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EURAM 2016
Manageable Cooperation?
JUNE 1-2-3 and 4, 2016 Paris /FRANCE

ADDITIVE MANUFACTURING IN SMES: A VIABLE PATH TO GROWTH AND COMPETITIVENESS?

Giacomo Marzi
UNIVERSITY OF PISA - Pisa, Italy
Lamberto Zollo
UNIVERSITY OF FLORENCE - Florence, Italy
Andrea Boccardi
UNIVERSITY OF FLORENCE - Florence, Italy
Cristiano Ciappei
UNIVERSITY OF FLORENCE - Florence, Italy

Category: 03 ENTREPRENEURSHIP >> 03_04 INTERNATIONALIZATION & GROWTH STRATEGIES FOR SME

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ISSN 2466-7498.

Additive Manufacturing in SMEs: A Viable Path to Growth and Competitiveness?

ABSTRACT

The aim of this paper is to analyze Additive Manufacturing (AM) in SMEs to investigate its effects on competitiveness and performance. Thanks to the analysis of an Italian gold jewelry district's firms, the paper examines the effects related to AM on firms highlighting empirical evidences suitable for other industry contexts. Thanks to latent content analysis, six conceptual themes have emerged concerning the main effects of AM. Such categories are process innovation, customer satisfaction, costs, revenues, profits, and sustainable competitive advantage. As a results, the introduction of AM has increased the firms' competitiveness by strengthening customer satisfaction and revenues, and may be therefore interpreted as a viable growing strategy for SMEs. Furthermore, thanks to AM customers' demand and payment availability have increased and evident advantages on firms' performance have been recorded.

Keywords: Additive Manufacturing, Innovation, SMEs, 3D printing

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Abstract

The aim of this paper is to analyze Additive Manufacturing (AM) in SMEs to investigate its effects on competitiveness and performance. Thanks to the analysis of an Italian gold jewelry district's companies, the paper examines the effects related to AM on companies, by highlighting empirical evidences usable for other industry contexts. Thanks to latent content analysis, six conceptual themes have emerged, concerning the main effects of such an innovative technology on companies, namely process innovation, customer satisfaction, costs, revenues, profits, and sustainable competitive advantage. Thanks to AM customers' demand and payment availability have increased and, as a result, evident advantages on firms' performance have been recorded. The introduction of AM has increased the firms' competitiveness by strengthening customer satisfaction and revenues, and may be therefore interpreted as a viable growing strategy for SMEs.

Keywords: Additive Manufacturing, 3D Printing, 3DP, SMEs, Process Innovation, Competitiveness, Innovation, Growth, Case Study.

1. Introduction

Additive Manufacturing (AM) represents a recent technological innovation that is attracting growing interest from manufacturing firms and is proving to be a viable path of technological innovation 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 viewpoint, and only with an engineering perspective (Lee, 2004; Dimitrov, 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), while literature configures AM as one of the most disruptive innovations of our 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 SME's competitiveness and performance. Notably, this study aims to verify whether the introduction of AM can determine the typical effects of process innovations: (1) promote product innovation, (2) improve productivity, and (3) 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).

The article is composed of five sections including this introduction. In the second section, we introduce the phenomenon of AM showing how such technology may be configured as a process innovation for SMEs. In the third section, after highlighting the significance of the sample and why we choose it, we present the methodology that consists in a qualitative analysis of case studies through interview's latent content analysis, which led to the following six conceptual themes: process innovation, cost, value offered to the customer, revenue, profits and

sustainability of competitive advantage. The six conceptual themes resulting from this analysis explained the effects of AM on SMEs; in particular, we emphasized the impact of AM on craftsmanship growth and competitiveness in SMEs. Consequently, in examining the effects of this technology on these aspects is possible to understand the overall effects of AM on SMEs. Finally, in the last section, we highlight main conclusions along with managerial implications and the limitations of the present work.

2. The 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 et al., 2005; Knight and Cavusgil, 2004). There is broad recognition that the introduction of innovative products and processes fosters the ability of organizations to enter in or create new markets by satisfying the demand of customers (Smith et al., 2005). It 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 needs the development of new products and service, along with the identification and the exploitation by the management of innovative changes that progressively allow the firm's sustainability in the competitive environment (Katila, 2002; Witt, 2009; Maggitti et al., 2013). As a consequence, it is clear that innovation has an effect both on behavior and organizational relationships, as well as on strategies and firm process (Li et al., 2013).

