

## Additive Manufacturing in SMEs: Empirical Evidences from Italy

Giacomo Marzi<sup>\*‡</sup>, Lamberto Zollo<sup>†§</sup>, Andrea Boccardi<sup>†¶</sup>  
and Cristiano Ciappei<sup>†||</sup>

*\*Lincoln International Business School  
University of Lincoln, Lincoln, UK*

*†University of Florence  
Department of Sciences for Business and Economic  
Florence, IT*

*‡gmarzi@lincoln.ac.uk*

*§lamberto.zollo@unifi.it*

*¶andrea.boccardi@unifi.it*

*||cristiano.ciappei@unifi.it*

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Research on innovative technological methods in SMEs' production processes is progressively receiving attention. However, little is known about the emerging phenomenon of additive manufacturing (AM), which may represent a significant strategic lever for fostering a company's competitiveness and performance, especially for SMEs. Our aim is to investigate the effects of AM on SMEs' production process, in order to better understand the relative outcomes of such an innovative technique. We used latent content analysis for empirically analyzing SMEs present in one of the most important Italian gold jewelry districts. Our findings suggest that the AM introduction in a company's production process effectively results in many positive outcomes, such as process innovation, customer satisfaction, costs, revenues, profits, and competitive advantage. Specifically, there is a positive linkage between AM and a company's performance. Hence, such an innovative technique may be interpreted as a viable growth strategy for SMEs. Theoretical and managerial implications are discussed.

*Keywords:* Additive manufacturing; 3D printing; 3DP; process innovation; product innovation; new product development; SMEs; competitiveness; case study; Italy.

### 1. Introduction

Additive manufacturing (AM) represents a recent technological innovation that is attracting growing interest from manufacturing firms and is proving to be viable in different sectors. Although AM in manufacturing environments is increasingly gaining attention, pertinent literature has addressed this type of innovation almost exclusively from a technical point of view, and only within an engineering perspective [Lee *et al.* (2005); Dimitrov *et al.* (2006)].

The study of AM as a process innovation in manufacturing firms can help broaden the literature in this area of research, since this type of innovation appears to be less developed than product innovation [Becheikh *et al.* (2006); Reichstein and Salter (2006); Taifi *et al.* (2012); Marzi *et al.* (2017)] and the current literature posits that AM is one of the most disruptive processes of the current decade [Reeves *et al.* (2011); Sealy (2011); Petrick and Simpson (2013)]. Thus, the effects of introducing AM in firms' production processes have not been adequately studied. To fill such a literature gap, the present research aims to explore the impact of AM on manufacturing SMEs' competitiveness and performance. Notably, this study aims to verify whether the introduction of AM can determine the typical effects of process innovations in the following ways: (1) to promote product innovation; (2) to improve productivity; (3) to improve competitiveness [Martinez-Ros (1999); Reichstein and Salter (2006); Hall *et al.* (2009)]. Regarding practical implications, the goal of this study is to increase the awareness of managers about the importance of such an innovation and its effect on SMEs [Linder *et al.* (2003)].

This paper is composed of five sections including this introduction. In Sec. 2, the authors introduce the phenomenon of AM showing how such technology may be configured as a process innovation for SMEs. In Sec. 3, after highlighting the significance of the sample and why it was chosen, the methodology is presented by way of a qualitative analysis of case studies through latent content analysis. The analysis led to the following six conceptual themes: process innovation, cost, value offered to the customer, revenue, profits, and the competitive advantage. The six conceptual themes resulting from this analysis explain the effects of AM on SMEs; the impact of AM on craftsmanship growth and competitiveness in SMEs is particularly emphasized. Consequently, in examining the effects of this technology on these aspects, it is possible to understand the overall effects of AM on SMEs. Finally, Sec. 4 highlights the main conclusions along with managerial implications and the limitations of the present work.

## 2. AM as an Innovation Process

### 2.1. *The innovation process*

Management scholars traditionally stress how innovativeness is crucial for firms' performance and survival [Damanpour (1991); Smith and Tushman (2005); Knight and Cavusgil (2004)]. There is broad recognition that the introduction of innovative products and processes fosters the ability of organizations to enter into or create new markets by satisfying the demand of customers [Smith and Tushman (2005)]. This is an essential requirement to sustain a competitive position in an increasingly technologically advanced environment [Li *et al.* (2013)]. For this purpose, acquiring new information and knowledge is fundamental to the creation of innovative products and services in firms [Katila and Ahuja (2002); Knudsen and Levinthal (2007)]. The innovation process requires the development of new products and services, along with the identification and the exploitation by the management of innovative changes that progressively allow the firm's sustainability in a competitive environment [Katila (2002); Witt (2009); Maggitti *et al.* (2013)]. As a consequence, it is clear that innovation has an effect on both behavior and organizational relationships, as well as on strategies and firm processes [Li *et al.* (2013)].

The literature regarding innovation focuses on the identification of possible classifications regarding this concept [Miller and Miller (2012)]. The most famous are: (1) the distinction between administrative innovation or technical developments concerning the organizational process involved [Kimberly and Evanisko (1981); Damanpour (1991)]; (2) the differentiation between product innovation or process innovation regarding the specific object of innovation [Utterback and Abernathy (1975)]; (3) the distinction between incremental innovation and radical innovation, relative to the level of technological advancement imprinted within the organization [Ettlie *et al.* (1984); Dewar and Dutton (1986); Nord and Tucker (1987)].

