Economics
Cracow University of Economics, Cracow, Poland**

Abstract: The development of 3D printing enables the process of direct transfer of ideas (understood as digital vectors) into physical objects using only one universal device. Later these objects could be milled and the same material reused, allowing ideas for effective re-materialisation and de-materialisation done by individual consumers who become producers. New goods could be adjusted by consumers to their individual preferences as it was in the preindustrial craft era. A process of re-localisation of de-localised production from low paid labour countries to developed ones will be observed with spatial distribution. This new order could be named re-de economy. Expiration of key patents that protected 3D technologies between 2014 and 2016 will affect the spread of these new order consequences. The article also presents an analysis of 217 students' opinions collected in selected countries (Hungary, Italy, Lithuania, Poland, South Africa, Sweden and Ukraine) regarding their attitude to this technology.

Keywords: re-localisation, industrial revolution, creative destruction, 3D printing, technological innovation

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1. Introduction

The development of IT technologies in previous decades caused a transfer of many services into the virtual sphere. Simultaneously, we observed digitalisation of a growing number of products, which are consumed by using electronic equipment but without later materialization (like computer programs, games, books, music and many others). The development of 3D printing technologies, also called rapid prototyping, solid freeform fabrication, or most commonly – additive manufacturing, allows making a three-dimensional solid object based on a digital model by joining materials layer by layer. This technology could soon lead to a new revolution in the economy compared to the invention of the steam engine. Despeisse et al. (2017) treat 3D as crucial factor of the circular economy, which allows eliminating the concept of waste. We have at our disposal not only the process of direct transfer of ideas (understood as digital vectors) into physical objects using one universal tool (3D printer), but also a possibility to reuse the same materials by simply milling them. In this way ideas could be simply re-materialised and de-materialised making space for new shapes and functions of objects. Semiotic codes connected with the role of the symbolic value that consumers derive from products typical of creative industries become the most important (Jones, Lorenzen, and Sapsed, 2015). The easiness of copying designed standard goods is connected with unknown possibilities of adjusting them by consumers to their individual needs. The global Internet network makes the process of idea transfer fast and almost unlimited. The main feature of products price, connected with scarcity, is losing its value. Previous decades were connected with transfer of goods production to developing countries, where costs of production were much smaller, and it was accompanied by a decline in jobs in the manufacturing sector. 3D printing will return production back to developed countries and what is more, it will be dispersed into individual consumers who become producers and will make home products, recycling by using mills for unnecessary or broken products. Re-localisation of de-localised production from low paid labour countries to developed ones, thanks to additive manufacturing connected with re-materialisation and de-materialisation (by milling ‘printed’ goods) of ideas, will have a great impact on current economic and consequently on social relations. This new order could be named re-de economy. The fact that the legal protection of key patents in 3D technologies expired in the years 2014-2016 will encourage a spread of these new order consequences. The article presents an analysis of 217 students’ opinions collected in selected countries (Hungary, Italy, Lithuania, Poland, South Africa, Sweden and Ukraine) regarding their willingness to use 3D printing and their attitudes to its development.

2. Market dimension of re-de economy

2.1. Independence of the final consumer

Innovations are usually profitable for their creators, often by securing a kind of short-term monopoly. The difference in the case of 3D printing is connected with the fact that it empowers the final consumers with the potential of individual goods production and reduces their long term dependency on market products. So re-de economy gives final consumers a high level of independence, which is connected with the limits of money transfer to a wide range of traditional goods producers. 3D printing, using a taxonomy of innovations proposed by Freeman (1994), could be categorised as a technological revolution which changes the techno-economic paradigm and affects the entire economy. Because of its potentially enormous impact on economic relations, the re-de economy could be a catalyst of a new wave or cycle, which was firstly described by Kondratieff (1984 [1925]). 3D printing could be the beginning of a new technological revolution that takes place after the Age of Information and Telecommunications, which was described by Perez (2002) as the fifth technological revolution. It is consistent with the assumptions of two basic features which are specific to each technological revolution, being ‘the strong interconnectedness and interdependence of the participating systems in their technologies and markets and the capacity to transform profoundly the rest of the economy (and eventually society)’ (Perez, 2009: 9).

2.2. Expiration of 3D technology patents

Although 3D technology has been available for almost 4 decades, we are just coming to the point where the price of the printer makes its purchase profitable for individual users. One of the reasons behind the expected production growth of this technology is connected with expiration of many patents crucial for it. One of the most important expired on January 2014, that is Selective Laser Sintering (SLS) patented by Carl R. Deckard (the application filed in May 1994 and the patent issued in January 1997).² Some others like Simultaneous Multiple Layer Curing in Stereolithography expired in April 2014, Method and Apparatus for Producing a Three-Dimensional Object by Stereolithography expired in June 2015, and that for Method and Apparatus for Prototyping a Three-Dimensional Object expired in December 2016.

² Currently most US patents expire after 20 years, but there are some exceptions for patents issued before June 1995.

The possible impact of additive manufacturing on the economy could be analysed in the context of 3D printers, which can be used for making their copies. Such a project entitled RepRap (Replicating Rapid-Prototyper) was initiated by Adrian Bowyer, a mechanical engineer at the University of Bath in the United Kingdom in 2005. The idea of RepRap was based on free software license under the GNU General Public Licence on the web (*Pearce 2012*). The ability to produce most parts using one's own 3D printer makes the process of self-manufacturing more independent from traditional manufacturers not only at the level of individual objects, but also at that of machine park.

According to *Wohlers Report 2015 (2015)*, in 2014 additive manufacturing services were increased by 38.9% compared to those in 2013 and achieved a \$2.105 billion market in that year. Direct parts manufacture for this kind of services in 2014 grew to 42.6% of the total product and service revenues from additive manufacturing since 2003.