The literature on innovation focuses on the identification of possible classifications regarding this concept. The most famous are: (1) the distinction between administrative innovation or technical developments concerning the organizational process involved (Daft , 1978; Kimberly

and Evanisco, 1981; Damanpour, 1987); (2) the differentiation between product innovation or process innovation, regarding to 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; North and Tucker, 1987).

Especially the second distinction between product and process innovation is considered fundamental about the pursuit of competitive advantage, which will be one of the focuses of the present research (Hull et al., 1985). While product innovation is related to new products and services introduced into the market, usually to meet latent needs of consumers (Ettlie, 1983; Damanpour, 1991), process innovations refers to new elements introduced in the firms' operation 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.

In the following paragraphs, we will present both traditional and recent innovation literature, firstly in the SMEs' context and next in the manufacturing industry.

2.2.The innovation process in SMEs

Given that innovation fosters firms' growth, internationalization, and performance (Sapienza et al., 2006), recent literature has widely focused on innovativeness in SMEs (Ruzzier et al., 2006) thus attenuating the widespread lack of attention to innovation phenomenon in such firms (Love and Roper, 2015). Enhancing innovativeness in SME's seems crucial for the economic development of community and regions (Jones and Tilley, 2003), thus fostering strategic alliances and collaborations between such firms (Kleinknecht and Reijnen, 1992; Narula, 2004). Laursen and Salter (2004) found that innovation in SME's is present as well as in large-size firms, especially concerning radical innovation. 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 superiorities 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 been recently analyzed by Van de Vrande et al. (2009), who find that small firms are increasingly achieving a noticeable role in modern innovation scenario. 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 increase both explorative and exploitative innovative ability of the firm; (b) high levels of dynamism and competitiveness are positively correlated with SME's innovation; (c) innovation in SME's represents a partial mediator between the dynamic and competitive environment and the firm's performance (p.1663). It emerges how 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 surviving, grow and develop (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 sustainable competitive advantage (Sapienza et al., 2006; Hurmelinna-Laukkanen et al., 2008). Especially manufacturing SMEs need to continually improve their processes to maintain a competitive advantage in the long term (Lagacé and Bourgault, 2003).

2.3.Innovativeness 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 manufactory 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 innovation process phenomenon may weaken the firms' ability to achieve product innovation, thus compromising the entire innovation process (Becheikh et al., 2006). Becheikh (2006) shows that a large part of the literature analyzes only the product innovations; however only a slight percentage of works focus exclusively on process innovation. Nevertheless, certain studies delve into the characteristics of the process innovation and highlight its importance (Martinez-Ros, 1999; Reichstein and Salter, 2006; Raymond and St-Pierre, 2010). Firstly, process innovation increases firms' productivity

(Reichstein and Salter, 2006). Second, process innovation determines to achieve 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 most related to product innovations. Evangelista et al. (1997) analyze Italian manufacturing firms showing the existence of two innovation models: the pattern of large firms founded on R&D investment and innovation model of SMEs characterized by informal innovative.

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 processes innovation in manufacturing and service firms noting that, in most of the analyzed firms, product innovation is equally considered 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 results in about three times more than service firms (Sirilli and Evangelista, 1998). Further, a longitudinal analysis (Becheikh et al. 2006) on literature regarding innovation in manufacturing firms demonstrates that researches in this area are mainly dedicated to product innovations. The literature review made by Becheikh et al. (2006) on innovation in manufacturing firms' shows that a large part of scholars focuses only on product innovations. However, only a slight percentage of work focuses exclusively on process innovation, resulting in scarce scholarly interest in process innovation (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 have a 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 flexible technology without substantial investments. However, these considerations are not adequately studied due to novelty represented by this type of innovation. For this reason, an initial exploratory study is needed to shed light on this new breakthrough innovation for manufacturing SMEs, but also for manufacturing firms in general.

2.4. AM: prototyping and production

AM as a technological innovation is increasingly becoming ground-breaking in many industrial sectors, thus acquiring more and more a strategic function for improving competitiveness both for large firms and SMEs. 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, used for both the production of semi-finished or intermediate artifacts and the production of finished products.