The second distinction between product and process innovation is considered especially fundamental to the pursuit of competitive advantage, and will be one of the primary focuses of the present research [Hull *et al.* (1985); Sorli and Stokic (2011)]. While product innovation is related to new products and services introduced into the market, usually to meet latent needs of consumers [Ettlie *et al.* (1984); Damanpour (1991)], process innovation refers to new elements introduced in the firms' operations and production processes such as new materials, equipment for firms' inputs, information flow, and work tasks [Utterback and Abernathy (1975); Damanpour (1991)]. The latter typology of innovation represents the object of study of the present research.

For the purpose of this study is also important to remark that innovation fosters firms' growth, internationalization, and performance and this effect are both visible in large firms and SMEs [Sapienza *et al.* (2006)]. In particular, recent literature has widely focused on innovativeness in SMEs [Ruzzier *et al.* (2006); Siqueira and Cosh (2008)].

Enhancing innovativeness in SMEs is crucial for the economic development of community and regions [Jones and Tilley (2003)], and it fosters strategic alliances and collaborations between such firms [Kleinknecht and Reijnen (1992); Narula (2004)]. Laursen and Salter [2004] found that innovation is present in SMEs as well as in large-size firms, especially concerning radical modernization. Intriguingly, Lee *et al.* [2010] stressed how open innovation is essential for SME's development, arguing that: "Where large firms focus mainly on R&D in open innovation efforts, SMEs focus more on commercialization because, while many of them have super-iorities in technology for invention, they often lack the capacity in terms of manufacturing facilities, marketing channels, and global contacts to introduce them effectively to the innovation market" [p. 291; see also Laursen and Salter (2006)]. The incidence of open innovation on SMEs has recently been analyzed by Van de Vrande *et al.* [2009], who find that small firms are increasingly achieving a noticeable role in modern innovation scenarios. Notably, the authors stress how "innovation in SMEs is hampered by a lack of financial resources, scant opportunities to recruit specialized workers, and small innovation portfolios so that risks associated with innovation cannot be spread. SMEs need to heavily draw on their networks to find missing innovation resources" (p. 426). In-line with these results, Chang *et al.* [2011] proposed several assumptions concerning such a topic, pointing out that: (a) the development and improvement of knowledge increases both explorative and exploitative innovative ability of the firm; (b) high levels of dynamism and

competitiveness are positively correlated with the SME's innovation; (c) innovation in SMEs represents a partial mediator between the dynamic and competitive environment and the firm's performance (p. 1663). It thus emerges that innovativeness is crucial for SME's organizational, technological, and strategic development. However, due to the specific features characterizing SMEs, managers have to be aware of the risks and boundaries linked to applying technological advances in the firms' organizational structure. That is why strategic alliances, knowledge-based investments, and entrepreneurial awareness and motivations about this phenomenon are crucial factors to be assessed.

In general, SMEs have neither access to higher resources to invest in R&D nor the possibility to invest in human resources devoted to development programs. Hence, innovative activities and informal problem-solving activities are closely linked to the production process [Freel (2005)]. SMEs differ from large firms because of the investments made to support innovations. In fact, in large firms, investments in R&D prevail, while in SMEs the major expenses are the acquisition of new machinery, equipment, and facilities to encourage innovation [Evangelista *et al.* (1997)]. Finally, it is noted that for SMEs, innovation is a key factor to survival, growth, and development [Acs and Audretsch (1990)]. In particular, for small- and medium-sized firms, innovation is needed to counter the weaknesses arising from operating in a global context [Hoffman *et al.* (1998); Ruzzier *et al.* (2006)].

To create value in this globalized environment for SMEs, it is necessary to constantly innovate and exploit new opportunities for maintaining a competitive advantage [Sapienza *et al.* (2006); Hurmelinna-Laukkanen *et al.* (2008)]. In particular, manufacturing SMEs need to continually improve their processes to maintain a competitive advantage in the long term [Lagacé and Bourgault (2003)].

## **2.2. Innovation in manufacturing firms**

The different typologies of innovation traditionally stressed by literature [Utterback and Abernathy (1975); Hull *et al.* (1985)] acquire particular significance in the context of the manufacturing industry. Innovation studies show that the two types of innovation described above, namely product and process innovation, are closely linked and interdependent [Martinez-Ros (1999)]. Neglecting the initial process may weaken the firms' ability to achieve product innovation, thus compromising the entirety of the firms' advancement [Becheikh *et al.* (2006)]. Becheikh *et al.* [2006] shows that a large part of the literature analyzes only the product innovations; however, only a minor percentage of works focus exclusively on process innovation. Nevertheless, certain studies delve into the characteristics of process innovation and highlight its importance [Martinez-Ros (1999); Reichstein and Salter (2006); Raymond and St-Pierre (2010)]. First, process innovation increases firms' productivity [Reichstein and Salter (2006)]. Second, process innovation achieves competitive advantages mainly through the reduction of production costs [Reichstein and Salter (2006)] and the increasing production flexibility [Lefebvre *et al.* (1991)]. Finally, process innovation can promote product innovation [Martinez-Ros (1999); Hall *et al.* (2009)]. The main contributions to process innovations show that investments related

to product innovation regard the acquisition of new machinery, equipment and facilities [Hall *et al.* (2009)], while investments in R&D are mostly related to product innovations. Analyzing Italian manufacturing firms, Evangelista *et al.* [1997] show the existence of two innovation models: the pattern of large firms founded on R&D investment and innovation models of SMEs characterized by informal modernizations.