2.3. Limitation of goods accumulation

The possibility of having almost any object by its copying may paradoxically result in decreasing the desire to accumulate wealth. This phenomenon will be supported, on the one hand, by a paradox formulated by Veblen (1899) at the end of 19th century, according to which consumers use objects to manifest their social status. Indeed, if anyone can copy an object then it can no longer provide information about the level of the holder's wealth. In a situation when everyone can simply print any article, the interest in purchasing it disappears anyway. The possibility of a rapid change in the form of matter by milling the object and printing of a new one should also help to reduce the number of objects in the household as a result of the elimination of unnecessary items. The product more than ever before will be 'current', limited in a period of time, with the form of that matter that can easily be changed. Universal, dispersed opportunity to copy products will compensate for the disparities in the availability to them. Access will be limited indeed to having 3D printers but minimized by the cost of transport. How universal the potential of additive printing is evident in the idea of NASA to use local material in printing buildings with cosmic dust on the moon or already completed printing objects at the space station.

The impact of 3D printing technology on the economy will grow along with the expanding possibilities to adjust the parameters of materials, from which objects will be created, to their expected functions. It will depend on the level of differentiation of the characteristics of the material (in the dimension of quality parameters, texture or colour) by mixing the

components inside the printer (by analogy with the tinting machine which is able to match colours to suit individual customer's needs). The ability to copy items that cannot be distinguished at first glance from the originals produced by traditional methods, due to lower production costs, will be a challenge to the existing production system.

2.4. Personalization of goods production

The re-de economy means a symbolic return to the days before the industrial revolution, characterized by production almost exclusively on request, so without the risk of a lack of buyers. In this way the problem of overproduction will be solved, which has always been associated with the inefficient allocation of resources and unnecessary burden on the environment. At the same time, however, 3D printing means virtually unlimited opportunity to increase the supply of certain goods manufactured outside the traditionally conceived system of manufacturing. Personalization fully adapted to the reported demand will provide a boost to the industry of 3D printers and technologies connected with it, at the expense of the wider traditional methods of production. It is clear that for a long period of time 3D printing capabilities were limited both in terms of price competitiveness compared to traditional methods of preparation and due to technological barriers (mainly related to the nature of the material used). A serious consequence of 3D printing will be reduction in the demand for labour in the manufacturing industry, especially in manufacturing of parts, which requires relatively low qualifications.

2.5. Limitation of demand for human labour

Similar to every technological revolution, 3D printing innovation generates disruptions to the market and creates problems with the relocation of labour force characterised by qualifications which do not meet new standards as mentioned. The state is perceived as the key player and regulator in the process of mitigating the effects of these changes. Minsky stressed that the evolution of the private sector's institutional structure is driven by the market and 'This evolution can undermine the barriers to instability and inefficiency' (1996: 33). Possible consequences of lower demand on labour force in a globalised economy connected with the re-de economy could require broader changes in the current system of relations between market and government as a regulator. Socialization of the risk for workers connected with new technologies implementation will probably be one of the most important challenges for

politicians. Previous approaches to managing the social consequences of creative destruction were formulated by Soros (2002) in his Report on Globalization. As a consequence of capital market liberalization, no too optimistic scenario could be developed also in a re-de economy phase, where benefits do not come to firms (except to 3D printer producers and suppliers). The possibility of common object printing and decline in prices for many materialised goods could be a mitigation tool which should partly compensate for negative consequences of temporary labour market destabilization within first phase of the re-de economy.

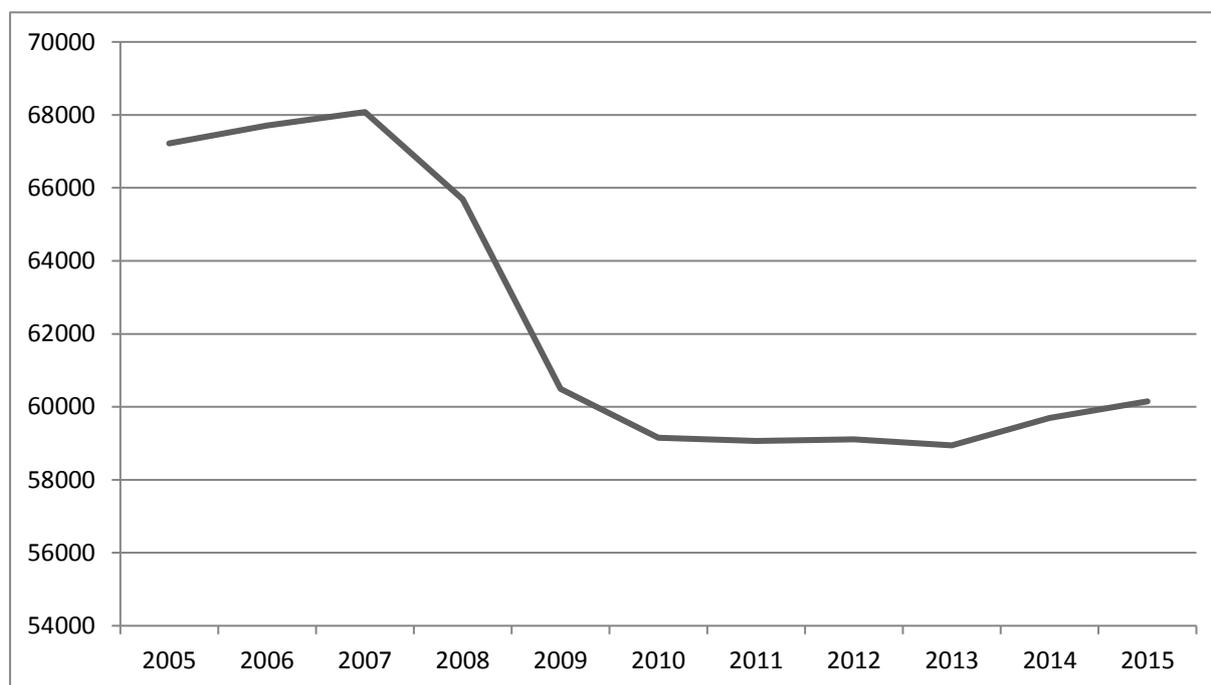
The limitation of demand for human labour connected with 3D printing can be treated as an element of a wider process of jobs replacement by computers and robots and lower demand for codified jobs (Nedelkoska 2013). The fear of losing jobs because of technological development has a long tradition, with the best example being the English textile workers named Luddites, who started breaking threshing machines in the 19th century. The problem of technological unemployment is especially important in times of crises and was even in the field of interest of Keynes who wrote ‘due to our discovery of means of economising the use of labour outrunning the pace at which we can find new uses for labour’ (1933: 3). Both robots and 3D printers, by producing goods, create substitutes for labour for which the demand is declining and which, in consequence, can lead to further decline in wages and labour force standard of living. One of the proposed solutions by Sachs et al. (2015), which could stop this process and further growth of social inequalities, is government redistribution which can ensure that the effects of productivity growth will be distributed to society, mainly to young workers, whose lack of qualifications puts them at a disadvantage in the labour market. An analysis of the probability of computerisation for 702 detailed occupations in the US showed that about 47% of the total US workforce are at risk (Frey and Osborne, 2013). 3D printing can lead to further labour polarization, which was observed at the beginning of the industrial revolution in the US (Katz and Margo 2014).