Under a technological viewpoint, there are three basic methods by which you can print an object in 3D (Dimitrov, 2006): Stereo Lithography method (SLA), the 3D-Plotting method and the Drop on Demand System method (DOD). Regarding the first method, it is based on the polymerization of liquid resin by laser. In this case, the laser creates from top to down the entire object 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 instead is comparable to the operation of an inkjet printer with the only difference 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 working area by depositing a first layer of plastic material and then it 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, DOD method is similar to the 3D-Plotting system with the only difference that the machine works simultaneously on all three Cartesian axes with a considerable decreasing time taken for molding 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 and a physical replication that allows users to touch what is already virtually designed via software (Lee, 2004). Each of these three methods has specific characteristics and different applications: the SLA method is better for the production of prototypes or objects in mass 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 "fusion" as the SLA.

Figure 1 summarizes the logical process of using the 3D Print from design up to machine use.

Fig 1 About Here

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 embodiments pioneering in the biomedical field where, for example, it was possible to create dental prosthesis

ready graft on the subject. In this area, the AM has given several benefits: reduced production time of prosthesis, a significant increase in the accuracy of reproduction of the dental arch and finally high increase in the level of customization (Katstra, 2004). In general, it seems that the use of AM in the process of product development allows reducing costs, increasing the speed of development, influencing positively in the time to market, and fostering 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 in larger companies, where this innovation would have less impact in the production process.

3. Research methodology

In this study, we want to deepen the introduction of AM as 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, we want to expand the literature on this phenomenon showing that is an important challenge for SMEs growth and competitiveness (Becheikh et al., 2006; Reichstein and Salter, 2006). Moreover, we want to raise awareness in 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 the 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:

- Promote product innovation (Martinez - Ros, 1999; Hall et al., 2009).
- Improve productivity and competitiveness (Reichstein and Salter, 2006).
- Improve SMEs growth chance (Love and Roper, 2015).

3.1.Sample

To study the effects of AM we 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 in particular 3D printers.

Within the jewelry industry, we chose to analyze the district of Arezzo because in this context the introduction of AM has begun since the 2000s and is intensely developing. The firms of Arezzo district 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 our sample today and justify the reason underlying our choice to understanding 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 seventies and eighties. In detail, the system is composed of approximately 70% of firms dedicated exclusively to jewelry, 24% of exclusive silverware while the remaining 6% shares equally its turnover in the two sectors[1]. The turnover of the entire gold jewelry industry and processing precious stones (NACE code 36.2) is around 1,055 million euro[2] representing along with fashion and nautical one of the three most important Italian industry in light manufacturing.

The last census in 2014 found 2,045 active firms in Arezzo with a total of 8,903[3] 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

[1] ISTAT data processing for 2014.
[2] ISTAT data for year 2014.
[3] Italian District Observatory data for 2014.

of 2013 and a decrease in 2014[4]. Specifically, in the second quarter of 2015 exports increased by 7% after a year of contraction[5].

Regarding the sample, we have chosen 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 outsource. To select the sample, we carried out an initial exploratory analysis during the trade fair "Arezzo Gold 2014", which allowed us to define a heterogeneous sample, representative of the district. Afterward, we completely update the exploratory scanning and the consequent data collection and analysis during "Arezzo Gold 2015" fair.

The eight firms chosen have demonstrated a consolidated use of AM in the production process, the knowledge of the effects on the performance, and availability 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 introduced, family control or presence of outside managers and, type of products. The firms in the sample were defined by Greek alphabet - *alpha*, *beta*, *gamma*, *delta*, *epsilon*, *zeta*, *eta*, *theta* - to ensure firms' anonymity.

3.2.Methodology

The purpose of our study has been pursued with a qualitative methodology supported by multiple case study of eight firms that use AM in the gold jewelry industry of Arezzo District. Multiple case study has been conducted under the guidelines proposed by main 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

[4] Intesa San Paolo – Monitor of Tuscan Districts – Data for 2013, 2014, 2015.
[5] Intesa San Paolo – Monitor of Tuscan Districts – Data for 2013, 2014, 2015.

useful way of doing so (Eisenhardt, 1989, Yin, 2004). According to Stake (2005, p. 443), the case study approach is not "a methodological choice, but a choice of what is to be studied", in our study we have chosen interviews as method of collection data and latent content analysis as method of analysis data (Mayan, 2009, Berg, 2012).