Innovation in manufacturing firms assumes special features and is different from innovation in service firms [Becheikh *et al.* (2006)]. Numerous contributions have focused on studying innovation in the manufacturing sector [Evangelista *et al.* (1997); Freel (2000); Becheikh *et al.* (2006); Reichstein and Salter (2006); Hall *et al.* (2009); Raymond and St-Pierre (2010); Terziovski (2010)]. Notably, Sirilli and Evangelista [1998] compare the characteristics of process innovation in manufacturing and service firms noting that, in most of the analyzed firms, product innovation is considered equally significant — a claim supported by Linder *et al.* [2003], who found significant strategic implications for integrating innovation processes in firms' competitive advantage. Moreover, another important difference is related to the cost of innovation that in manufacturing firms is about three times more than in service firms [Sirilli and Evangelista (1998)]. Further, a longitudinal analysis [Becheikh *et al.* (2006)] of literature regarding innovation in manufacturing firms demonstrates that research projects in this area are mainly dedicated to those concerning product innovation. The literature review made by Becheikh *et al.* [2006] on innovation in manufacturing firms show that most scholars focus only on product innovations. However, only a slight percentage of work focuses exclusively on process innovation as a result of scarce scholarly interest [Becheikh *et al.* (2006); Reichstein and Salter (2006)]. This type of innovation is often seen as an innovative activity of lesser importance compared to product innovation [Rosenberg (1982)]. Moreover, managers give less consideration to process innovation compared to product innovation [Linder *et al.* (2003)].

For the purpose of the present study, AM manufacturing seems to offer a great way for SMEs' growth and competitiveness [Mellor *et al.* (2014)] by offering a new and more flexible technology without substantial investments. However, these considerations are not adequately studied due to the novelty represented by this type of innovation. For this reason, an initial exploratory study is needed to shed light on this breakthrough innovation for not only manufacturing SMEs, but also for manufacturing firms in general.

### **2.3. AM: Prototyping and production**

AM as a technological innovation is increasingly becoming ground-breaking in many industrial sectors, thus acquiring more of a strategic function for improving competitiveness in both large firms and SMEs [Caputo *et al.* (2016); Kannattukunnel (2016)]. Notably, the introduction of AM can be configured as a radical process innovation. Such innovation is done with new machinery, namely 3D printers, which may be used in prototyping or directly in production for the

production of semi-finished or intermediate artifacts, and for the production of finished products.

To have an idea about the exponential growth of AM, Forbes [Columbus (2015)] estimates a growth of the AM market in a range from \$7 billion by 2020, on 18% CAGR to bull market scenarios as high as \$21.3 billion by 2020, at 34% CAGR. In particular, the worldwide AM printing industry is now expected to grow from \$3.07B in revenue in 2013 to \$12.8B by 2018, and exceed \$21B in worldwide revenue by 2020 with rapid prototyping (24.5%), new product development (16.1%) and product innovation (11.1%) are the three most common reasons why firms are adopting AM.

Under a technological viewpoint, there are three basic methods by which you can print an object in 3D [Dimitrov *et al.* (2006)]: the stereo lithography (SLA) method, the 3D-plotting method, and the drop on demand system (DOD) method. The first method is based on the polymerization of liquid resin by laser. In this case, the laser creates the entire object from top-to-bottom through material stratification. Once the object is completed it will be extracted and put into an ultraviolet oven to harden the material and make it usable for further work or production.

The 3D-plotting method, alternatively, is comparable to the operation of an inkjet printer with the only difference being that the main material with which the machine works is a thermoplastic polymer that is solidified on the various layers. In this particular case, the machine is positioned in the working area by depositing a first layer of plastic material. It then begins to move in all three directions to form the 3D item. In this case, the item from the machine work is finished and immediately ready to be used or colored. Finally, the DOD method is similar to the 3D-plotting system with the only difference being that the machine works simultaneously on all three Cartesian axes, considerably decreasing the time taken to mold a 3D piece.

It should be noted that the 3D molding phase is preceded by the design of the object using a 3D CAD modeling system based on a physical replication that allows users to touch what is already-virtually designed via software [Lee *et al.* (2005)]. Each of these three methods has specific characteristics and different applications: the SLA method is better for the production of prototypes or objects *en masse* as it allows a higher working speed and the ability to create a series of objects in a single working session. The other two methods are optimal for production requiring high precision or to create very complex shapes, with bends and corners which can hardly be developed through fusion, as in the SLA process.

The first applications of AM in SMEs included the prototype stage, but in recent years, this technology has also been used in the production phase [Mellor *et al.* (2014)]. Currently, the making of finished products through 3D printers is the real frontier for future development of this technology. Examples of objects produced through AM have some pioneering embodiments in the biomedical field where, for example, it is possible to create dental prosthesis-ready grafts on the subject [Zollo *et al.* (2015)].

In this area, the AM process has given several benefits: reduced production time of prosthesis development, a significant increase in the accuracy of reproduction of

the dental arch and, finally, a significant increase in the level of customization [Katstra (2000)]. In general, it seems that the use of AM in the process of product development reduces costs, increases the speed of development, positively influences the time to market, and fosters a high degree of product customization. Moreover, the AM phenomenon is particularly relevant for SMEs because the introduction of such technology determines more structured and radical innovation than might be pursued in larger companies, where this innovation would have less impact in the production process.

### 3. Research Methodology

In this research, the authors wish to study the introduction of AM as a process innovation in manufacturing firms with the aim of understanding the effects of this innovation on competitiveness.

