Is 3D Printing an Enabling Technology for Manufacturing Reshoring?

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Abstract Technologies embodied in the "Industry 4.0" concept are expected to heavily influence the competitiveness of countries, industries and companies. In this scenario, one of the most relevant technological transformations is represented by additive manufacturing technologies (AMTs). According to some scholars and practitioners, the adoption of such technologies may have a relevant impact on the location of production activities of many manufactured goods. This paper aims to verify the hypothesis that AMTs may act as an enabling technology for manufacturing reshoring, i.e., repatriation of (in-/outsourced) production activities earlier offshored. The paper adopts an explorative research approach based on secondary data belonging to the Uni-CLUB MoRe Reshoring dataset, containing information on more than 700 manufacturing reshoring decisions implemented by companies headquartered in the main Western countries. Based on such a dataset, eight companies were selected since they based their reshoring decisions on the adoption of AMTs. Findings from the analyzed case studies seem to confirm adoption of such technologies may contribute to the firm's decision to repatriate production in the home country. At the same time, AMTs seem to influence the firm's decision in terms of governance mode.

Keywords Reshoring · Additive manufacturing · 3D printer · Manufacturing · Case study

1 Introduction

The "Industry 4.0" scenario is attracting increasing interest from scholars, practitioners and policy makers. Technologies embodied in the "Industry 4.0" concept are expected to deeply influence the competitiveness of countries, industries and

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companies. In this scenario, additive manufacturing technologies (AMTs) are expected to promote the most relevant technological change.

Terms such as additive manufacturing (AM), 3D printing (3DP), rapid manufacturing, digital manufacturing, direct manufacturing, and generative manufacturing (Ebert et al. 2009; Holmström et al. 2010; Hopkinson and Dickens 2001; Vinodh et al. 2009) are generally used synonymously (Oettmeier and Hofmann 2016). In the rest of the paper the terms AMTs and 3D technologies (3DTs) will be used to refer to a combination of general purpose technologies (Garrett 2014; Kothman and Faber 2016) which build a product layer-by-layer based on its digital representation (Berman 2012). After years where 3DTs have been used mainly for rapid prototyping purposes, now they are more and more affecting the value chain as a whole.

According to some scholars and practitioners, the adoption of 3DTs may have a relevant impact on the location of production processes of many manufactured goods (Berman 2012; D'Aveni 2013; Gress and Kalafsky 2015; Laplume et al. 2016). Actually, such processes are often organized according to a global value chain (GVC) approach; i.e., distinct production stages with value being added in several different countries. In recent years, the dynamics of GVCs are becoming more pronounced and we can observe a diversified set of strategic decisions in terms of location of manufacturing activities. After decades of offshoring strategies, recently industrial companies have been deciding to revise their decisions in terms of manufacturing activities' locations. Among other alternatives (such as further offshoring and near-reshoring), they are also considering the manufacturing reshoring option, i.e., the repatriation of production to the home country, independently of the governance mode (insourcing vs. outsourcing) (Fratocchi et al. 2014).

The paper aims to verify the hypothesis that 3DTs may act as an enabling technology for manufacturing reshoring. In order to investigate this topic, the following research questions are considered:

(a) *Do benefits characterizing AMTs (e.g., high product customization, small production lot) adequately match motivations pushing companies to reshore their manufacturing activities to the home country (e.g. proximity to customers, R&D vicinity to production)?*
(b) *Are 3DTs and reshoring decisions diffused in the same set of industries?*
(c) *Does AMT adoption influence the governance mode (insourcing vs. outsourcing) of the reshored manufacturing activities?*

In order to shed light on such research questions, an explorative approach based on secondary data will be implemented, referring to evidence collected in the Uni-CLUB MoRe Reshoring dataset (Ancarani et al. 2015; Fratocchi et al. 2014, 2015a, b, 2016). This dataset contains information (e.g., home/host country, motivations, governance mode) belonging to more than 700 manufacturing reshoring decisions implemented by companies headquartered in the main Western countries. Based on such a dataset, eight companies were selected since they implemented their manufacturing reshoring decisions after adopting 3DTs.

Findings from the analyzed case studies seem to confirm the idea that AMTs may contribute to the firm's decision to repatriate production to the home country. At the same time, such technologies seem to influence the adopted governance modes after reshoring implementation.

The rest of the paper is divided into four main sections, the first of which is focused on the literature review. More specifically, three research streams are investigated and summarized: (a) reshoring definition and motivations; (b) benefits offered by AMTs and their diffusion among industries; and (c) the impact of 3DTs on the supply chain (SC). In the second section the adopted methodology is presented, while in the third the research findings are presented and discussed. Main conclusions—including managerial and policy implications—are provided in Sect. 4.

2 Literature Review

2.1 Manufacturing Reshoring

In recent years, the topic of manufacturing reshoring has gained momentum in the popular and specialized press (Booth 2013) and in reports by consulting firms (Sirkin et al. 2012; The Boston Consulting Group 2013). In times of global crisis, policy makers of several Western countries have seen reshoring as a partial solution to reduce unemployment rates (Tate 2014), and as a means to support re-industrialization (Pisano and Shih 2009, 2012).