3. De-localised production

3.1. Transfer of workplaces to lower-cost labour countries

The transfer of workplaces abroad in developed countries has been observed up to now at least since the 1960s. The transfer of factories to the developing markets was connected with differences in labour costs and de-location of production processes from one country to another, also called offshoring, creating a pressure on labour markets in developed countries. It can

deprive firms and their domestic ecosystems of critical knowledge for development of innovation (Buciuni et al. 2014). The scale of offshoring directed to lower-cost labour countries increased after China gained access to the World Trade Organization in 2001 and this process was connected with transfers of capital to developed countries (although limitation of manufacturing jobs is a worldwide phenomenon and concerns even China). According to available data from OECD for 26 countries of this organisation, the average loss of jobs in manufacturing in the period 2005–2014 was about 18% (Chart 1). The highest decline of such jobs took place in Greece (by 44%), Spain (31%) and Netherlands (28%), while it increased in only three countries: Poland (by 7%), the Czech Republic (3%) and Hungary (1%). The phenomenon of increasing manufacturing potential in Central and East European countries is connected with recovery after heavy manufacturing destruction linked to the transformation from centrally managed to market oriented economy in the 1990s. Stiglitz (2001) points out that the then recommended version of financial capitalism without taking into account its consequences for enterprises was a new utopian project of social engineering very similar to the earlier process of implementation of communism.



* Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, United Kingdom, United States

Chart 1. Total employment in manufacturing in thousands of people engaged in selected OECD countries* in period 2005- 2014

Source: own calculation based on OECD data base.

3.2. Return of production to developed countries

The development of 3D printing (in this case printing means simply production) is a milestone in the process of returning production to developed countries with high labour costs. What is more, the production will not return to factories but directly to users' homes. The limited demand for standard mass production and development of new communication technologies will increase the percentage of people working on-line. The new core value of companies will be the ability to design new products sold as a digital files (Mamica, 2014). Part of this work, notwithstanding laboratories, will be able to be done by dispersed workers (but the development of computers calculation capacities makes it possible to even replace traditional experiments, for example, in the field of work on new pharmaceuticals). The re-de economy will also partly solve the problem of translocation of the 'dirty' production process abroad, which was criticised as an amoral way of creating a sustainable economy without taking into account natural environment as a one, global, interdependent system.

Delocalisation or strong distraction of production within the re-de economy in some sense connects two sectors of economy described by Toffler as production and prosumerism, it means 'one in which we produce goods for exchange, the other in which we do things for ourselves' (1980: 387). Thanks to the 3D printing technology, people could produce goods for themselves, yet using the same technology to produce goods for others, based on added value connected with their own skills of computer programming and designing. In this case the border between attitude production and own needs satisfaction is blurred. The economy is closing a symbolic cycle reminiscent of the times of the primitive man, when the majority of surrounding products were produced by him alone. The re-de economy creates an input for relocation of production. It offers a chance to return the manufacturing goods process to developed countries which transferred their production capacity to cheap labour economies. This relocation does not mean transfer of production to factories in developed countries, but creation of goods at dispersed households.

4. Re-de economy in the context of sustainable economy

4.1. Re-de economy as an answer to limits of growth

The concept of sustainable growth in a modern sense was first used by the Club of Rome in 1972 in its report on the 'Limits to Growth' (Meadows et al., 1972). One of the two characteristics of the model researched by its authors was the capability of satisfying the basic

material requirements of all people (while the second concerned preventing the world from a sudden and uncontrolled collapse). The re-de economy, through ecological, fully recyclable at home production, is offering an important tool in fulfilment of this expectation. An almost closed delocalised circle of re-production in combination with renewable energy sources could be an answer to the problem of climate change. 3D printing could be treated as an important case of eco-innovation, which is defined as the process of developing new ideas, behaviour, products and processes which contribute to ecologically specified sustainability targets and a reduction in environmental burdens (Rennings, 2000). Additive manufacturing is a radical innovation which is treated by Hellström (2007) as much more desired, if real ecological change is to be achieved. Having in mind the very important, creative role of standards in eco-innovation policy (Vollebergh and Werf, 2014) also in the case of 3D printing, we can expect in the longer-term perspective, a positive impact on environment. Dosi (2005: 2) even treats the novel ‘ways of doing things’ as fundamental drivers of the evolution of contemporary economies.

