Additive Manufacturing
A social sciences perspective

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Societal issues

The wider public is increasingly seeing robotics and increased automation, including additive manufacturing, as a threat to job security

Concerns over privacy and sensitive data (e.g. medical field)

AM enables **co-creation and consumers that act as designers and producers** posing copyright and IP issues

Paulo Bartolo's presentation 4th February 2020

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Technological innovation in AM

Changes in production processes and techniques

Increases efficiency, flexibility and customization/ differentiated products

Reduction of: waste of materials, production stages, time to market, costs related to inventory management, logistics and communication

- labour saving seems not to be the economic incentive for the adoption of AM

Technological innovation and employment
Product or process innovation?

Process innovation

Direct effect of the introduction of new technologies on employment levels is expected to be negative, but possibly counterbalanced by indirect effects, related to the demand side

The direct effect on total labour demand also depends on how technology affects different types of labour (e.g., skilled vs. unskilled, male vs. female, across age cohorts) and their substitutability with the other factors of production

Change the relative demand for *skilled* vs. *unskilled* workers or between different tasks

- Obsolete skills and new skills needed
- Changes in occupation composition

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Technological innovation and employment

Indirect effect

Increase in the demand for a firm’s goods and, therefore, in production, sales and employment

Increase in the demand and production in those industries producing the new machines, but increased efficiency in sectors where the new machines are adopted should reduce costs and, at least to some extent, prices, thus increasing demand, production and employment

When technological change concerns the introduction of new final products or components, the demand channel is the prevailing one, since it results in new markets

These positive indirect effects of innovation on employment can be mitigated if new machines or new goods substitute the old ones, and/or markets are imperfectly competitive – in this case, lower costs only partially trigger price reductions

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Patent data for business and management research

Analysis of international competitiveness in AM

Patterns of producers and users of AM

Text mining and machine learning of patent documents to analyse cognitive interdependences and capabilities

- Patent data analysis allows mapping the ecosystem around 3D printing (i.e., software, post-processing, new materials, composites, powders)

- Patent document analysis can lead to classify information on the invention, descriptions of the features of the invention, the claims (breadth or scope of the invention) which determine the boundaries of the patent protection

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Patent data analysis

IPC class B33 in PATSTAT, created in 2015 to include all innovations associated with AM processes, apparatus, materials, ancillary equipment and software, as well as products made via 3D printing, i.e., all aspects of the technology not covered elsewhere in the IPC classification (WIPO, 2019)

"manufacturing of 3D objects by additive deposition, additive agglomeration or additive layering, e.g. by 3D printing, stereolithography or selective laser sintering" (USPTO, 2017)

Early patents: stereolithography by 3D Systems (1986) and fused deposition modelling (FDM) by Stratasys (1992), identified as earliest commercial sellers of 3D printers and earliest surviving members of the 3DP ecosystem

Table 1. Count of Additive Manufacturing Patent Families by Country and Year, Period 1999-2016

Country	Patent Count	Year	Patent Count
AUS	20.6	1999	45.7
AUT	10.9	2000	50.9
BEL	37.2	2001	52.0
CAN	63.2	2002	58.8
CZE	2.5	2003	54.5
DEU	383.9	2004	68.0
DNK	17.4	2005	62.0
ESP	42.3	2006	60.7
FIN	11.5	2007	59.6
FRA	95.3	2008	87.4
GBR	149.1	2009	69.9
GRC	0.3	2010	104.9
HUN	1.0	2011	132.5
IRL	4.0	2012	175.7
ISL	1.0	2013	352.9
ISR	59.5	2014	697.0
ITA	39.4	2015	934.0
JPN	577.1	2016	686.1
KOR	99.8		
LTU	1.0		
LUX	1.0		
MEX	1.3		
NLD	63.5		
NOR	4.6		
NZL	4.0		
POL	6.3		
SVK	0.6		
SVN	1.2		
SWE	51.8		
TUR	0.5		
USA	2000.7		
Total	3752.6	Total	3752.6

Notes: This table reports additive manufacturing patent families allocated to each country and year. Data refers to the period 1999-2016. Data on patent families were obtained from PATSTAT data set. Countries in our sample, which are not shown here, report zero applications for AM patent families.