An increasing number of scholars have been investigating this topic since 2007 (for an up-to-date literature review, see, among others Fratocchi et al. 2016 and Stentoft et al. 2016). Most of the extant literature is focused on defining and positioning the phenomenon (Ellram 2013; Fratocchi et al. 2014; Gray et al. 2013) and pinning down its underlying motivations (e.g. Ellram et al. 2013; Foerstl et al. 2016; Fratocchi et al. 2016; Kinkel 2014; Stentoft et al. 2016). With respect to the definition of manufacturing reshoring, a certain consensus has apparently been reached regarding many of its distinctive features—although a few of them remain (e.g., governance mode and countries where manufacturing activities are reshored). In this paper the author assumes as a reference the conceptualization proposed by Fratocchi et al. (2014) who define the phenomenon as "a voluntary corporate strategy regarding the home country's partial or total re-location of (in-sourced or out-sourced) production to serve the local, regional or global demands." In other words, manufacturing reshoring is a reverse decision with respect to an earlier implemented offshoring; therefore it may be conceptualized as a possible step of a nonlinear firm's internationalization process (Fratocchi et al. 2014, 2015a; Vissak 2010; Vissak and Francioni 2013; Vissak et al. 2012).

The identification and analysis of the reasons why firms decide to repatriate manufacturing activities are among the most common topics in reshoring studies;

therefore, a vast and varied array of motivations have been identified by scholars (for up-to-date literature review, see Bals et al. 2016; Fratocchi et al. 2016; Stentoft et al. 2016). Recently, Fratocchi et al. (2016) identified 38 distinct motivations, drawn either from the extant literature on reshoring or from drivers declared by companies sampled in the Uni-CLUB MoRe reshoring dataset. This dataset will be adopted in this paper for investigating the proposed research questions; therefore its main features will be analyzed in depth in the methodological section.

The last issue of the manufacturing reshoring literature relevant for the aims of this paper is represented by the governance mode implemented after the repatriation decision. As earlier noted, scholars do have not a unanimous position on this issue. More specifically, some authors only consider the case of reshoring choices coupled with insourcing strategies. The misleading interpretation regarding reshoring and insourcing originates from the diffused idea of commonalities among offshoring and outsourcing firm decisions (Mudambi and Venzin 2010). In this respect, Arlbjørn and Mikkelsen (2014) acknowledged that decisions about governance mode are conceptually independent of locational decisions, but they can be practically combined with the reshoring decision. Similarly, Bals et al. (2016) stated reshoring and insourcing are "interconnected" decisions. However, Gray et al. (2013) clearly pointed out that decisions regarding manufacturing locations (e.g. offshoring vs. reshoring) and governance mode (in-sourcing vs. out-sourcing) are two different managerial decisions. Therefore, they identified four alternative typologies of reshoring strategies: in-house reshoring, reshoring for outsourcing, reshoring for insourcing and outsourced reshoring. More recently, Bals et al. (2016) and Foerstl et al. (2016) enlarged this classification to include the cooperation alternative (e.g. joint ventures, strategic partnerships and long-term contracts) among the governance modes, thus identifying six alternatives, including the four proposed by Gray et al. (2013).

2.2 Additive Manufacturing

AMTs have been developed since the 1980s and were generally adopted for rapid prototyping, i.e., a fast build-up of prototypes and mock-ups. However, over the past few years, 3DTs have been increasingly adopted for producing industrial parts in several industries (Oettmeier and Hofmann 2016). Finally, they are also used for so-called "bridge manufacturing", i.e., a first small series of the product in order to launch it on the market. After product demand rises, more "traditional" manufacturing technologies are implemented (Berman 2012). The huge diffusion of AM among manufacturing companies is confirmed by large sales of industrial-grade 3D printers: according to D'Aveni (2015), such technologies represented one-third of the entire volume of industrial automation and robotic sales.

Compared to other, more "traditional" manufacturing technologies—such as milling and injection molding—AMTs offer distinct advantages. In order to investigate them, it is useful to group them according to the following categories:

(a) Cost: refers to the production process costs and the possibility to economically realize specific typologies of products (e.g., small lots);
(b) Customer: concerns issues impacting on the customers' perceived value;
(c) Design/product features: refers to the benefits related to the product design phase (excluding costs) and the product technical characteristics;
(d) Eco-sustainability: concerns a reduction in waste and energy consumption.

Table 1 summarizes the breakdown of benefits cited in the extant literature according to the proposed categories. Design/product feature and Costs are the two most cited categories of 3DT benefits. With respect to the former (design/product issues), some authors suggest that in the future 3DTs will make customers able to directly print products with their own 3D printers after downloading the design online. In this way the consumer also assumes the role of producer evolving to the prosumer role (Kothman and Faber 2016; Mohr and Khan 2015). This, according to Berman (2012), will be the third and final evolutionary phase of 3DTs. Regarding production costs, D'Aveni (2015) reports that General Electric Aviation will reduce its manufacturing costs of fuel nozzles for jet engines since AM permits them to directly produce a final product earlier, which is composed of 20 separately cast parts.

The manifold set of advantages offered by AMTs induces companies to adopt them in several industries, both in business-to-business and business-to-consumer contexts. In Table 2 industries cited in the academic extant literature are summarized. Firms' case studies cited in these academic sources show that technologies under investigation are adopted in different Western countries, though US evidence is more diffused. In this respect, Gress and Kalafsky (2015) recall that according to industry experts, the US is expected to remain the largest 3DP market until 2020 when Europe will become leader in terms of total sales of such technologies.