4.2. Need for new indicators of development

The re-de economy is coherent with a trend called decoupling, which means disconnection of human well-being and qualitative growth from usage of physical resources. The research of such a process is done within material flow accounting and analysis (MFA). It was developed at the beginning of the 1990s, when the first material flow accounts on the national level was done for the Austrian (Steurer 1992) and Japanese economies (Environment Agency Japan 1992). The analyses of Eurostat (2002) also confirmed that for many developed countries, growth rates are much higher for GDP than for domestic material consumption (DMC).

Because the re-de economy allows for better satisfying of some human needs by self-creation of goods rather than purchasing them, it creates pressure to look for other indicators of development than level of GDP, like Index of Sustainable Economic Welfare (Cobb and Cobb 1994). It is in common with other proposals of decoupling economic growth with social well-being, like that proposed by Haberl et al. (2004). After incurring the costs of producing 3D printers and the costs of creating the appropriate software, marginal costs of replicating the goods are at a low level. The increase in technological sophistication will allow using recycled plastics in additive manufacturing and improve waste recycling at local level (Garmulewicz et al. 2016).

4.3. Sustainable model of human needs fulfilment

The re-de economy is very close to achieving the final desired purpose in the idea of industrial metabolism. This concept, first proposed by Ayres (1989) concentrated on physical processes, which convert raw materials, energy and labour, into finished products and wastes. The flow of materials, which was at the core interest in industrial metabolism in the re-de economy process of goods production will be minimal and limited into individual households. The re-de economy will make home the new location of goods production, with very limited negative environmental impact. Thanks to simple methods of reusing the same materials (printed products can be simply milled) society can achieve benefits connected with lower costs of recycling, limitation of space needed for storage of waste and transportation of it. Such a trend is expected because of the decreasing potential of natural systems to absorb waste and emissions. 3D printing, because of elimination of transport costs, is going ahead when compared to all traditional recycling negatives. Reusing of materials and the much smaller space needed to transport material for printing compared with transport of final products will have a positive impact on delivery costs and, at the same time, will reduce the transport pollution pressure on the environment. When we add to this the development of different methods of individual energy production (like solar, or gas production from bio waste) the new model of human needs fulfilment will be more sustainable. The Internet, which will be the main channel of digitalized products distribution, will also support renewable energies productions as in the concept of ‘energy internet’ proposed by Rifkin (2011). The positive examples of progress in this matter is also observed in less developed countries like India, where the solar industry grew 200-fold in five years (Ghosh, 2015) and countries like Denmark are leading in this field (Olabi, 2014). 3D printing could also be used directly for making wind turbine modules, like in the Helix_T project realised under Creative Common license (Kostakis et al., 2013).

4.4. Decreasing role of resources in creating the value of economy

The re-de economy is a progressive step in reducing material intensity and refers to the concept of ‘factor 4’ changes proposed by Weizsacker and Lovins (Weizsacker et al., 1997) who measured such intensity as the mass of material input per dollar value. The recycling possibilities of 3D goods printing will, in a significant way, decline a national waste potential analysed in the context of determinants of material consumption (Weisz et al., 2006). Also, Høyer and Næss (2001) connect dematerialisation at the product level with the possibility of

recycling. Rodrigues et al. (2005) treat dematerialisation as an effect of innovations which contribute to resource savings. The re-de economy is in line with general trends of decoupling economic growth from environmental pressure, while living standards continue to increase with lower pressures on resources consumption. Such analyses were done, for example, for Australian economy (Schandl and Turner, 2009). Dematerialisation will be accompanied by higher concentration of designers on longevity and design for disassembly (Andrews, 2015).

The re-de economy is a next step in the observed process of diminishing the role of resources in creating the value of economy. Resource productivity for 28 EU countries measured as gross domestic product divided by domestic material consumption in Euro per Kilogram in the years 2000-2015 (Chart 2) increased from 1.3 in 2000 to 2.2 in 2015.

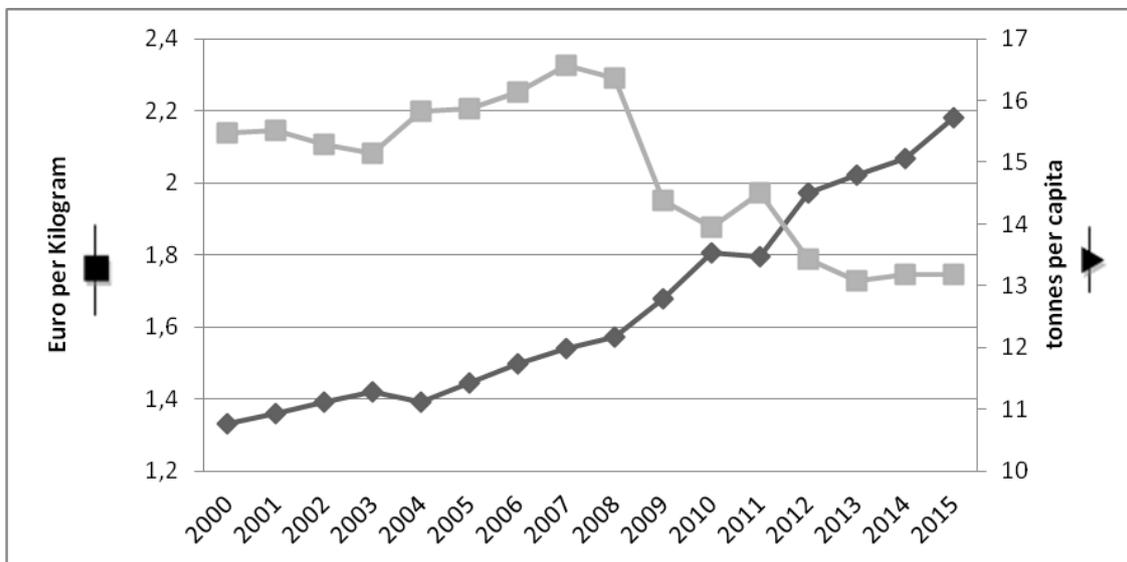


Chart 2. Resource productivity (gross domestic product divided by domestic material consumption) in Euro per Kilogram and domestic material consumption (tonnes per capita) in 28 EU countries in years 2000-2015

Source: own calculation based on EUROSTAT data base

Some signals of dematerialisation of economy are also visible when we analyse domestic material consumption (Chart 2). While in 2007 it was 16.73 tonnes per capita in 28 EU countries, in 2015 it was only 13,17, although part of this diminishing could be connected with economic crisis. Popularisation of 3D technology printing will be associated with redesigning the patterns of consumption and lifestyles also in the institutional dimension (Vezzoli et al., 2015).