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

The research diaries, in which were transcribed interviews and collected data, have been updated and regularly revised to emphasize the conceptual subjects emerging every time new and significant results were discovered (Human and Provan, 1996). The data relating to the phenomenon have always been linked to conceptual subjects that we wanted to check to examine them again in the light of the new results. Our 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, we 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 used had 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 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 firm representative of each examined firm. Two interviews were carried out with owners or managers of each firm for a total of 16 interviews. These interviews have lasted for at least two hours to a maximum of four hours and were recorded and transcribed for analysis. Although the interview protocols have been modified and adapted during the process of data collection, we used a set of stable applications that can be summarized and classified in the following topics:

a) The economic-financial and strategic reasons that led top management to introduce the AM in the production process.
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 sustainability of competitive advantage.

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

content analysis aims to count specific words used or ideas expressed to generate statistics on the content of the data (Mayan, 2009).

In our study, through the latent content analysis, we have 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, we followed four step: coding, categorizing, thematizing and, finally, 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 non-relevant and putting together what was significant (Eisenhardt, 1989). All interviews were transcribed, read and reread, writing notes next to conceptual subjects emerging from the text in reference (Anderson et al., 2010). After the transcription of interviews, about sixty pages, we began a process of manual selection and coding of the main theoretical concepts emerging from the interviews (Saldana, 2012).

The first step was to code the data to identify units of meaning connected to the effects of AM within the data set (Mayan, 2009). This phase of coding analysis generated fifty issues that were named ‘codes’. Thanks to the support information derived from the Internet, newspapers, magazines, 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 we followed the protocol described by Finch (2002), applied to management research by Anderson et al. (2010).

After this second phase, the conceptual subjects that emerged were reduced to thirty “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 make the conclusion and to build the "big picture" (Spiggle, 1994; Mayan, 2009). This was the real process of "theorizing. The figure below highlights the aggregation of the thirty categories in the six themes, which emerged from latent content analysis.

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Fig 2 about here

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4. Results and discussion

In this section, the authors present the results of latent content analysis (see Table 1) with the thirty categories identified in the interviews and associated with the following six conceptual themes: *process innovation, cost, value offered to the customer, revenues, profits, sustainability of competitive advantage*.

These conceptual themes are the main aspects that respondents have cited to explain the effects of AM during the interviews. We report the quotes that best exemplify the effects of AM on every aspect on the table for each conceptual category.

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Table 1 about here

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The six conceptual themes are illustrated graphically by the following conceptual scheme that illustrates how these affect the company's competitiveness.

Fig 3 about here

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 competitiveness. In other words, the six conceptual themes are the main aspects that influenced by this technology. Consequently, by examining the impact of AM on these elements is possible to understand the overall effects of this innovation on competitiveness (Mayan, 2009). Below we describe the primary empirical evidence resulting from interviews, concerning the impact of AM on the six conceptual themes arising from latent content analysis.

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 the AM has made significant process innovation in the gold industry. In the sector under analysis, the AM may be qualified as a process innovation. That type of production could previously only be carried through a long manual work done by highly skilled craftsmen. Consequently, one 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 of the reasons that push companies to internalize this technology is the need for absolute control over 3D printers for to hide information to competitors on the production 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 is a significant co-opted 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 their 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. These suppliers have high bargaining power due to the higher concentration of 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 determines advantage 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, we can talk about innovation that facilitates the process of creating new products without being born for this. After the introduction of AM, the analyzed firms in the sample can create objects with complex geometries that were impossible to do by hand. It has allowed firms to offer new products with the greater value offered which forces willingness to pay higher prices by customers. On the contrary, 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 told 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 and Mairesse, 2009) as it allows the access to new markets, new segments, and competition no longer based only on cost but also on design and complexity of sold items.

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

4.4.Effects on Revenues

Concerning revenues, case studies show that AM has affected the revenues through two main effects.

Firstly, 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 sold quantity, AM has affected mainly sale price, as stated in the words of manager of 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."*

Secondly, the creation of new products has allowed the access to new market segments according to the managers' opinion. In particular, AM made firms competitive under the cost side by producing handcrafted items in mass, the use of the AM has allowed firms in the sample to produce high refined items at reasonable prices. It allows firms to enter in a mass-market with products which before the introduction AM were reserved only to and high-end market due to high selling prices.