Further insights, in terms of diffusion of 3DTs, were recently offered by Laplume et al. (2016) who classified sectors in terms of their readiness to implement such technologies:

(a) already adopting AMTs on a large scale (5 out 24 ISIC sectors);
(b) expected to adopt them in the near future (10);
(c) not adopting (presently and in the near future) (9).

Comparing the classification proposed by Laplume et al. (2016) with the findings summarized in Table 2, it seems those authors assumed a more restrictive approach, such as in the case of aerospace and automotive industries (both expected to adopt investigated technologies only in the near future) which are already highly cited in the extant literature.

AMTs are expected to have a huge impact on business activities inducing scholars to classify them as "revolutionary" (Goulding et al. 2013), "disruptive" (Berman 2012; D'Aveni 2015; Hyman 2011; Kothman and Faber 2016; Rylands et al. 2016), "game-changing" (Kothman and Faber 2016) and even "magical"

Table 1 Benefits of 3D technologies

Benefit category	Benefit	Reference
Cost	Reduction of production costs (especially for small batches) since no object-specific tools are needed	D'Aveni (2015), Mellor et al. (2014), Petrick and Simpson (2013), Rylands et al. (2016)
Cost	Reduction of production costs since assembling is no longer required	D'Aveni (2015)
Cost	Possibility to economically manufacture complex and unique parts	Berman (2012), Holmström et al. (2010), D'Aveni (2015), Cohen et al. (2014), Petrick and Simpson (2013), Rylands et al. (2016)
Cost	Less waste material, reducing costs and improving the firm's eco-sustainability	Khan and Mohr (2016), Kothman and Faber (2016), Janssen et al. (2014), Mellor et al. (2014), Mohr and Khan (2015)
Customer	Possibility to economically offer customized outputs	Cohen et al. (2014), Petrick and Simpson (2013), Mellor et al. (2014), D'Aveni (2013, 2015), Mohr and Khan (2015)
Customer	Enabling printing at point of purchasing/consumption	D'Aveni (2013), Mohr and Khan (2015), Petrick and Simpson (2013), Rylands et al. (2016), Tassey (2014)
Customer	Shortening lead times and lowering inventories since (printing "on demand")	D'Aveni (2013), Petrick and Simpson (2013), Mellor et al. (2014), Mohr and Khan (2015)
Design/Product features	Rapidity in design changes	Berman (2012), D'Aveni (2015), Mellor et al. (2014), Mohr and Khan (2015)
Design/Product features	Increased freedom of design	D'Aveni (2013), Cohen et al. (2014), Mellor et al. (2014), Mohr and Khan (2015), Petrick and Simpson (2013), Rylands et al. (2016)
Design/Product features	Improve the optimization and integration of mechanical, thermodynamic and electrical functions of products	Glasschroeder et al. (2015)
Design/Product features	Possibility to produce lightweight objects (grids and hollow structures)	Petrovic et al. (2011)
Design/Product features	Building in a single piece objects formerly composed of several subcomponents	D'Aveni (2015)
Eco-sustainability	Improve eco-sustainability of final products (e.g. lighter automobiles or airplanes will be more fuel-efficient)	D'Aveni (2015)
Eco-sustainability	Less waste material, reducing costs and improving the firm's eco-sustainability	Khan and Mohr (2016), Kothman and Faber (2016), Janssen et al. (2014), Mellor et al. (2014), Mohr and Khan (2015)

Table 2 Industries adopting additive manufacturing

Industry/Product	Reference	Firms	Firm's home country
Aerospace	Atzeni and Salmi (2012)	Boeing	USA
	Mellor et al. (2014)	Lockheed Martin	USA
	D'Aveni (2015)	Aurora Flight Science	USA
	Gress and Kalafsky (2015)	General Electric Aviation	USA
	Oettmeier and Hofmann (2016)		
Automotive (including parts)	Ruffo et al. (2007)	Red Bull F1 team	Austria
	Bradshaw et al. (2010)	BMW	Germany
	Cooper et al. (2012)	Honda	Japan
	Mellor et al. (2014)		
	D'Aveni (2015)		
Camera lens accessories	Bradshaw et al. (2010)		
Construction	Kothman and Faber (2016)		
Electronics (including PCs)	Mellor et al. (2014)	Google (for outsourced consumer electronics products)	USA
	Gress and Kalafsky (2015)		
	D'Aveni (2015)		
Filter and filtration solutions	Rylands et al. (2016)	Anonymous company	UK
Food processors (replacement parts)	Bradshaw et al. (2010)		
Footwear	Berman (2012)	Timberland	Turkey (at the time Italy)
Household (replacement parts)	Bradshaw et al. (2010)		

(continued)

Table 2 (continued)

Industry/Product	Reference	Firms	Firm's home country
Houseware	Berman (2012)	Alessi	Italy
Lighting	Mellor et al. (2014)	LUXeXcel	The Netherlands
	D'Aveni (2015)		
Medical & dental applications (e.g. Dental crown, Hearing aids molds, Prosthetic limbs)	Berman (2012)	Align Technology	USA (worldwide HQ Netherlands)
	Mellor et al. (2014)	Anonymous company	Germany
	D'Aveni (2015)	Anonymous company	Switzerland
	Oettmeier and Hofmann (2016)		
Measurement devices	D'Aveni (2015)		
Sunglasses	D'Aveni (2015)		
Telecom infrastructure	D'Aveni (2015)		
Wallpaper	Rylands et al. (2016)	Anonymous company	UK

(Massis 2013). The disruptive potential of such technologies was clearly evident in the US hearing aid industry where companies "converted to 100% additive manufacturing in less than 500 days […] and not one company that stuck to traditional manufacturing methods survived" (D'Aveni 2015). Among the issues influenced by the disruptive nature of 3DTs, supply chain management (SCM) activities are the most relevant according to the extant literature.