In discussions about the process of minimising the amount of physical resources in creation of goods and economic values, the problem of hazardous substances used in production processes and their negative impact on environment should be remembered. In effect,

a quantitative approach should be taken into account alongside a qualitative one, which refers to the scale of a negative environmental influence of particular substances used in production processes. In this aspect, the full recycling process of 3D technology printing is an almost optimal solution in the process of avoiding hazardous substances. Generally, additive manufacturing will decrease ecological footprint (area of wilderness needed to supply resources to a human population) and ecological rucksack (the total quantity of the natural material that is disturbed in its natural setting in order to generate a product).

5. Redefinition of materialised product

5.1. Status of temporary materialised ideas for products

The role of design has considerably risen in the last decades, also without the 3D products printing. Popularization of these methods of goods manufacturing will put the design in the form of a digital file at the top of products value elements. Computer programs which will allow parameter modification of goods according to client preferences will increase the economic role of software.

The simplicity of goods creation by using 3D printers can paradoxically limit the consumption pressure in developed economies. As mentioned before, the fact that a wide range of products are available immediately and can be easily re-materialised, can bring an self-reflection of consumers about the necessity of a permanent consumption increase. Such negative aspects of a cycle of work and spending, intensified by marketing and advertising activities was identified in the American economy (Schor, 1998). In the re-de economy, products as never before get the status of materialised ideas, which as ideas could simply change their current form. When every three-dimensional shape could be printed by using the same technology, the concept rather than the material product becomes the central asset in the total value of an article. Some analogies could be observed when we compare the amount of human work which must be spent in order to produce some goods in developed and developing countries and their value for customers. In developed economies the value of products manufactured is connected with labour effort at a much smaller scale than with brand and design. It is visible when we analyse relatively low prices of high intensive handmade products imported from developed countries. The possibility of self-creation of materialised products in the re-de economy is close to the concept of creative industries, in which we have observed 'shifting the emphasis from what might be called an industrial "object" sense to what might

best be called today a post-industrial “experience” sense of human life’ (Defining ..., 2013: 85). The word ‘experience’ obtained by 3D printing technology obtains new unknown capabilities of mass scale experiments done almost by everyone at a relatively low cost.

5.2. Protection against unauthorized copying of products files

The development of 3D computer programmes will allow not only creating material objects by printing based on delivered digital files, but also copying the existing products and modifying their parameters. All this will make popular treatment of products as simple materialization of ideas, where the process of materialization takes place at home. The range of possible materials used by 3D printers will broaden the sphere of potential goods which could be created in this way. The homemade process of dematerialisation of created goods in this way will put the project as a core value of products used by consumers. Products will become artefacts, which could be easily transformed from one form to another, using the same resources in a closed chain process of production and recycling limited to home spaces. The re-de economy allows for personalisation of products as it was in the period before industrial mass production, but with a focus on consumers who partly replace the former craftsmen.

Redefinition of materialised products will increase the pressure on effective protection against unauthorized copying of files. Another fact which can decrease the profits of producers (producers of digital models) is connected not with illegal transfer of files, but with printing more goods for sale by the buyer of the original file. We can estimate that willingness to share with others results of common non-profit activities for free or within Creative Common licenses will also be popular in the case of files for object printing using 3D printing technology. So the program file will be treated almost as a final material product. The re-de economy should also be a factor of creativity growth in society as a whole in which the possibility to modify the form and the ability to easily create fully functional prototypes will be an incentive to experiments.

6. Digitalization of materialised products

6.1. Digitalization and immediate world-wide transfer

The creation of re-de economy would not have been possible without the digital revolution started in the late 1950s and strengthened by the invention of the Internet which achieved internationally accepted standards at the beginning of the 1980s. Two features of this revolution, digitalization and immediate world-wide transfer play the key role in the

development of the re-de economy. In fact, 3D printing will allow materialisation of products from digital files which are distributed by the global internet network.

Firstly, dematerialisation is associated with formation of various types of computer programs and applications that can be sent via the Internet. One of the functions of computer programs is to support the design process of material goods, whose production is, however, adapted to the existing forms of technology. In most cases automation processes are based on the control of production lines adapted to a variety of materials. 3D printing technology opens up the possibility of a closed process of production of goods, which, thanks to the use of mills, can be characterized by an unlimited number of re-combinations. Savona and Steinmueller (2013) found that innovations that re-allocate the productive and co-productive efforts of consumers and producers depend on the nature and degree of informatisation investment.