By studying the effects of a particular process innovation, this research expands the literature on this phenomenon by showing that is an important challenge for SMEs' growth and competitiveness [Becheikh *et al.* (2006); Reichstein and Salter (2006)]. In fact, several empirical studies remark the connection between innovation, competitiveness, and growth for SMEs. In particular, regarding the cooperation networks and innovation [Zeng *et al.* (2010)], the link between innovation and exports for SMEs' growth [Golovko and Valentini (2011)], open innovation and competitive performance [Parida *et al.* (2012)] and financial orientation to improve innovation [Tajeddini (2016)].

Moreover, the authors of this paper want to raise awareness among entrepreneurs and managers about the importance of process innovations [Linder *et al.* (2003)] and its effect on SMEs. Thus, this study aims to explore if AM can determine the typical effects of process innovations and if it can be a viable path to growth and competitiveness for SMEs.

In particular, this study wants to explore if AM:

- Promotes product innovation [Martinez-Ros (1999); Hall *et al.* (2009)].
- Improves productivity and competitiveness [Reichstein and Salter (2006)].
- Improves SMEs growth chances [Love and Roper (2015)].

#### 3.1. Sample

To study the effects of AM, the authors chose the jewelry industry because, in this context, AM is widespread and it is consolidated with the peculiarity that is used not only for prototyping but also in the production phase. The jewelry production process requires the production of prototypes, models and semi-finished products that can be made in an advantageous manner with the use of AM technologies and 3D printers in particular.

Within the jewelry industry, this paper analyzes the district of Arezzo because the introduction of AM began in the 2000s and is intensely developing. The firms of Arezzo were the first gold firms to successfully introduce this innovation, and today the use of AM is critical to their competitiveness. The use of AM is a consolidated

phenomenon in the sample today and justifies the reason underlying the choice in attempting to understand the economic effects and management insights. In the Arezzo district, the processing of precious metals has been developed on an industrial scale mainly in the nineteen-seventies and eighties. In detail, the system is composed of approximately 70% of firms dedicated exclusively to jewelry, 24% exclusively to silverware, while the remaining 6% equally share turnover in the two sectors. Data are provided by Italian National Statistical Institute (ISTAT) and elaborated by the authors. The turnover of the entire gold jewelry industry and processing of precious stones (NACE code 36.2) is around 1055 million Euro (ISTAT data for 2015) representing — along with fashion and nautical — one of the three most important Italian industries in light manufacturing.

The last census in 2014 found 2045 active firms in Arezzo with a total of 8903 employees. Although this sector has been affected by the economic downturn, production levels remained satisfactory thanks to the improvement in exports that in 2015 increased again after the exploits of 2013 and a decrease in 2014. Specifically, in the second quarter of 2015, exports increased by 7% after a year of contraction (ISTAT data for 2013, 2014 and 2015).

Regarding the sample, eight gold jewelry companies from Arezzo that have introduced AM in the production process and use such technology in-house without outsourcing — as other companies in the sector have — were chosen for this research. To select the sample, the authors carried out an initial exploratory analysis during the trade fair “Arezzo Gold 2015”, allowing one to define a heterogeneous sample that was representative of the district. Afterward, the exploratory scanning and the consequent data collection and analysis during “Arezzo Gold 2016” fair was completely updated.

The eight firms chosen have demonstrated a consolidated use of AM in the production process, the knowledge of the effects on the performance, and the ability to collaborate. The representativeness of the sample is ensured by the heterogeneity of companies regarding turnover, the number of employees, the year when AM was first introduced, family control or presence of outside managers, and type of products. The firms in the sample were defined by the Greek alphabet — *alpha*, *beta*, *gamma*, *delta*, *epsilon*, *zeta*, *eta*, *theta* — to ensure the firms’ anonymity. Table 1 summarizes the firms’ sample.

Table 1. Sample detailed description.

Firms	Yearly revenues (2015)	No. employee	Additive manufacturing introduction
Alpha	€5.250.189	18	2003
Beta	€3.241.432	31	2003
Gamma	€12.308.621	40	2004
Delta	€33.011.427	86	2006
Epsilon	€3.546.245	12	2007
Zeta	€24.765.027	56	2008
Eta	€4.325.893	29	2008
Theta	€11.746.324	33	2009



### 3.2. Methodology

The purpose of this study has been pursued with a qualitative methodology supported by a multivariate case study of eight firms that use AM in the gold jewelry industry of Arezzo district. The multivariate case study has been conducted under the guidelines proposed by leading literature [Yin (2004); Pratt (2009)]. This methodological choice rested on the general agreement that qualitative research seeks to answer the “how” and “why” questions, and that the case study method is a useful way of doing so [Eisenhardt (1989); Yin (2004)].

In this study, the authors have chosen interviews as the method of data collection and latent content analysis as the method of analysis [Mayan (2009); Berg (2012)].

The researchers employed the three steps of data collection procedures as established by Yin [2004]: interviews, documentation, and observation. Also, Woodside and Wilson [2003] agree that case study research should entail multiple approaches to data gathering and through which the in-depth interviews are a fundamental qualitative method performed through open-ended or focused interviews. The researchers opted for a semi-structured, open-ended approach because the variables involved were not clear in the referring literature [Yin (2004)].

The data relating to the phenomenon have always been linked to conceptual subjects that the researchers wanted to re-examine in the light of the new results. The qualitative analysis involved the constant comparison between theoretical concepts and observed phenomena, trying to identify concrete examples relevant to the theoretical level in the data collected [Anderson *et al.* (2010)].