2.3 Additive Manufacturing Technologies and the Supply Chain

Oettmeier and Hofmann (2016) state that research addressing AMTs may be classified in six autonomous streams; one of them investigates such technologies in the context of SCM. More specifically, authors assume 3DTs have an effect on all the three elements comprising an SC (Lambert 2014):

(a) network structures: i.e., the member firms and their interconnections;
(b) processes: regarding activities producing a specific output (e.g., supplier relationship management, manufacturing flow management);
(c) components: belonging to methods implemented to integrate and manage business processes across the SC (e.g., IT infrastructures).

Consequently, AMTs influence not only the firm adopting them but also its suppliers and customers. This has relevant consequences, among others, for governance mode (make vs. buy) and location (home vs. host countries). With respect to the former (governance mode) there is no convergence among scholars. For instance, Berman (2012) maintains that AM adoption induces firms to prefer outsourcing, since product designs are easy to share. D'Aveni (2015) shares such an expectation, pointing out the potential role of "platforms", such as eBay, Autodesk and 3D Systems (the first company to commercialize 3D printers). In contrast, Ruffo et al. (2007) found the make option to be preferred, not only in terms of mere production costs but also of logistics costs and delivery time.

The impact of AM on the geographical location of manufacturing activities was deeply discussed in the extant literature; however, scholars do not share the same position in this respect. Some of them point out that 3DTs will greatly reduce the need for labor, especially in the (almost total) absence of the assembling phase. Therefore, low wage countries will lose their competitive advantage, while shipping times and costs for producing offshore will remain (Berman 2012; D'Aveni 2013; Kianian et al. 2015). However authors' positions partially differ in terms of product typologies—for instance, Berman refers only to those manufactured in small lot sizes and time span. Kianian et al. (2015) expect manufacturing repatriations only in the near future. At the same time, Mohr and Khan (2015) suggest that the adoption of 3DTs will permit a quick response to changes in customer demand both in terms of volume and product features. Therefore, it is preferable to locate production activities in the home country, reducing lead times, which in turn mitigates the risk of product obsolescence. However, their expectations are related only to small volume productions of goods having high technological features.

On the other hand, Gress and Kalafsky (2015) maintain that at least large batch and cost-sensitive productions will still remain in low cost countries. The same choice should be implemented for the final assembly of consumer electronics products and cars, since they allow longer lead times. However, the same authors suggest small batch specialized or customized consumer products may be relocated to the home country.

Finally, D'Aveni (2015) states that firms adopting AMTs will decide where to print their products "in real time, adjusting shifts in foreign exchange, labour costs, printer efficiency and capabilities, materials, energy costs and shipping costs".

3 Methodology

The earlier conducted literature review clearly shows the relevance of research questions addressed in this paper:

(a) *Do benefits characterizing AMTs (e.g., high product customization, small production lot) adequately match motivations pushing companies to reshore their manufacturing activities to the home country (e.g. proximity to customers, R&D vicinity to production)?*
(b) *Are 3DTs and reshoring decisions diffused in the same set of industries?*
(c) *Does AMT adoption influence the governance mode (insourcing vs. outsourcing) of the reshored manufacturing activities?*

Yin (1994) states that the research strategy to be adopted must be chosen on the basis of three elements: (a) type of research question; (b) extension of investigator control over investigated behavioral events; and (c) nature of events with respect to the time dimension (historical vs. contemporary). Since there is limited empirical evidence on the research questions investigated in this paper, this research is exploratory in nature. At the same time, the analyzed events are contemporary and the investigator has no control over them. Therefore, a research methodology based on secondary data is well suited to meet the requirements of answering the proposed research questions. This research methodology was already applied both in International Business and in Operations Management research (Roth et al. 2008; Yang et al. 2006). Among sources of secondary data, a specific role is played by written records such as newspapers and magazines, which have been considered particularly useful when no other sources are available (Cowton 1998; Franzosi 1987; Mazzola and Perrone 2013). This might be the case of manufacturing reshoring, since the unit of analysis is often at the product or component level (rather than at the firm level) and therefore public secondary data are difficult—if not impossible—to obtain (Gray et al. 2013). Moreover, Judd et al. (1991) state that written records, such as newspapers, are suitable sources for longitudinal and multi-country studies. This is confirmed by Yang et al. (2006) who found that 20 empirical articles published in six leading international business journals from 1992 to 2003 adopted samples based on newspapers articles.