6.2. Adjusted copies of physical objects

Dematerialisation so far has mainly been connected with development of services, which were provided and consumed in a virtual, Internet-based environment. Carolan (2004) treated dematerialisation as the digital revolution by which production requires less resources than in other more material forms of production. Digitally recorded music, books and newspapers show that the value does not need to have material support. Another aspect of dematerialisation is connected with the decreasing amount of energy needed for production (Sun, 2001). Electronic transfer of money and the introduction of plastic credit cards were important steps on the way to a dematerialised economy. This process is also supported by artists, which results in creative activities that very often exist only in digital forms. The global increase in the number of the Internet users and reduction of prices for IT hardware make data and transnational information transfer available at an unprecedented level. It means that digital product designs could transfer all over the world and individually produced by 3D printing technology. Digitalization and re-materialization of products will support commons-based peer production (Benkler 2006) and strengthen open source movement. The real revolution of digitalized products is connected not with simplicity of copying them by having a digital version, but with the ability to make copies of physical objects and adjust them to one's own preferences. Some projects could be realised in open formula, where people offer their free time and skills to produce values, which are beyond the control of corporations. The already existing free available resources of cultural goods will be supported by portals, where it will be possible to find files for printing many objects. The benefits of it will not be limited to owners of 3D

printers, but there will probably be professional points of goods printing similar to modern copy centres. Digitalised products will minimise profits of traditional producers and probably increase pressure on restrictions regarding free Internet-based data transfer.

7. Manufacturing history comes full circle

7.1. Improved version of the Third Wave manufacture

The re-de economy is the fruit of the processes described by Toffler as the third wave, which was in opposition to the second wave characterised by mass production, mass distribution and mass consumption. In his book titled *The Third Wave*, Toffler writes ‘The essence of Second Wave manufacture was the long "run" of millions of identical, standardized products. By contrast, the essence of Third Wave manufacture is the short run of partially or completely customized products’ (1980: 181). 3D printing has given technological tools to implement on a large scale the postulate of fully customized products. The re-de economy could be treated as a new phase of a ‘new super-symbolic system for creating wealth’ which was proposed by Toffler (1990: 29). 3D printing technology should be treated as a technological paradigm, the term proposed and described by Dosi as “model” and a “pattern” of solution of selected technological problems based on selected principles derived from natural sciences and on selected material technologies’ (1982: 152). The effects of 3D printing will have an impact on many industrial sectors. According to Dosi ‘the dynamics of each industry influences and is influenced by the patterns of change in the other industries by means of inter-industrial diffusion of innovations’ (1984: 284). The scope of technological phases of production which could be avoided by using 3D technology compared with more traditional methods of manufacturing is in a long-term perspective, almost unlimited.

7.2. Back to preindustrial phase of production

If we divide the history of production of goods into three phases: preindustrial, mass scale industrial production³ and the re-de economy, we can observe high similarities among the first and the third phase (Table 1). Both in the preindustrial phase and in the re-de economy, the dominating type of goods production is a response to individual demand, while in the mass scale industrial production phase, production is for stock, with overproduction occurring fairly

³ Mass scale production phase was initiated in about 1760 in line with the industrial revolution was characterised by transition from manual production methods to the use of machines.

often. In effect, in the first and the third phases, adjustment to individual aesthetic preferences is very high, while in the mass scale industrial production it is low (although in recent years we have observed higher flexibility in adjusting products to individual expectations even in this phase). The ability to adjust to individual physical differences (ergonomics) was high in preindustrial phase and is high again in the re-de economy in opposition to mass scale production, where any changes in the typical shape were most expensive. The level of copying complexity was low in the first and the third phase and medium or usually high in mass scale industrial production. The difference between the preindustrial and the re-de economy phase is visible in the case of cost of short series or unique product production, which is the highest in the mass scale industrial production phase. While in the first phase it was at medium level, in the re-de economy it is really low and omitting the cost of the computer file, the unit production cost is in fact the same in case of one or many products. To sum up, we can conclude that re-de economy is offering all important advantages typical of the preindustrial phase of production with a major difference connected to the much lower price of product manufacturing.

Table 1. Comparative analysis of parameters regarding production of goods in phases of preindustrial revolution, mass scale industrial production and the re-de economy

parameters of goods production process	phases of production history	preindustrial revolution phase	mass scale industrial production phase	re-de economy
dominating type of goods production		answer to individual demand	production for stock, overproduction	answer to individual demand
adjustment to individual aesthetic preferences		high	low/medium	high
adjustment to individual physical differences (ergonomics)		high	low	high
level of copying complexity		low	medium/high	low
cost of short series or unique product manufacture		medium	high	low

There are different categorizations of technological revolutions. In one proposed by Perez (2002), between the 1770s and the 2000s we can distinguish 5 of them: The Industrial Revolution, the Age of Steam and Railways, the Age of Steel, Electricity and Heavy Engineering, the Age of Oil, the Automobile and Mass Production and the Age of Information and Telecommunications. For each of them she points one “big-bang” initiating the revolution for the first. They were as follows: the opening of Arkwright’s mill in Cromford [1771] for the first, for the second, the testing of the ‘Rocket’ steam engine for the Liverpool-Manchester

railway [1829], for the third – the Carnegie Bessemer steel plant opening in Pittsburgh [1875], the fourth – the First Model T coming out of the Ford plant in Detroit, Michigan [1908], and the fifth – the Intel microprocessor announced in Santa Clara, California [1971]. The development of a prototype system based on the process called stereolithography (addition of layers by curing photopolymers with ultraviolet light lasers) by 3D Systems Corporation in 1984 could be treated as the “big-bang” initiating the sixth technological revolution of objects printing (although the period of time from the invention to the real market impact is in this case relatively long and has not achieved a critical point up to now). So because of its spread, maybe it is better to consider the year 2014 to be the beginning of the re-de economy, when the patent for Selective Laser Sintering (SLS), regarded as one of the most important for 3D printing, expired. One of the two basic features of technological revolution pointed out by Perez is ‘The capacity to transform profoundly the rest of the economy (and eventually society)’ (2009: 9) is largely probable, but still expected. Global economy is therefore in forefront of the next critical point caused by the creative destruction process treated by Schumpeter as an ‘essential fact about capitalism. It is what capitalism consists in and what every capitalist concern has got to live in’ (2003 [1943]: 83). There is a common understanding that additive manufacturing is changing rules of the economic system. Despeisse et al. (2017) treat combination of 3D printing with new materials, Industrie 4.0 and the Internet of Things as factors which are radically changing the industrial landscape.