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

Insight 4: AM affects revenues thanks to a better willingness to pay by costumers.

4.5.Effects on Profits

Regarding the impact of AM in profitability, case studies show a positive impact. It is possible due to higher revenues in the face of 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 SMEs. In fact, the product innovations allowed by AM can cause a better value offered to customers, an increase in the willingness to pay and to get into new market segments, resulting in an improvement in the revenue stream. The positive impact on competitiveness made by AM introduction is in agreement with the literature findings literature 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.

Insights 5: AM impacts on profits thanks to possibility to access new markets and segments.

4.6.Effects on Sustainability of Competitive Advantage

The sum of the aforementioned results converges in a better competitive advantage as shown in Figure 3 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 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, in such a case, 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 push the firms inside that district to improve products quality. The final result of this competition shows their outcomes in a better aggregate competitive advantages for all the firms in the district.

Finally, the main competitive advantage created by AM regards the competition within developing countries. As 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 create a cascading effects that converges in a better competitive advantage for the single firm as well at district level.

5. Conclusion

The case studies showed that AM can improve the competitiveness of SMEs. In fact, innovation allowed by AM can create a bigger value offered to customers, an increase in the willingness to pay and to get into new market segments, resulting in an improvement in the revenue stream. These effects appear to be generalized and extended to firms in other sectors due to the primary effects of AM, among which we highlight: the impulse to product innovation, creating more value for customers, improving time to market, personalization and creative possibilities (Martinez - Ros, 1999; Hall et al., 2009; Reichstein and Salter, 2006; Love and Roper, 2015). The effects on costs appear more related to the sector and manufacturing processes instead. The AM determines the common effects of process innovations identified by the literature: promotes product innovation and improve business competitiveness, but acting more on revenues than on cost reduction (Becheikh et al., 2006).

We can, therefore, say that AM can be a viable development path for the manufacturing sector. In particular, this technology has proven its effectiveness in the areas where it is required the production of complex objects by going to affect production costs, and especially in the possibility to turn a small-scale production in a large-scale production (Mellor and Zhang, 2014). This fact, along with a low adoption cost seems particularly interesting SMEs growth is making them 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 difficult to product imitation thanks to a high technical and design knowledge.

Hence, AM seems to favor innovation and growth process manufacturing firms, since the introduction of this innovation is a primary competitive factor that becomes a critical role in customer service and activities. In this context, the introduction of AM can allow SMEs in countries with mature economies to remain competitive. It is possible due to the growing

direction of service typical of the service sector in which economic activity has gradually moved in the direction of service industries.

The last fundamental consideration is that the 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. We also aim to stimulate the attention of decision makers towards process innovations and its effect on firm competitiveness.

In conclusion, it should be noted that our work has limitations related to sample size and analysis of a single industry. As a result, the possible developments for future research may consist in the study of the effects of AM on the competitiveness of companies in different industries. 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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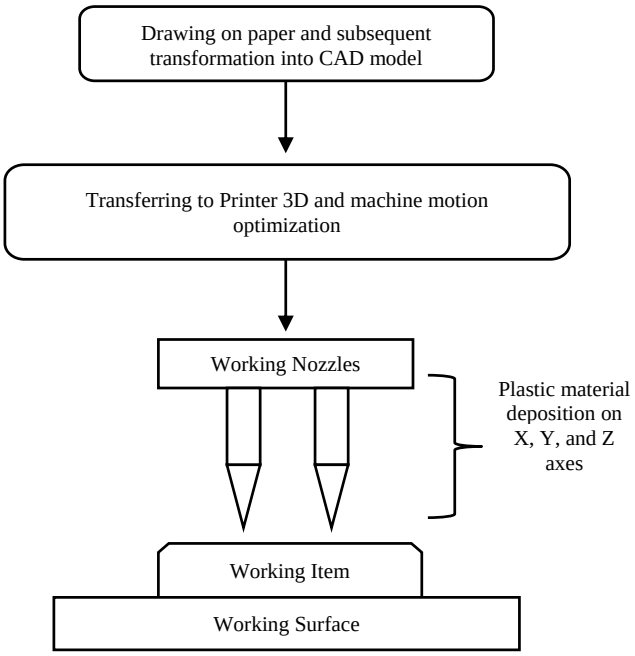

Figure 1: Schematization of how 3D printer works.