Secondary data adopted to investigate the proposed research questions belong to the “Uni-CLUB MoRe reshoring” developed by five Italian Universities (Catania, L’Aquila, Udine, Bologna and Modena & Reggio Emilia). To the best of author’s knowledge, the Uni-CLUB MoRe dataset is the most relevant in terms of the number of single reshoring decisions and home/host countries. This dataset has already been adopted in several researches on such a phenomenon (Ancarani et al. 2015; Fratocchi et al. 2014, 2015a, b, 2016) since it contains evidence of manufacturing reshoring decisions implemented—or at least announced—from 2011 to the end of 2015. Information was gathered from several sources: historical archives of relevant national and international business newspapers (e.g. Wall Street Journal, Financial Times) and business magazines (e.g. The Economist, TIME, Bloomberg

Businessweek); white papers by major consulting companies (e.g. Boston Consulting Group, McKinsey, Accenture); and the only public database currently available (www.reshorenow.org). For each observation, information was recorded on the company involved; company size; industry; headquarters country of origin; year in which backshoring strategy was implemented; year in which offshoring strategy was implemented; "abandoned" host country; declared motivations for backshoring; greenfield versus merger and acquisition entry mode. In order to avoid misinterpretation of the text, each observation was reviewed by two independent researchers of the group and cross-validated. In case of different positions, a third researcher was involved.

At the end of 2015, manufacturing reshoring decisions sampled in the dataset totaled 728 belonging to 600 companies, since some of them implemented more than one decision (from to two to six). Reshoring firms are widespread among 29 home countries, of which 21 are placed in North America and Europe, confirming that this is mainly a phenomenon belonging to Western countries. With respect to host countries, almost one half (350) of the sampled decisions belongs to China and the other 84 the rest of Asia. In terms of industries, firms belong to 22 manufacturing sectors but the first five account for more than half (370) of the total amount of firms' decisions (Table 3).

Reshoring motivations were declared by more than three out of four sampled companies; such firms cited from one to ten different drivers. Among these drivers, eight firms explicitly cited the adoption of AMTs (Table 4).

Finally, with respect to the governance mode adopted before and after the manufacturing reshoring decision, the majority of sampled firms do not implement any change. More specifically, 385 out of 661 decisions (for which governance mode data are available) prefer to maintain the insourcing mode, while 138 continue to outsource their production activities even after repatriation (Table 5).

In order to investigate the first proposed research question (eventually matching 3D benefits and reshoring motivations) a two steps approach will be implemented:

(a) first of all, each driver included in the dataset is compared with the benefits of 3DTs found in the extant literature. This will permit the author to verify—at a general level—if AM has the potential to support reshoring strategies;
(b) secondly, attention will be focused on the eight companies declared to have adopted 3DTs. More specifically, the reshoring motivations they cited will be compared with AM benefits reported in the extant literature. In so doing, a more fine-grained check will be implemented to shed new light on the research questions under investigation. In order to enrich the knowledge of the eight companies, further secondary data were collected from annual reports, firms' Internet sites and other news sources.

The main features of the sampled companies are summarized in Table 6. It is worth noting that only one company (Nomiku) limited the reshoring decision to the prototyping activities; other companies also repatriated series production. All the sampled firms reshored from China and Taiwan, confirming the available findings on host countries (Fratocchi et al. 2015a; Kinkel 2014). Six of the sampled

Table 3 Breakdown of reshoring companies by industry

NACE Code	Sub-code	Description	No. Of decisions	% of total decisions
26		Manufacture of computer, electronic and optical products	97	13.3
27		Manufacture of electrical equipment	78	10.7
14		Manufacture of wearing apparel	67	9.2
28		Manufacture of machinery and equipment n.e.c.	64	8.8
32	Other manufacturing		64	8.8
	32.1	Manufacture of jewelry, bijouterie and related articles	2	
	32.2	Manufacture of musical instruments	5	
	32.3	Manufacture of sports goods	11	
	32.4	Manufacture of games and toys	23	
	32.5	Manufacture of medical and dental instruments and supplies	10	
	32.9	Other manufacturing n.e.c.	13	
29		Manufacture of motor vehicles, trailers and semi-trailers	53	7.3
25		Manufacture of fabricated metal products, expert machinery and equipment	50	6.9
15		Manufacture of leather and related products	49	6.7
22		Manufacture of rubber and plastic products	42	5.8
30		Manufacture of other transport equipment	35	4.8
31		Manufacture of furniture	32	4.4
10		Manufacture of food products	22	3.0
20		Manufacture of chemicals and chemical products	19	2.6
21		Manufacture of basic pharmaceutical products and pharmaceutical preparations	11	1.5
23		Manufacture of other non-metallic mineral products	11	1.5
13		Manufacture of textile	10	1.4
24		Manufacturing of basic metals	9	1.2
17		Manufacture of paper and paper products	5	0.7
16		Manufacture of wood and of wood products and cork, except furniture	4	0.5
11		Manufacture of beverages	3	0.4
18		Printing and reproduction of recorded media	2	0.3
12		Manufacture of tobacco products	1	0.1
Total			728	100.0

Source Uni-CLUB MoRe reshoring dataset

Table 4 Motivations declared by reshoring companies

#	Reshoring motivation	No. of decisions
1	Logistics costs	136
2	"Made in effect"	124
3	Offshored production poor quality	122
4	Labor costs differentials' reduction	103
5	Total cost of ownership	101
6	Increasing service level	97
7	Lead time	82
8	Government aids	69
9	R&D vicinity to production	68
10	Firm's global reorganization	68
11	Coordination costs foreign units	63
12	Minimum size lot	40
13	Host country HR inadequacy	33
14	Global economic crisis	29
15	Organizational flexibility	28
16	Walmart incentives (only for US firms)	26
17	Emotional elements (e.g. patriotism)	17
18	Trade mark counterfeiting	16
19	Availability of production capacity at home	15
20	Host market low attractiveness	15
21	Social pressure at home country (e.g. unions)	12
22	IP issues	12
23	Duties for re-import	10
24	Process automation/New production technologies	9
25	Energy costs	8
26	Adoption of 3D technologies	8
27	Absence of suppliers in the host country	6
28	Eco-sustainability	3