8. Development of 3D printing technology usage from the perspective of individual customers

8.1. Methodology of research

The study dedicated to getting information about existing and potential usage and preferences regarding 3D printing technology among individual consumers was conducted in 2016 among 217 people (64% of the respondents were women). The questionnaire survey was carried out among students in the following countries: Hungary – Miskolc University (50 respondents, 23% of the), Italy – University Roma Tre (46, 21.2%), Lithuania – School of Economics and Business at Kaunas University of Technology (22, 15.2%), Poland - Krakow University of Economics (46, 21.2%), South Africa - Stellenbosch University (19, 8.8%), Sweden - Stockholm University (14, 6.5%) and Ukraine – National University of Kyiv-Mohyla Academy (9, 4.1%). Half of the respondents were not less than 22 years old (median), the average age of respondents being 23.4 years, and the standard deviation age is 5.8 years.

8.2. Usage and intention to use 3D printing technology

3D printing technology is still a very uncommon way of goods creation. Only 6 of the respondents (2.8%) indicated that they sometimes use 3D printing, while 135 of the examined (62.2%) declared that they may benefit from this technology. 25 people (11.5%) definitely want to take advantage of 3D printing and 12 (5.5%) did not know what this technology is. As many as 22 people surveyed (10.1%) declared that they certainly do not intend to use 3D printing, and a further 13 people (6%) indicated that they will not do it. The performed statistical tests (chi2 test) showed that gender does not significantly impact the intention to use 3D technology. Statistical tests confirmed, however, that nationality has a significant effect on the intention to use 3D technology. The most enthusiastic for 3D printing are South Africans (one third of them declare that they definitely will use 3D printing), next Lithuanians (where a quarter gave such declaration), Swedish and Ukrainian (about one fifth in each group). The highest number of students who declared that they will definitely not use 3D printing technology is among Italian (about one third) and South African (one fifth).

Table 2. Intention to use 3D printing technology in the context of gender and nationality of respondents

Variables	Group							chi ²	p value
		A certainly do not	not	maybe	yes	definitely yes	lack of knowledge		
Gender	women	10	7	89	6	13	10	8.191	0.146
	men	12	6	44	2	12	2		
Nationality	Lithuanians	4	0	20	0	8	1	132.4	<0.001*
	Poles	1	0	38	0	4	3		
	South Africans	4	0	7	0	6	2		
	Swedish	0	0	10	0	3	1		
	Ukrainians	0	0	7	0	2	0		
	Hungarians	0	13	24	8	0	5		
	Italians	13	0	29	0	2	0		

note: n=217; * p - the value statistically significant

The performed statistical tests ANOVA Kruskal - Waliss (p-value <0.05) confirmed that the age of the people surveyed has a significant influence on the declared willingness to use 3D printing technology. POST-HOC (Dunn Bonferroni) showed that the age of the people who declared that they certainly do not benefit from 3D technology is significantly higher than the age of those who confirmed that they benefit from this technology.

It was also checked whether the intention to use 3D printing technology depends on the actions performed while working on a new project (Table 3). The performed statistical tests (chi2 test) confirmed such relations ($p=0.003$). In a group of respondents who declared that they like to experiment and look for non-standard solutions, the number of those who declared their intention to use 3D printing technology is by 4 percentage points higher than in the group of those who declared that they prefer to look for existing solutions to the problem, attempting to modify them. Also, the number of respondents who declared that they are not interested in using 3D technology is by 18 percentage points higher in the group who are looking only for an existing solution to the problem than in those who describe themselves as liking to experiment and look for non-standard solutions.

Table 3. Intention to use 3D printing technology and attitude to experimenting (in %).

	Intention to use 3D printing technology		
	yes	no	maybe
Attitude to experimenting			
liking to experiment and look for non-standard solutions	0.18	0.10	0.63
looking for an existing solution to the problem, attempting to modify it	0.14	0.15	0.70
looking only for an existing solution to the problem	0.15	0.28	0.47

8.3. Validity of different aspects of 3D printing

Respondents gave opinions on the importance for them of different aspects of 3D printing. The most important for them was the ability to design products, which (in the 5-point scale, where 1 means “not important” at all and 5 – “very important”) received the average mark 3.74. In the second place was the ability to fit products to the dimensions of one's own body (average mark 3.52) and in the third position – the ability to copy existing products (average mark 3.36).

The performed statistical tests (chi2 test) showed that gender does not impact significantly on the importance of various aspects of 3D printing technology but nationality significantly affects the validity of the various aspects of 3D printing.

The ability to design products by 3D technology ranked the highest among the Italian students (4.14), next – among the Polish (4.00) and the lowest - with the Swedish (2.86) and South African (3.26). The ability to personalize products (e.g. fit to the dimensions of one's own body) was the most important to the Ukrainian (3.72) and the Hungarian (3.72) students. The

most sceptical were the Swedish students (2.38). The ability to copy existing products received the highest rank in Lithuania and Italy (both 3.70) and the lowest in Sweden (2.15).