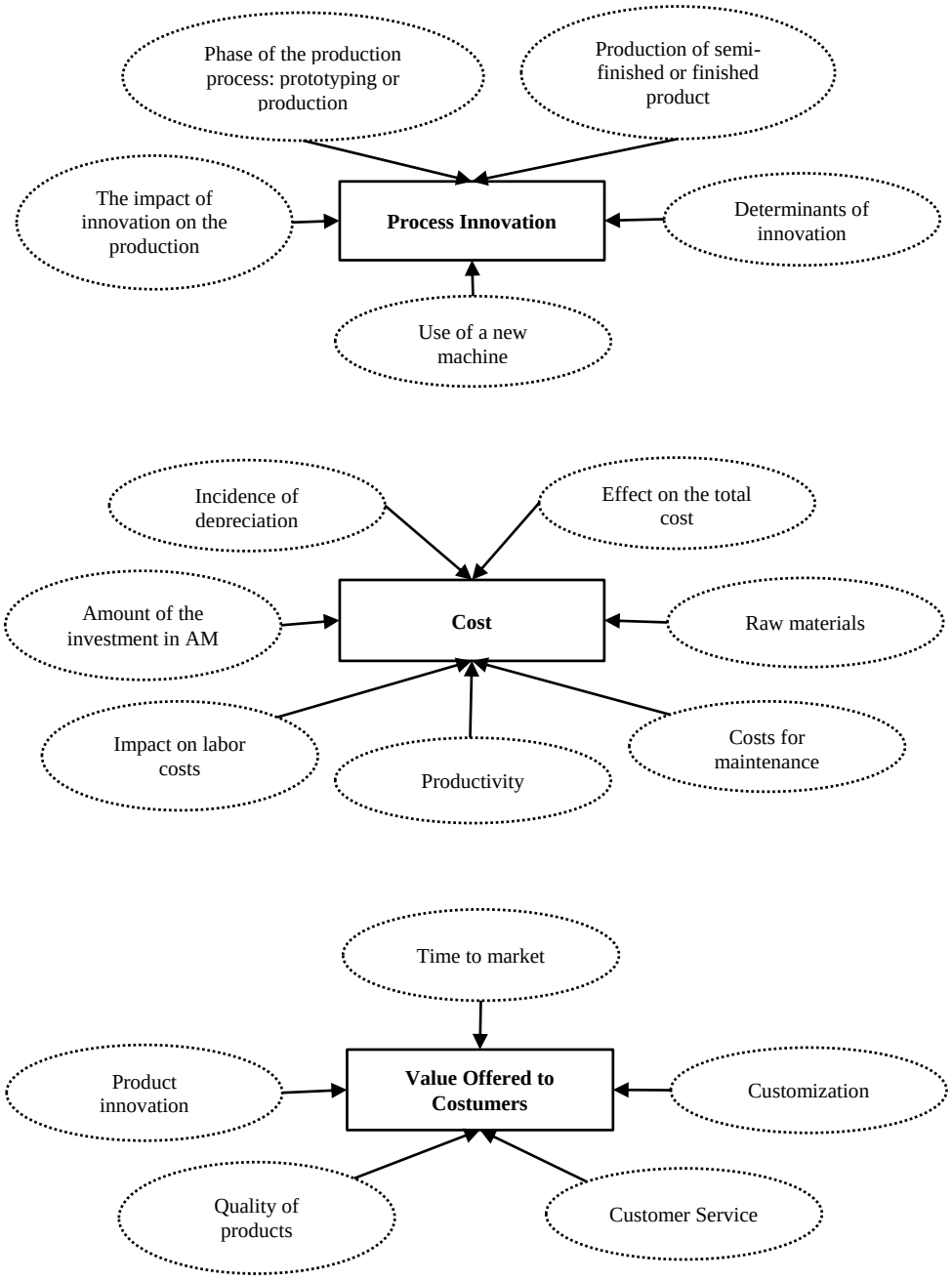

Figure 2: Latent Content Analysis, from Categories to Themes
(continues in the page below)