Source Uni-CLUB MoRe reshoring dataset

Table 5 Governance mode adopted by reshoring companies

Ex ante versus Ex post governance mode	Number of decisions
IN–IN	385
IN–OUT	4
IN IN & OUT	2
OUT–IN	132
OUT–OUT	138
n.d.	67
Total	728

Source Uni-CLUB MoRe reshoring dataset

Table 6 Characterization of reshoring companies adopting 3D technologies

Year of reshoring	Company name (Group Holding)	Home country	Product line	Host "left" country
2013	Element 14	UK	Computers (Raspberry Pi)	China
2013	Brinsea Product	UK	Egg incubators	China
2013	Maxx Sunglasses	USA	Sunglasses	Taiwan
2014	Nomiku	USA	Kitchen appliance for sous vide cooking technique	China
2014	Thinklabs Medical	USA	Medical stethoscope	China
2014	Inertia Racing Technology Wheels	USA	Bicycle components (carbon based wheels)	Taiwan
2016	Superstar Components	UK	Bicycle components (pedal sets)	China
2017 (planned)	Reebok (Adidas Group)	USA (D)	Athletic shoes	China

Source Uni-CLUB MoRe reshoring dataset

companies are small in terms of employees, while Element 14 belongs to the UK retailer group Premier Farnell (listed on the FTSE) and Reebok is part of the German Adidas Group listed at the "Deutsche Börse" stock exchange in Frankfurt. This finding clearly shows ATMs are affordable for both large and small/medium enterprises, since 3D printers' costs have dramatically fallen in recent years.

With respect to the second research question (industry matching) the two steps research method described earlier is implemented with some adjustments. Specifically:

(a) first of all, the eventual matching among industries cited in AM literature and those sampled in the adopted dataset is verified. After this, industries characterized for the presence of both phenomena will be evaluated in terms of their magnitude, i.e., the relevance of reshoring decisions made by them with respect to the total repatriation decisions;
(b) attention will then be paid to the eight companies declaring to have adopted 3DTs, whose industries will be verified by those of the extant literature.

With respect to the governance mode, attention will be directly paid to the sampled companies, verifying the eventual changes in governance mode between the offshoring and reshoring phases.

4 Results

Referring to the first research question, Table 7 summarizes the results of the comparison between reshoring motivations and AMTs benefits. Findings shows that eight out of 28 motivations sampled in the Uni-CLUB MoRe reshoring dataset are matched by at least one of the 3DTs benefits cited in the extant literature.

Table 7 Comparison among reshoring motivations and AM benefits

#	Reshoring motivation	3D benefit (literature review)	Other explanations
1	Logistics costs		Adopting AM assembling is no longer required, the number of components will decrease reducing transportation needs
2	"Made in" effect		The product is printed in the home country so it may benefits from the "made in" effect
3	Offshored production of poor quality		Additive manufacturing may assure product quality and its replicability
4	Labor costs differentials' reduction	Reduction of production costs since assembling is no longer required	
5	Total cost of ownership	Reduction of production costs (especially for small batches) since no object-specific tools are needed	
		Reduction of production costs since assembling is no longer required	
		Possibility to economically manufacture complex and unique parts	
		Reduced waste material, reducing costs and improving the firm's eco-sustainability	
6	Increasing service level	Possibility to economically manufacture complex and unique parts	
		Rapidity in design changes	
		Enabling printing at point of purchasing/consumption	
		Possibility to produce lightweight objects (grids and hollow structures)	
7	Lead time	Shortening lead times and lowering inventories since (printing "on demand")	
8	Government aids		Some countries developed a specific policy to support diffusion of AM technologies (see, for instance, Gress and Kalafsky 2015; Kianian et al. 2015; Rylands et al. 2016)

(continued)

Table 7 (continued)

#	Reshoring motivation	3D benefit (literature review)	Other explanations
9	R&D vicinity to production	Rapidity in design changes	
		Increased freedom of design	
		Improve the optimization and integration of mechanical, thermodynamic and electrical functions of products	
		Possibility to produce lightweight objects (grids and hollow structures)	
		Building in a single piece objects formerly composed of several subcomponents	
10	Firm's global reorganization		
11	Coordination costs foreign units		For instance, those related to coordination among R&D, engineering and production in the design phase (Berman 2012; D'Aveni 2015; Mellor et al. 2014; Mohr and Khan 2015)
12	Minimum size lot	Reduction of production costs (especially for small batches) since no object-specific tools are needed	
13	Host country HR inadequacy		
14	Global economic crisis		
15	Organizational flexibility	Rapidity in design changes	
16	Walmart incentives (only for US firms)		
17	Emotional elements (e.g. patriotism)		
18	Trade mark counterfeit		
19	Availability of production capacity at home		
20	Host market low attractiveness		

(continued)

Table 7 (continued)