Table 4. Importance of different aspects of 3D printing in context of gender and nationality of respondents

Variable	Group	Aspect	Average importance	chi ²	p value		
gender	women	the ability to design products	3.76	3.395	0.494		
	men		3.73				
	women	the ability to copy existing products	3.38				
	men		3.32				
	women	the ability to fit products to the dimensions of one's own body	3.61			6.262	0.18
	men		3.39				
nationality	Lithuanians	the ability to design products	3.76	39.05	0.027*		
	Poles		4.00				
	South Africans		3.26				
	Swedish		2.86				
	Ukrainians		3.67				
	Hungarians		3.60				
	Italians		4.14				
	Lithuanians	the ability to copy existing products	3.70				
	Poles		3.29				
	South Africans		3.37				
	Swedish		2.15				
	Ukrainians		3.75				
	Hungarians		3.16				
	Italians		3.70				
	Lithuanians	the ability of fit products to the dimensions of one's own body	3.55			37.153	0.042*
	Poles		3.65				
	South Africans		3.26				
	Swedish		2.38				
	Ukrainians		3.88				
	Hungarians		3.72				
	Italians		3.54				

* p - the value statistically significant

8.4. Willingness to pay more for personalized products made using 3D printing compared with to similar standard products

The average tested person would be willing to pay 30.2% more for a customized product made by using 3D printing compared with a similar standard product. The lowest level of payment for personalized product was 0%, and the highest was 300%. At least 25% of the surveyed people would be willing to pay up to 10% extra for such a product, and as many as 75% of respondents would pay more, even 31.5% more than the standard product.

Table 5. The impact of gender and nationality of respondents on willingness to pay more for personalised product made in 3D technology

Variable	Group	Average	Test U	p value
Gender	men	33%	3735.5	0.531
	women	25%		
Variable	group	average	test H	p-value
Nationality	Lithuanians	20.4%	22.229	0.001*
	Poles	45.6%		
	South Africans	43.8%		
	Swedish	20%		
	Ukrainians	31.4%		
	Hungarians	19.5%		
	Italians	31.3%		

test U – U Mann-Whitney test; test H - Kruskal – Wallis test; * p - the value statistically significant

The performed statistical Mann-Whitney test ($p\text{-value} > 0.05$) did not confirm the fact that gender of those surveyed has a significant impact on the level of subsidies for customized product made in 3D. In turn, the ANOVA Kruskal-Wallis tests confirmed that nationality has a statistically significant impact on willingness to pay more for a customized product made in 3D technology. The Poles and South Africans are willing to pay the most for such a product, respectively 45.6% and 43.8%. The lowest willingness to pay more for personalised products by 3D printing technology was declared by the Hungarian (19.5%). The performed statistical tests ($p\text{-value} > 0.05$) did not confirm the assumption that age significantly affected the level of payments for personalized products.

9. Contribution and conclusion

This study offers a perspective on changes in current industrial production order, which will be sped up by the expiration of key patents protecting 3D technologies between 2014-2016.

It analysed a new de-localised production system in which products, as never before, get the status of materialised ideas, which as ideas could simply change their current form. Products will be created locally, with much lower environmental costs. The development of displaced renewable energy sources will support de-localised production. The re-de economy is offering all important advantages typical of the preindustrial phase of production, with a major difference connected with a much lower price of product manufacturing. The new order will be characterised by high product personalisation and easy copying of products. The ability to protect intellectual property will determine the capacity of profit creation by firms. Although 3D printing is still used by a marginal percentage of interviewed young consumers, two-thirds of them (62.2%) declared that they may benefit from this technology. Statistical tests have confirmed that nationality has a significant effect on the intention to use 3D technology. The age of students who responded that they certainly do not benefit from 3D technology is significantly higher than the age of people who responded that they do benefit from this technology. Students who declared that they like experimenting and looking for non-standard solutions declared more often the intention to use 3D printing technology. The most important aspect of this technology is connected with the ability to design products and later the ability to personalize them. People are ready to pay extra for goods created in 3D printing technology, 75% of the respondents would pay more, even about one third more (31.5%) compared with the price of a standard product. Nationality has a statistically significant impact on willingness to pay more for customized products made using 3D technology.

10.Limitations and Future Research

3D printing technology is still a relatively rarely used method of goods production, so its current impact on real production processes is marginal. However, this research shows the big interest of potential users in this technology and their willingness to pay more for goods created in such a way. As in the case of almost every new machine, and especially one dedicated to individual customers, its costs in the initial phase considerably hamper price competition with former production methods. A rise in the usage scale minimises its costs and improves this technology. The real impact of 3D printing technology on the economy will depend on the price of printers, possible new materials for creation of goods and access to files of projects. These processes should be monitored. Especially interesting is the development of home production by additive manufacturing, which will probably have the highest impact on the spread of this

technology and the highest market impact because of possible labour costs reduction, especially important in developed countries.

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**ZDEMATERIALIZOWANA I RE-ZDEMATERIALIZOWANA GOSPODARKA -
DRUK 3D JAKO KLUCZOWA INNOWACJA TECHNOLOGICZNA
PRZYJAZNA DLA ŚRODOWISKA**

Streszczenie

Rozwój technologii druku 3D umożliwia proces bezpośredniej zamiany idei (rozumianych jako wektory cyfrowe) w obiekty fizyczne przy użyciu tylko jednego uniwersalnego urządzenia. Obiekty te mogą następnie zostać przetworzone za pomocą procesu mielenia i przyjąć nową formę przy wykorzystaniu tego samego materiału. Daje to możliwość re-materializacji i dematerializacji wykonywanej przez indywidualnych konsumentów, którzy stają

się jednocześnie producentami. Nowe towary mogą być dostosowywane przez konsumentów do ich indywidualnych preferencji, tak jak to było w erze przedprzemysłowej. Ten nowy porządek można nazwać relokacją zdematerializowanej produkcji z krajów o niskich kosztach wytwarzania do państw wysokorozwiniętych. Wygaśnięcie kluczowych patentów chroniących technologie 3D w okresie od 2014 do 2016 r. wpłynie na rozprzestrzenianie się następstw nowego porządku. W artykule przedstawiono również analizę 217 opinii studentów w wybranych krajach (Węgry, Włochy, Litwa, Polska, RPA, Szwecja i Ukraina) dotyczących ich stosunku do technologii druku 3D.

Słowa kluczowe: re-lokalizacja, rewolucja przemysłowa, twórcze zniszczenie, druk 3D, innowacje technologiczne

Kody JEL: O14, O31, Q55

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