From a practical viewpoint, after identifying the sample, the researchers conducted semi-structured interviews with top management [Richards and Morse (2007)]. According to Richards and Morse [2007], semi-structured interviews are suitable when the authors have a general idea of the phenomenon and can ask questions about the topic but are not able to predict responses [Richards and Morse (2007); Mayan (2009)]. The protocol required scheduled interviews with open-ended questions about the overall effect made by AM and the impact of AM on firms’ competitiveness. The subsequent latent content analysis [Mayan (2009); Berg (2012)] has allowed the identification of conceptual themes that represent particular aspects which, according to the top management, explains the impact of AM on performance.

Data collection was done through personal interviews with a representative of each examined firm. At least two interviews were carried out with owners or managers of each firm for a total of 16 interviews. Table 2 summarizes the interviewed subjects.

Although the interview protocols have been modified and adapted during the process of data collection, the researchers used a set of stable applications that can be summarized and classified in the following topics (for a detailed interview plot, please see Table A.1):

- (a) the economic-financial and strategic reasons that led top management to introduce AM in the production process;

Table 2. Detailed information about interviewed subjects.

#	Genre	Age	Position	Interview duration (minutes)	Interview date
1	M	64	Owner	118	19 September 2015
2	M	65	Owner	92	20 September 2015
3	M	51	Owner	47	20 September 2015
4	M	48	Manager	81	27 September 2015
5	F	48	Manager	73	27 September 2015
6	M	52	Owner	44	9 October 2015
7	M	46	Manager	72	9 October 2015
8	M	55	Manager	39	9 October 2015
9	F	67	Owner	45	12 October 2015
10	M	38	Owner	111	9 May 2016
11	M	31	Owner	54	9 May 2016
12	F	29	Manager	62	13 May 2016
13	M	26	Manager	57	17 May 2016
14	M	29	Manager	68	17 May 2016
15	M	65	Owner	55	21 May 2016
16	F	41	Manager	103	21 May 2016
Total time				1121 minutes	

- (b) the effects of this process innovation on employees, production process, product, costs, revenues, and profits;
- (c) the evolution of the relationships with corporate stakeholders, with particular focus on the customer;
- (d) the main consequences of this innovation on economic performance and on the competitive advantage.

In addition to the interviews, the researchers also made six on-site observations guided by managers or owners in order to better understand the phenomena.

Table 3 summarizes the on-site observations.

Subsequently, the data collected through interviews were analyzed by the method of latent content analysis [Mayan (2009); Berg (2012)]. This is the process of identifying, coding and categorizing the primary topics in the data [Spiggle (1994); Thompson (1997); Mayan (2009); Berg (2012)]. It aims to identify the most important topics within the data to classify it into codes, categories, and themes [Mayan (2009)]. Through this process of coding, the analysis highlights the most important themes connected to specific research questions. Consequently, the purpose of latent content analysis is to understand the symbolism underlying the

Table 3. Detailed description of on-site observation.

Firm	Area	Day	Duration (minutes)
Alpha	Production	20 September 2015	62
Beta	Production	21 September 2015	33
Delta	CAD design	27 September 2015	30
Epsilon	Production	9 October 2015	45
Zeta	Production	9 May 2016	77
Theta	CAD design	13 May 2016	32
Total			279

physical data [Berg (2012)]. Alternatively, manifest content analysis aims to count specific words used or ideas expressed to generate statistics on the content of the data [Mayan (2009)].

In this study, through latent content analysis, the authors examined the content of the interviews to identify themes that would explain the effects of AM on the competitiveness and performance of the firms. To realize this interpretative process, four steps were followed: coding, categorizing, thematizing, and integrating [Mayan (2009)]. The entire process of selection and coding was done manually without the aid of any software.

The process of content analysis began with the analysis of all data collected through interviews, eliminating what has been deemed non-relevant and putting together what was significant [Eisenhardt (1989)].

The first step was to code the data to identify units of meaning connected to the effects of AM within the dataset [Mayan (2009)]. This phase of coding analysis generated 50 issues that were named “codes”. Thanks to the support information derived from the Internet, newspapers, magazines, and reports of companies, each of the authors began axial coding to make the group analysis. The results of this second phase of content analysis have been shared with the work team and compared to the differences and concerns raised during the analysis. At this stage, the authors followed the protocol described by Finch [2002], and applied to management research by Anderson *et al.* [2010].

After this second phase, the conceptual subjects that emerged were reduced to 30 categories. In this phase, the codes were combined and conducted by similarities and affinity of meaning within the same category [Spiggle (1994)]. The third phase of analysis identified six themes that represent the main conceptual aspects used by respondents to explain the effects of AM on business competitiveness. These themes tie the categories together, and they were identified with a process of abstraction [Spiggle (1994); Mayan (2009)]. In the last step, namely integrating, the different themes were correlated with each other to form the conclusion and to build the big picture [Spiggle (1994); Mayan (2009)]. This was the real process of theorizing.

#### 4. Results and Discussion

In this section, the authors present the results of the latent content analysis (see Table 4) with the 30 categories identified in the interviews and associated with the following six conceptual themes: process innovation, cost, value offered to the customer, revenues, profits, competitive advantage. These conceptual themes are the main aspects that respondents have cited to explain the effects of AM during the interviews.

The six conceptual themes are illustrated graphically (see Fig. 1) by the following conceptual scheme that illustrates how these affect the companies’ competitiveness. Every circle represents one of the emerged themes and the dashed line represents the whole effect of competitive advantage theme.