#	Reshoring motivation	3D benefit (literature review)	Other explanations
21	Social pressure at home country (e.g. unions)		
22	IP issues		
23	Duties for re-import		
24	Process automation/New production technologies		
25	Energy costs		
26	**Adoption of 3D technologies**		
27	Absence of suppliers in the host country		
28	Eco-sustainability	Improve eco-sustainability of final products (e.g. lighter automobiles or airplanes will be more fuel-efficient)	
		Reduced waste material, reducing costs and improving the firm's eco-sustainability	

Moreover, for another four drivers the matching is deduced on the basis of the technical features of 3DTs; for instance, the possibility of reducing/eliminating assembling activities determines the reduction in transport costs for components, supporting the "logistic costs" reshoring driver. At the same time, the possibility to print directly in the home country, permits companies to benefit from the so-called "made in effect", i.e., the higher value customers recognize when products are manufactured in a specific country. Finally, national government aids to promote the adoption of AMTs were cited by several scholars (Gress and Kalafsky 2015; Kianian et al. 2015; Rylands et al. 2016). Therefore, it seems there is a relevant overlapping between reshoring motivations and 3DTs' benefits in at least half the analyzed cases. In this respect, it must be noted that such an overlap is referred to in nine out of the ten most relevant motivations in terms of reshoring firms' citations. Consequently, it seems—at least at a general level—that AM may represent an enabling technology for manufacturing reshoring.

In order to verify such a finding from a more fine-grained perspective, it is useful to pay particular attention to motivations (other than 3DTs adoption) declared by eight firms belonging to the Uni-CLUB MoRe reshoring dataset (Table 8). The most cited reshoring driver (five out eight companies) is lead time; this finding is particularly interesting since this driver is one of the most cited in both the extant literature on AMTs (D'Aveni 2013; Mellor et al. 2014; Mohr and Khan 2015; Petrick and Simpson 2013) and in the dataset evidence (15% of total decisions for which motivation was available). The relevance of this motivation is confirmed by the magnitude of time savings declared by investigated companies: for instance, Superstar components (operating in the bicycle industry) had a shift from 7/8 months to a few days while Brinsea Products went from 16 weeks to one week. The impact of such a time reduction on the firm's competitiveness is easy to evaluate.

A further reshoring motivation declared by the eight sampled companies belongs to more strategic issues. More specifically, two companies pointed out that AMTs not only make it possible to reshore their manufacturing activities but also to modify their product range and/or their market positioning. More specifically, Max Sunglasses—initially operating in only the sunglasses business—diversified its product assortment to include chess sets and gift items. At the same time, Superstar components—initially a niche high price manufacturer—enlarged its customer targets to become an affordable alternative to low-cost Taiwanese contractors. This finding is coherent with the most recent debate regarding manufacturing reshoring, where some scholars stated that such a decision is "more than just a geographical shift of operations. It is also a reconfiguration of systems" (Mugurusi and de Boer 2014, p. 275) and/or a firm's strategy redefinition (Grandinetti and Tabacco 2015).

Focusing attention on the second research question, Table 9 summarizes the results of comparisons, in terms of industry diffusion, of the two investigated phenomena: AMTs and manufacturing reshoring. Data clearly show a complete overlapping in eight out of the ten more relevant industries in terms of reshoring evidence. At the same time, it is confirmed that the Laplume et al. (2016) expectations, in terms of adoption time of 3DTs, are quite restrictive with respect to the extant literature and theoretical findings.

When considering the eight sampled companies, the huge variety of applications of AMTs is confirmed once more. Such firms offer seven different typologies of products, since two compete in the same business (bicycle components) (see Table 6). They belong to five different industries since Brinsea Products and Nomikou both belong to the "Manufacturing of electrical equipment group" (NACE Code 27). All five industries are among the ten most relevant in terms of number of manufacturing decisions according to evidence from the Uni-CLUB MoRe reshoring dataset. Therefore, a diffused matching in terms of industries among the two analyzed phenomena seems confirmed.

The last investigated research question is regards the governance mode, i.e., the choice among insourcing and outsourcing in both the offshoring and reshoring phases. As pointed out earlier, in the extant literature there is no convergence among scholars. At the same time, empirical data regarding reshoring manufacturing induce us to expect that companies do not change their governance mode while transferring manufacturing activities back to the home country. Quite unexpectedly, analysis of the eight companies offers totally different evidence. More specifically, in the seven cases for which data are available (excluding

Table 8 Reshoring motivations declared by companies adopting 3D technologies

Reshoring motivation	Brinsea Product	Element 14	Inertia Racing Tech.	Max Sunglasses	Nomiku	Reebok (Adidas Group)	Superstar components	Thinklabs
Lead time	x	x		x		x	x	
Strategic elements (e.g. diversification strategy)				x			x	
Interactions R&D/Engineering/Manufacturing					x			X
Higher product innovation					x			X
Made in effect		x						
Lower stock holding	x							
Difficulties in insuring overseas activities	x							
Prototypes’ costs			x					
Control over the production process							x	
Proximity to customers						x		
Production costs						x		

Table 9 Comparison among manufacturing reshoring and AM technologies diffusion among industries