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3D Systems and Stratasys

	3D systems	Stratasys
Founding date	**1986**	**1989**
First patented technology	*"Apparatus for Production of Three-dimensional Objects by Stereolithography"* Patent 4575330A (1986)	*"Apparatus and Method for Creating Three-dimensional Objects"* Patent 5121329 (1992)
IPO date	3 June 2011	20 October 1994
Headquarters	Rock Hill, South Carolina,United States	Eden Prairie, Minnesota, United States / Rehovot, Israel
Founder	Chuck Hull (currently CTO)	S.Scott Crump (currently Chairman)
CEO	Vyomesh Joshi (4Apr2016)	Ilan Levin (1Jul2016)
Key Mergers & Acquisitions	2014 Cimatron ($97m) — Design software Simbionix ($120m) — Medical simulation and training solutions 2013 Xerox's 3D Passets ($32.5m) 2009 Acu-Cast Technologies (undisclosed)—custom manufacturing 2001 DTM($45m)—3D Printing	2015 Econolyst (undisclosed)—Strategic consultancy 2014 GrabCAD ($100m)—Design software 2014 Solid Concepts & HarvestTech. (undisclosed)—custom manufacturing 2012 Objet($634m)—3D printing, resulted in creation of Stratasys Inc. 2011 Solidscape—($38m) Aerospace Manufacturing 1995 IBM's 3D Passets ($0.5m and 0.5m shares in Stratasys)
Technologies	Stereolithography (SLA), Selective Laser Sintering (SLS), Color-Jet Printing (CJP), Multi-Jet Printing (MJP), Direct Metal Printing (DMP)	PolyJet, Fused Deposition Modelling (FDM)
Revenue 2016	$633 million	$696 million
Market Capitalization 2017	$1.022 billion	$1.155 billion
R&D as a % of revenue	3.4%	3.5%

Impact of AM on the organization of production and innovation

Changes in the process for designing products

Transformation of both the number and the nature of parts and components, and the interdependencies among them, i.e., the product architecture

General Electric (“GE”) used 3D printing technology to redesign (core components of) its airplane engines—objects that had been architecturally stable for decades. In 2015, GE introduced an engine in which 12 components replaced 855 in the previous model. A fuel nozzle tip went from having 20 components to having just one

These changes have implications for firms’ boundaries and product strategies, as well as positioning and value appropriation

Entire supply chains might disappear because of such changes, with obvious employment implications. New ecosystems may emerge

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Patented vs. Open source 3D Printing technology

In 2004, in UK, Dr Adrian Bowyer launched an *open-source* 3D printer project: the RepRap (self-replicating rapid prototyper), capable of manufacturing the majority of its own component

Open-source innovation includes more participants than proprietary or closed-source innovation within firms, and it is less encumbered by intellectual property issues

Thus the trajectories of improvement are steeper than in traditional manufacturing technologies. Improvements are essentially continuous, as new designs are published almost daily

- *Reprap.org* introduced unique versions of the Darwin 20 times between 2006 and 2009, 41 times in 2010, and 99 times in 2011

Patented 3D technology	**Open source 3D technology**
Multi-year technical evolution	Weekly improvements
Plastic 3-D printers > $ 20k+	RepRaps < $ 400–3k
Proprietary feedstock (even when it is common plastic)	Wide variety of feedstock (even waste plastic)

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Global Value Chain in AM

Factor costs differentials / Labour arbitrage (country-specific)

If the labour input in additive manufacturing is relatively modest, wage differentials would play a minor role
Shift in the capital / labour cost ratio
Relocation of (A) manufacturing to advanced countries

Scale economies (firm-specific)

Traditional manufacturing and price competition require large production scale for manufactured goods (such as white goods, domestic appliances, sport shoes, and laptops, typically produced in global value chains)

If the minimum efficient technical scales are significantly lower for additive manufacturing than for traditional production, then scale economies would no longer constitute a pivotal cost advantage in manufacturing

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Product differentiation and customization (users side)

3D printers can produce extremely high variety without additional manufacturing costs

The customizability of open-source 3D printers makes the creation of very small batches possible, opening up the possibility of business models catering to customers who desire highly distinct prints (i.e., personalized applications)

New skills needs: software programmers with technical knowledge

Closer interaction between marketing department with (new) product design/ R&D

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GVC and Technological Inseparability

3D printing technology creates “whole” products with few intermediate goods, thereby eliminating the need for assembly and reducing the need for intermediate goods

3D printing often allows raw materials to be converted directly into finished goods

Value chains are affected by how many intermediate goods must be included

AM of finished goods implies existing value chains become more compressed, reducing alternatives for allocating tasks across a set of independent producers

Shorter global value chains – less global?

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Financing innovation in AM

Role of different types of investors

Corporate venture capitalists (CVC) versus independent VCs (IVC)

Drivers and locations of 3D printing investments

- Wages – do investments go more to high wage countries?
- Does availability of human capital/ skilled/ highly educated workers matter?
- CVC and IVC and the geography of investments: are they international?