As anticipated, the six conceptual themes resulting from the content analysis are the main features used by respondents to explain the effects of AM on business

Table 4. Latent content analysis analytical results.

Categories	Themes
Phase of the production process: prototyping or production	Process innovation
Production of semi-finished or finished product	
Impact of innovation on the production process	
Determinants of innovation	
Use of a new machine	
Amount of the investment in 3D printer	Cost
Incidence of depreciation	
Effect on the total costs	
Impact on labor costs	
Raw materials	
Costs for maintenance	Value offered
Productivity	
Product innovation	
Quality of products	
Time to market	
Customization	Revenues
Customer service	
Effect on total revenue	
Effect on the quantities sold	
Willingness to pay customers	
Sales prices	Profit
Access to new market segments	
Total impact on profits	
Improvement of profits	
Causes of changes in profits	
Value added between the difference in willingness to pay and cost	Competitive advantage
Competitive strategy	
Innovation imitation	
Craftsmanship	
Competition with developing countries	

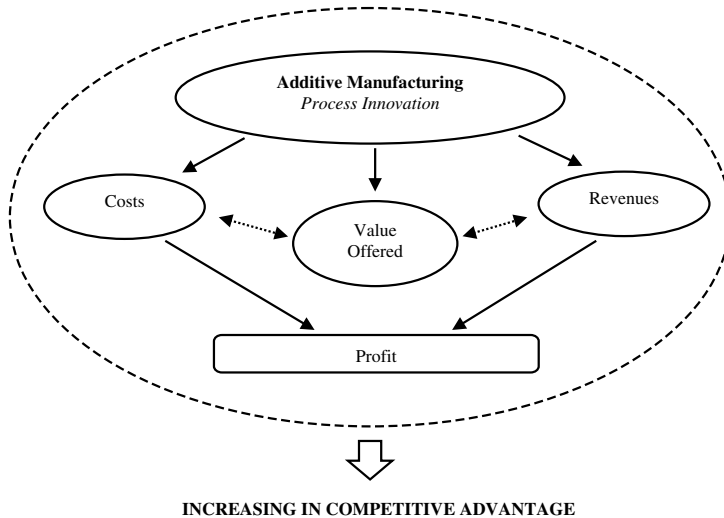


Fig. 1. Conceptualization of the emerging themes from latent content analysis.

competitiveness. In other words, the six conceptual themes are the main aspects that are influenced by this technology.

Consequently, by examining the impact of AM on these elements, it is possible to understand the overall effects of this innovation on competitiveness [Mayan (2009)]. The primary empirical evidence resulting from interviews, concerning the impact of AM on the six conceptual themes arising from latent content analysis is described below.

#### 4.1. *AM as a process innovation*

The first conceptual theme refers to process innovation. The case studies analyzed during the research have shown that AM has significantly increased process innovation in the gold industry.

As Alpha's manager claim: *I was the first to introduce the 3D printing in the gold sector. This sector was the first in which the manufacturing has spread the use of 3D printing at the industrial level, with the peculiarity that in our industry we transformed a machine from prototyping in a machine for the production. After a first phase in which the 3D printing was used in prototyping, now it is used directly in the production to achieve the molds, from which will be born the jewel.*

In the sector under analysis, AM may be qualified as a process innovation. That type of production could previously only be carried out through a long process of manual work done by highly skilled craftsmen. Consequently, one set of empirical evidence is that AM in the gold jewelry firms is used not only in the prototype stage but also in the production phase. The first stage of the production process is accomplished through AM, in which the semi-finished products are created to realize the final output — specifically, the jewels.

Moreover, the cases carried out in the field show that most of the companies internalize this innovation. The analyzed interviews showed that one reason companies push to internalize this technology is the need for absolute control over 3D printers in order to hide information from competitors on the production's progress. Thus, the analyzed firms are internally equipped with this technology, spending resources in the purchase of 3D printers.

Also, two of the respondents claim that the use of AM for the production of semi-finished products will be overcome by the direct creation *of the jewel through powder sintering metal*, as can be perceived from the words of Delta's manager.

**Insight 1:** *AM significantly increased process innovation.*

#### 4.2. *Effect on costs*

Regarding the cost effects, case studies have shown that gold jewelry companies that use AM do not have a substantial reduction in costs, while there is *a slight increase caused by the amortization, the costs of maintenance, the costs of training the staff and especially the costs of raw materials*, as evidenced by the words of Gamma's manager.

Important evidences concerning the cost regard the change in companies' structure. In fact, there is a high impact on 3D printers' cost amortization of about two years that stimulate the continuous innovation of products and speed up the production cycle. Besides, 3D printers' maintenance costs are significant. Moreover, costs are increased due to necessary personnel training needed to use the new technology. Finally, the cases show that the most critical aspect concerning cost effect is represented by raw material costs as firms are obliged by contract to buy the raw materials for the printer from the 3D printer suppliers.

In fact, Gamma owner remarks: *When I purchased the 3D printer is as if I had married a second time, because we are obliged to buy the resins by those who sold us the 3D printer.* These suppliers have high bargaining power due to the high concentration of the AM producer industry.