NACE Code	Sub-code	Description	No. of decisions	% of total decisions	Industries/Products cited in AM literature	Diffusion according to Laplume et al. 's (2016) classification
26		Manufacture of computer, electronic and optical products	97	13.3	YES (several products)	In the future
27		Manufacture of electrical equipment	78	10.7	YES (Lighting, Domestic appliance)	In the future
14		Manufacture of wearing apparel	67	9.2		In the future
28		Manufacture of machinery and equipment n.e.c.	64	8.8		Today
32	Other manufacturing		64	8.8		Today
	32.1	Manufacture of jewellery, bijouterie and related articles	2			
	32.2	Manufacture of musical instruments	5			
	32.3	Manufacture of sports goods	11			
	32.4	Manufacture of games and toys	23			
	32.5	Manufacture of medical and dental instruments and supplies	10		YES	
	32.9	Other manufacturing n.e.c.	13			
29		Manufacture of motor vehicles, trailers and semi-trailers	53	7.3	YES	In the future
25		Manufacture of fabricated metal products, expert machinery and equipment	50	6.9	YES (Houseware)	In the future
15		Manufacture of leather and related products	49	6.7	Yes (Footwear)	Never

(continued)

Table 9 (continued)

NACE Code	Sub-code	Description	No. of decisions	% of total decisions	Industries/Products cited in AM literature	Diffusion according to Laplume et al. 's (2016) classification
22		Manufacture of rubber and plastic products	42	5.8	YES (Filters)	Today
30		Manufacture of other transport equipment	35	4.8	YES (Aerospace)	In the future
31		Manufacture of furniture	32	4.4		In the future
10		Manufacture of food products	22	3.0		In the future
20		Manufacture of chemicals and chemical products	19	2.6		Never
21		Manufacture of basic pharmaceutical products and pharmaceutical preparations	11	1.5		In the future
23		Manufacture of other non-metallic mineral products	11	1.5		Today
13		Manufacture of textile	10	1.4		Never
24		Manufacture of basic metals	9	1.2		Never
17		Manufacture of paper and paper products	5	0.7	YES (wallpaper)	Never
16		Manufacture of wood and of wood products and cork, except furniture	4	0.5		Never
11		Manufacture of beverages	3	0.4		Never
18		Printing and reproduction of recorded media	2	0.3		In the future
12		Manufacture of tobacco products	1	0.1		Never
Total			728	100.0		

Brinsea Products), the governance mode adopted during the offshoring phase was outsourcing; on the other hand, after the manufacturing reshoring all companies shifted to the insourcing alternative.

5 Conclusion

In this paper the eventual contribution of 3DTs to the manufacturing reshoring phenomenon has been investigated. Due to the lack of earlier studies on this issue, an explorative research approach was adopted based on secondary data. More specifically, three research questions were developed, the first of which is regarding the eventual relation between AMTs' benefits and manufacturing reshoring motivations. The latter were defined on the basis of an in-depth literature review (see reference in Table 1), while the former were extracted by the most up-to-date and internationally widespread available dataset on reshoring decisions (Uni-CLUB MoRe reshoring). A further investigation was then developed, analyzing the eight cases of companies belonging to the dataset which declared having implemented 3DTs. Findings of both analyses provided evidence that there is a large overlap among 3DTs' benefits and reshoring motivations.

The second research question is regarding the eventual homogeneity among the industry diffusion of two investigated phenomena: 3DTs and manufacturing reshoring. Also in this case, findings based on the analysis of the extant literature (see reference in Table 2) were compared with both the information contained in the manufacturing reshoring dataset and that of the eight sampled companies. A diffused overlapping among these three elements was also found in this case.

Finally, the third research question is regarding the eventual changes in governance modes implemented in the offshoring and reshoring phases. While AM scholars did not reach a homogeneous theoretical position (e.g. Berman 2012; D'Aveni 2015; Ruffo et al. 2007), evidence from the dataset supports the idea that no changes are generally implemented. On the contrary, evidence deriving from the eight case studies shows the adoption of 3DTs induces the re-insourcing of the manufacturing activities after the reshoring implementation. This finding could, at least partially, be explained by the size of the investigated companies, i.e., mainly small ones. More specifically, it is possible to speculate that AMTs—which generally do not require huge investments—make production technically and economically feasible for such a type of company, since there is virtually a total absence of scale economies with respect to more "traditional" technologies (adopted in the offshoring phase). As a consequence, when adopting 3DTs and reshoring production activities, firms are induced to re-insource them.

The main limitation of this paper is the impossibility to generalize findings, due to its explorative nature. However, it does shed new light on an under-investigated topic which seems very relevant for both International Business and International Operation Management scholars. In this respect, AM and manufacturing reshoring phenomena are expected to influence the competitiveness of industrial companies in the near future. Further research should be implemented in order to enlarge evidence and reach more generalizable findings.

In terms of implications, those regarding policy makers seem to be particularly relevant. In the extant literature there are several examples of national policy supporting the diffusion of 3DTs (see, among others, Gress and Kalafsky 2015; Kianian et al. 2015; Rylands et al. 2016). At the same time, there is evidence also of various legislations supporting manufacturing reshoring (Bailey and De Propris 2014a, b; Fratocchi et al. 2015b; Guenther 2012; Livesey 2012). In analyzing such policies, some communality emerges, such as aids for human capital building and/or incentives for renewing production systems. Therefore, an effort should be implemented to integrate these two types of public policy.

Finally, with respect to managerial implications, it must be pointed out that the decision making and implementation phases are extremely critical for both the strategic decisions: adoption of AMTs (Rylands et al. 2016) and manufacturing reshoring (Bals et al. 2016). Therefore managers should develop specific decision supporting tools; among them, the Total Cost of Ownership (Ellram 1995) seems to be one of the most useful approaches.

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