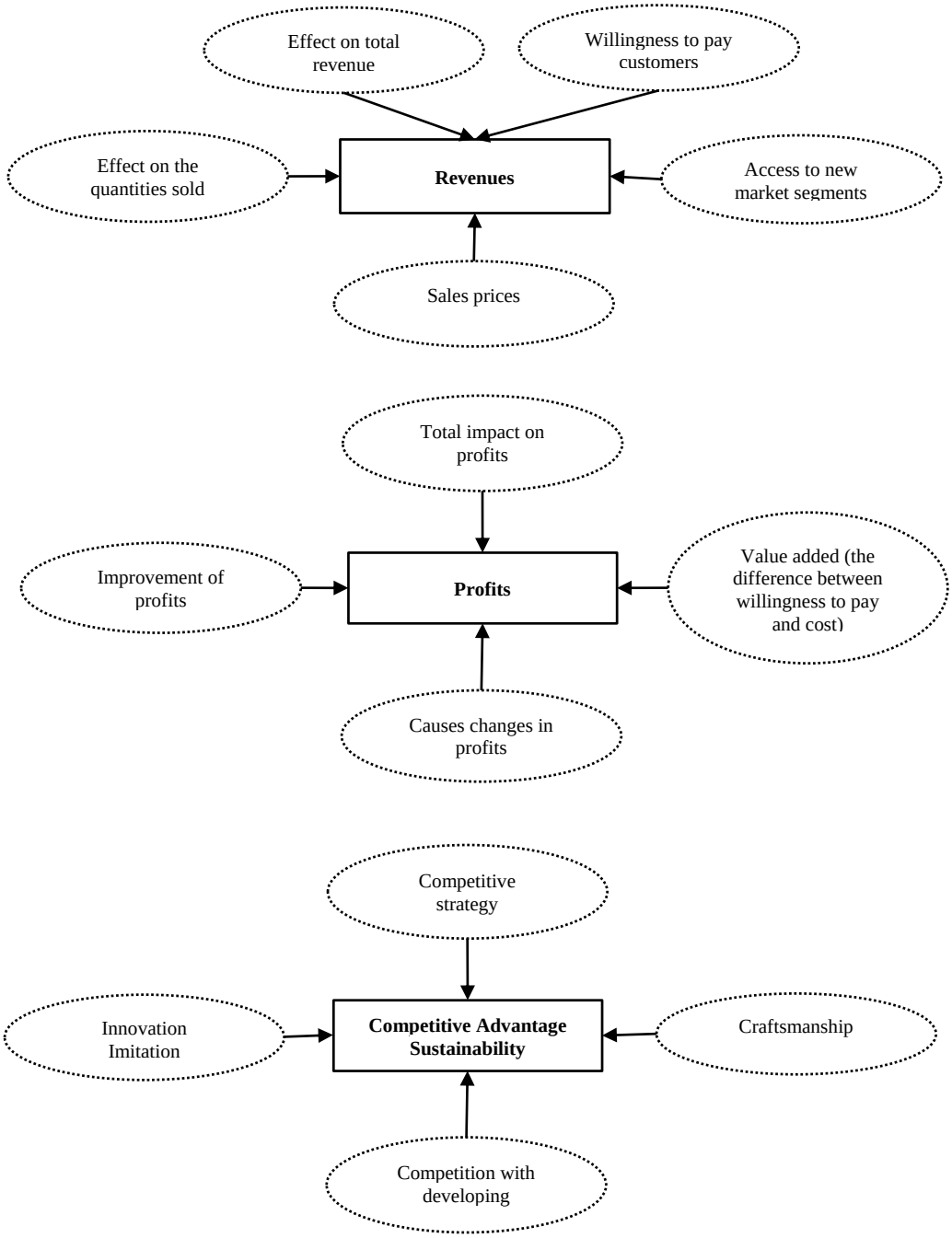

Figure 2: Latent Content Analysis, from Categories to Themes

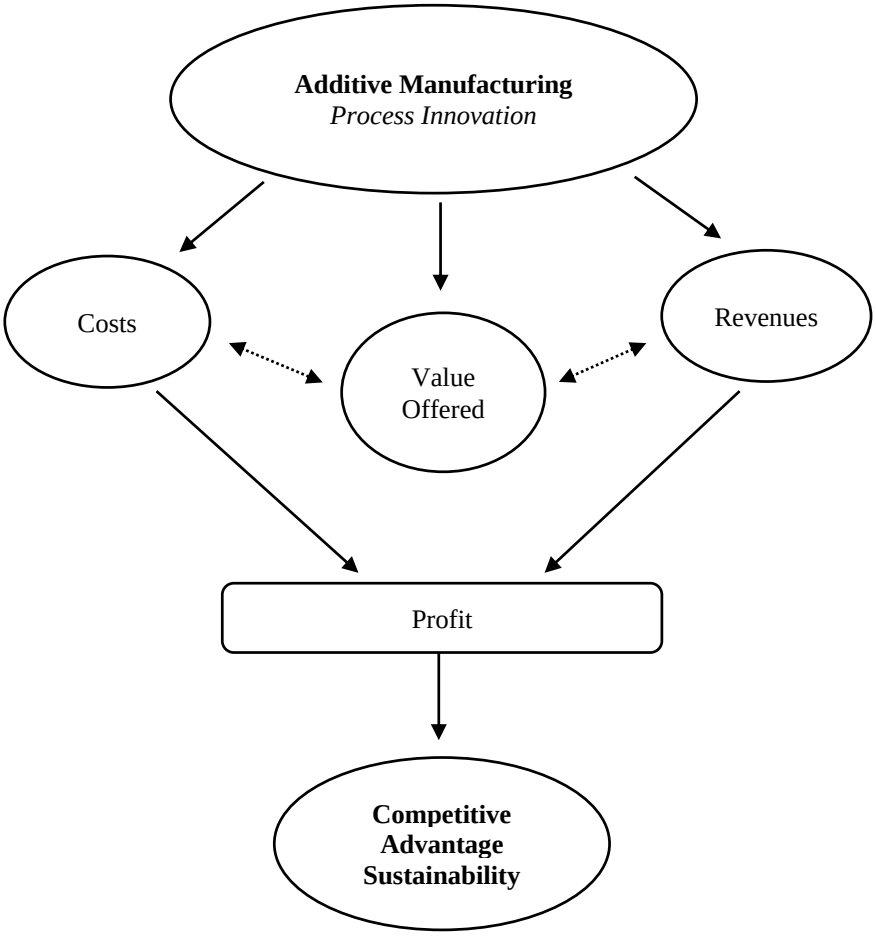

Figure 3: Conceptual Framework of AM effects

Tables

Categories	Themes	Quotes
•Phase of the production process: prototyping or production •Production of semi-finished or finished product •The impact of innovation on the production process •Determinants of innovation •Use of a new machine	**Process Innovation**	*"I was the first to introduce the 3D printing in the gold sector ... The gold sector was the first in which the manufacturing sector has spread the use of 3D printing at 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 "* *"The new frontier will be the direct production of jewellery through the sintering of powders of metals"*
• Amount of the investment in 3D Printer • Incidence of depreciation • Effect on the total cost • Impact on labour costs • Raw materials • Costs for maintenance • Productivity	**Cost**	*"It is good to point out right away that the introduction of 3D printing has not led to lower costs, but rather we have a slight increase caused the amortization, the costs of maintenance, costs for staff training and especially costs for the raw materials ... 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 "*
• Product innovation • Quality of products • Time to market • Customization • Customer Service	**Value Offered**	*"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"* *"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"*
• Effect on total revenue • Effect on the quantities sold • Willingness to pay customers • Sales prices • Access to new market segments	**Revenues**	*"Revenue increased primarily due to higher selling prices, made possible by the improvement in the quality of products ... The amount did not increase, and also with 3D printers we have industrialized the production of small batches"*
• Total impact on profits • Improvement of profits • Causes changes in profits •Value added the difference between willingness to pay and cost)	**Profit**	*"Profits have improved thanks to higher revenues, compared with a substantial stability of costs"* *"The main cause of the profit improvement has been the increase in sales prices"*
• Competitive strategy • Innovation Imitation • Craftsmanship • Competition with developing countries	**Competitive Advantage Sustainability**	*"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"* *"This technology allows us not to fear the threat of developing countries, which are less likely to invest in technology and in any case it is better to compete on technology than on labour costs, for which we should come to terms with the phenomena of "social dumping" instead".*

Table 1: Categories, Themes and Quotes Examples