**Insight 2:** *AM increases production cost due to significant acquisition, maintenance, and personnel expenditures.*

### 4.3. *Effects on value offered to costumers*

The examined cases show that AM promotes advantages related to customer service. First, it encourages product innovation, in-line with what the literature says about the process innovations [Martinez-Ros (1999); Hall *et al.* (2009)]. In fact, AM allows firms to create new products, perceived by customers as the finest regarding aesthetics and quality. More specifically, one can talk about innovation that facilitates the process of creating new products without being born for this purpose alone. After the introduction of AM, the analyzed firms in the sample can create objects with complex geometries that were previously impossible to do by hand. It allowed firms to offer new products with greater value, enticing customers to pay higher prices. As Eta's manager pointed out: *The 3D printing has enabled us to create products with the forms that before the introduction of this system of processing were physically impossible to implement, allowing to expand the range of products offered and surprise our regular customers.*

The case studies have shown that the primary purpose of the introduction of AM within companies will evolve in the creation of new products. In general, it can be said that the technology in question appears as a process innovation that enables companies to create new products in-line with the literature mentioned above [Reichstein and Salter (2006); Hall *et al.* (2009)].

This evolutionary step, as shown in the following paragraphs, weighs heavily on the opportunities for growth and development of SMEs [Hall *et al.* (2009)]. It is highlighted by Gamma who remark: *Thanks to this processing method the quality of our products has improved exponentially, we can sell at a higher price items with best quality standards.*

Thus, AM allows access to new markets and segments, while competition is no longer based only on cost but also on the design and complexity of sold items.

**Insight 3:** *AM encourages product innovation that evolves into new product development.*

#### 4.4. *Effects on revenues*

Concerning revenues, the case studies show that AM has affected revenues of the firms in two ways.

First, revenues increased thanks to higher sale prices connected to the greater value offered to the customer. In fact, customers are willing to pay a higher price for better physical characteristics or new products. Concerning the relationship between price and items sold, AM has affected mainly the former. As stated in the words of the manager from company Zeta: *Revenue increased primarily due to higher price sales, made possible by the improvement of product quality*. It should also be noted that AM allows the industrial production of small batches as evidenced by the words of the owner of the company Zeta: *The amount was not increased, and also, 3D printers have industrialized the production of small batches*.

Second, the creation of new products has allowed access to new market segments according to the managers' opinion. In particular, AM made firms more competitive under the cost-side by producing handcrafted items *en masse*. The development of AM has allowed firms in the sample to produce highly-refined items at reasonable prices. It allows firms to enter into a mass-market with products which, before the introduction AM, were reserved only to high-end markets due to their high selling prices.

This observed second effect is particularly interesting for SMEs as it allows them to expand their competitiveness even under the cost-side, without decreasing their products' quality and craftsmanship.

**Insight 4:** *AM affects revenues thanks to a greater willingness to pay by customers.*

#### 4.5. *Effects on profits*

Regarding the impact of AM in profitability, the case studies show a positive impact. This is possible due to higher revenues in the face of a substantial stability of production costs. In fact, Theta claimed: *Profits have improved thanks to higher revenues, compared with a substantial stability of costs*.

The analysis of the aforementioned conceptual themes allows us to affirmatively respond to our research question, pointing out that AM improves the competitiveness of SMEs. In fact, the product innovations allowed by AM result in a better value offered to customers, an increase in the willingness to pay, and greater access into new market segments, resulting in an improvement in the revenue stream as noted by Gamma's manager: *The main cause of the profit improvement has been the increase in sales prices*.

The positive impact on competitiveness made by AM introduction is in agreement with the literature findings regarding process innovation [Reichstein and Salter (2006)]. It should be noted that while the literature on process innovation attributes the improved competitiveness on cost reduction [Becheikh *et al.* (2006)], the introduction of AM primarily produces revenues. Hence, the effect on profits is a direct outcome of an increase in revenues.

**Insight 5:** *AM positively impacts profits thanks to the possibility of access to new markets and segments.*

#### 4.6. *Effects on competitive advantage*

The sum of the aforementioned results converges in a better competitive advantage as shown in Fig. 1 as a cause of AM introduction in manufacturing SMEs. The case studies have shown that AM is a driver of competitive advantage but not a sufficient factor for such advantage, as this innovation needs to be combined with other production technologies and entrepreneurial skills. As Beta’s owner remarks: *The use of 3D printing is fundamental to face with our competitor. Not only the technology can resolve a strategic affair that is composed also by design, customer relation and international geopolitics situation. However, without the use of 3D printing, our company would be failed five years ago.*

As the managers involved in the study stated, AM can be easily reproduced by other competitors in the Arezzo district, which creates benefits especially for the first-mover inside that industry. However, once AM has been introduced by the first-mover, it has become a required factor for survival. Nevertheless, the “forced” large-scale adoption of AM within the district pushes the firms inside it to improve the quality of its products. The final result of this competition shows their outcomes in a better aggregate of competitive advantages for all the firms in the district. In fact, as Beta noted: *The introduction of 3D printing by other companies of the district does not cause an adverse effect on our competitiveness nor on profits, but rather improves the reputation and image of the district by promoting our ability to create unique products and makes it more competitive aggregate level.*

Finally, the main competitive advantage created by AM regards the competition within developing countries. As the Gamma manager remarks, this technology allows SMEs not to fear the threat from developing countries. As Gamma’s manager pointed out, [. . .] *in any case it is preferable to compete with emerging countries on technology rather than on labor cost.*

**Insight 6:** *AM creates a cascading effect that converges in a better competitive advantage for the single firm as well at the district level.*

### 5. Conclusion

The case studies showed that AM can improve the competitiveness of SMEs (Insight 6). In fact, innovation allowed by AM can create a better value offered to customers (Insight 3), an increase in the willingness to pay (Insight 4), and better access to new market segments (Insight 5), resulting in an improvement in the revenue stream (Insight 4). These effects appear to be generalized and extended to firms in other sectors due to the primary effects of AM, among which the authors highlight: the improvement of product innovation (Insight 3), creating more value for customers, improving time to market, and personalization and creative possibilities [Martinez-Ros (1999); Hall *et al.* (2009); Reichstein and Salter (2006); Love and Roper (2015)]. Likewise, the effects on costs appear more related to the sector and manufacturing



processes. The AM process determines the common effects of process innovations (Insight 1) identified by the literature: it promotes product innovation and improves business competitiveness while acting more on revenues than on cost reduction [Becheikh *et al.* (2006)].

The authors can, therefore, say that AM is a viable development path for the manufacturing sector. In particular, this technology has proven its effectiveness in the areas where it is required for the production of complex objects by affecting production costs, especially in the possibility to turn a small-scale production into a large-scale one [Mellor *et al.* (2014)]. This fact, along with a low adoption cost, shows that SMEs are becoming more competitive on two sides. The first is the ability to have access to new markets by expanding the range of products offered. The second, and perhaps most important, concerns the difficulty to produce imitation thanks to highly technical processes and design knowledge.

Hence, AM seems to favor innovation and growth processes within manufacturing firms, since the introduction of this innovation is a primary competitive factor that becomes a critical role in customer service operations as Beta's owner have remarked in Sec. 4.6. In this context, the introduction of AM can allow SMEs in countries with mature economies to remain competitive. This is possible due to the direction in which economic activity has gradually moved in the direction of service industries.

The last fundamental consideration is that AM does not create a loss of craftsmanship, but rather increases the creative potential of entrepreneurs and designers. Although less manual craftsmanship is required in this production stage, it is important to highlight that in general the traditional approach and creativity are enhanced by a new technological tool.

Regarding practical implications, the study aims to increase the awareness of entrepreneurs and managers against the effects of the introduction of AM on firm performance and to shed light on this growing phenomenon, especially regarding the effects on costs. In fact, manager and entrepreneurs should have to pay attention to this fundamental evidence, especially if they would be competitive on the costs-side.

The authors also aim to stimulate the attention of decision-makers towards process innovations and its effect on firm competitiveness. AM is helping the Arezzo district to survive, granting a competitive advantage to their SMEs in the next years.

In conclusion, it should be noted that this work has limitations related to sample size and analysis of a single industry. As a result, the possible developments for future research may consist of the study of the effects of AM on the competitiveness of companies in different industries. Another limitation of this study consists that the authors have used a qualitative technique to report some quantitative results. In particular, regarding productivity and revenues, it is only possible to report on perceptions of value created by managers and owners rather than a direct quantitative causative relationship.

Finally, it should also be noted that in literature analysis there are few contributions focused on AM due to the novelty of the phenomenon in question.

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## Appendix A.

Table A.1. Detailed interview plot.

	Questions	Area of investigation
1	What reasons prompted you to use additive manufacturing (or 3D printing)?	Innovation
2	Was it a particularly onerous or a sustainable investment?	Effect on cost
3	Has additive manufacturing (or 3D printing) made a significant innovation in the production process?	Process innovation
4	What effect has additive manufacturing (or 3D printing) made in the HRM?	Organizational effects
5	Does additive manufacturing (or 3D printing) produce any effects on cost reduction?	Effect on cost
6	Does additive manufacturing (or 3D printing) produce any effects on cost structure?	Effect on cost
7	What have been the effects on the cost of designing and developing new products?	Effect on cost/new product development
8	Does additive manufacturing (or 3D printing) stimulate product innovation?	Product innovation
9	Has additive manufacturing (or 3D printing) allowed you to improve your products in terms of quality or complexity?	Product innovation
10	Compared to the past, what has changed in the value offered to consumers?	Product innovation/value offered

(Continued)

Table A.1. (*Continued*)

	Questions	Area of investigation
11	Does additive manufacturing (or 3D printing) make it possible to increase the willingness of customers to pay a higher price?	Value offered/willingness to pay
12	Does additive manufacturing (or 3D printing) have any effects on items sold?	Revenues
13	In terms of value added, have you acted more on cost or value offered to the customer?	Value offered
14	Does additive manufacturing (or 3D printing) have any effects on competitiveness? If yes, do you think that it is defensible in the long run?	Competitive advantage
15	Do you think that additive manufacturing (or 3D printing) is needed to compete today?	Competitive advantage

## Biography

**Giacomo Marzi** is a Lecturer in Strategy and Enterprise at Lincoln International Business School. His research is mainly focused on innovation management, new product development and bibliometric. He has authored and co-authored a number of papers that appeared in journals such as *Scientometrics*, *Business Process Management Journal* and *World Review of Entrepreneurship, Management and Sustainable Development*. His work has also been presented at conferences such as the Academy of Management and the European Academy of Management.

**Lamberto Zollo** is a Post-Doc Candidate in Management and Business Administration at University of Florence. His research interests include strategy, business ethics, social entrepreneurship, and cross-sector social interactions. He carried out research activities at Kent Business School (UK) as a Ph.D. Visiting Student. He attended many international conferences of general management and business ethics.

**Andrea Boccardi** is a Post-Doc Candidate in Management and Business Administration at University of Florence. His research interests focus on entrepreneurship, innovation, business ethics, and social entrepreneurship.

**Cristiano Ciappei** is a Full Professor in Strategy at University of Florence. His research interests focus on business ethics, strategy, innovation, business ethics, big data and social entrepreneurship.