Investigaciones Regionales - Journal of Regional Research
ISSN: 1695-7253
ISSN: 2340-2717
investig.regionales@aecr.org
Asociación Española de Ciencia Regional
España

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Investigaciones Regionales - Journal of Regional Research, no. 39, 2017, pp. 39-57
Asociación Española de Ciencia Regional
España

© *Investigaciones Regionales — Journal of Regional Research, 39 (2017) — Pages 39 to 57*
Section ARTICLES

Journal of Regional Research Investigaciones Regionales

Disruptive Technological Innovations as New Opportunities for Mature Industrial Clusters. The Case of Digital Printing Innovation in the Spanish Ceramic Tile Cluster

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ABSTRACT: Over the last few decades, many studies have focused on the role that incremental innovations play in cluster contexts. However, few authors have analysed the impact of disruptive innovations on these entities. The present research analyses the emergence, development and dissemination of a disruptive technological innovation in an industrial cluster. In particular, we study the case of the introduction of inkjet printing technology in the Spanish ceramic cluster as a paradigm of how a disruptive innovation can impact the industry's value chain. This technological change ended up revolutionizing what was considered a mature and stable sector. In short, we will describe how a disruptive technological innovation is capable of renewing the life cycle of a cluster favouring the recovery of competitiveness and, even, creating new opportunities for diversification.

JEL Classification: O30; O32; O33.

Keywords: disruptive technological innovation; industrial cluster; digital printing; inkjet technology; ceramic tile industry.

Innovaciones tecnológicas disruptivas como nuevas oportunidades para los clústeres industriales maduros. El caso de la tecnología de impresión digital en el clúster cerámico español

RESUMEN: En las últimas décadas, muchos estudios se han centrado en el papel que desempeñan las innovaciones incrementales en el ámbito de los clústeres. Sin embargo, pocos autores han analizado el impacto que las innovaciones disruptivas o radicales han tenido en estas agrupaciones territoriales. La presente investigación analiza la generación, desarrollo y difusión de una innovación tecnológica disruptiva en el seno de un cluster industrial. En particular, estudiamos el caso de

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Received: 09 march 2017 / Accepted: 20 september 2017.

la introducción de la tecnología de impresión digital en el clúster cerámico español como paradigma del impacto que una innovación tecnológica disruptiva puede tener sobre la cadena de valor de una industria. Este cambio tecnológico ha revolucionado lo que se había considerado un sector maduro y estable. En conclusión, vamos a analizar cómo una innovación tecnológica disruptiva es capaz de renovar el ciclo de vida de un cluster, favoreciendo así la recuperación de la competitividad e, incluso, creando nuevas oportunidades para la diversificación de las empresas integrantes.

Clasificación JEL: O30; O32; O33.

Palabras clave: Innovación tecnológica disruptiva; clúster industrial; impresión digital; tecnología inkjet; industria cerámica.

1. Introduction

In the last decades, radical or disruptive innovations have received increasing attention from various authors (Charitou and Markides, 2002; Christensen, 1997; Tellis, 2006). Unlike incremental innovations, radical innovations generate important transformations in products, markets or technologies, leading even to the obsolescence of existing ones (Chandy and Tellis, 2000).

In this work, we analyse the territorial dimension of these discontinuities, adopting the concept of *cluster* as a frame of reference (Becattini, 1979; Porter, 1990). It is important to point out that we consider a cluster as a network within a production context in a geographically defined area (Boschma and Ter Wal, 2007; Parrilli and Sacchetti, 2008). Most clusters are characterized by the prevalence of small firms, which have comparatively greater access to external knowledge resources than firms in other contexts. This fact is relevant since it can become an important source of innovation for cluster's firms.

However, the capacity of an agglomeration to create and develop disruptive innovations has been widely questioned for a long time by different authors in cluster literature. The literature developed by these authors argues that the dynamics of clusters seem to be much more appropriate for the generation and development of incremental or contextual innovations, to the detriment of radical or disruptive ones (Maskell, 2001). On the one hand, the proximity between companies, which facilitates the frequency of contacts and, on the other hand, the proximity between the actors, leads to the formation of a dense network structure, as well as strong relationships among the different actors. These characteristics often hinder the diffusion of new ideas as well as exclusive or more radical innovations (Molina-Morales, 2002).

In order to overcome the aforementioned limitations regarding generation of radical advances, many authors defend the need to open the cluster to external sources of knowledge (Belussi, Sammarra and Sedita, 2008). In that sense, authors as Sammarra (2005) or Biggiero (2006), proposed a selective relocation of certain activities out from the cluster. Other authors, such as Giuliani (2011), have focused on the role

played by technological *gatekeepers* in providing new ideas, knowledge or technologies which are subsequently developed and disseminated within the cluster.

The foregoing reflections and considerations have motivated our investigation. As far as we know, authors who have focused their approaches in the context of the cluster have rarely analysed the process leading to the generation and diffusion of disruptive innovations. These authors have typically focused on descriptions of the main actors, as well as their connections and other related issues. Our approach tries to go one step further and aims to focus on how clusters can achieve the development and diffusion of disruptive innovations which are able to reshape both the internal and external relationships in them.

With this aim, this work focuses on analysing the appearance of disruptive technological innovation (Markides, 2006), in the heart of the Spanish ceramic tile cluster. We refer to the so-called digital printing technology or inkjet technology. We will use this case to illustrate how this cluster has been able to capture a new technology coming from abroad and later, to develop it internally, adapting it to the cluster idiosyncrasy and even spreading the adapted technology successfully beyond its boundaries.

Finally, our study shows how the deep knowledge acquired by key players in the cluster, as well as the new skills they developed, provide them with new competencies that can be used in other industrial sectors. In fact, the new technology has created many diversification opportunities for those companies which realized their potential and successfully transferred this knowledge to other industrial fields similar to the ceramic one.

2. Theoretical framework

2.1. Disruptive innovations

Nowadays, companies and organizations are constantly struggling to create and introduce product, process and service innovations in the markets (Bayus, Griffin and Lehmann, 1998). In fact, a company's innovation capacity has probably become one of the best indicators of value creation for the company (Tsai and Ghoshal, 1998). In the context of our research, we consider the distinction between incremental and disruptive innovations to be particularly relevant.

The first approach to the generic concept of disruptive innovation is due to the Schumpeterian notion of *creative destruction* (Schumpeter, 1942). Later, the differentiation between the concepts of incremental and disruptive innovation was introduced by Abernathy y Utterback (1978) and by Abernathy y Clark (1985). Unlike incremental innovations, disruptions produce fundamental changes, revolutions in technology, clearly diverging from existing practices (Ettlie, 1983; Ettlie, Bridges, and O'Keefe, 1984). These innovations are important ways of expanding and developing new markets, as well as providing new functionalities which, in

turn, radically change the existing links of the market. It leads to the obsolescence of not only products but also technological and market capacities (Bower and Christensen, 1996; Christensen and Raynor, 2003; Danneels, 2004). As the interest of researchers increased, this concept has widened its scope to encompass different types of innovation. Currently, under the term *disruptive innovation* we will find business model innovations, radical product innovations or technological ones (Markides, 2006). The concept of disruption in the innovation literature has emerged recently as something strategically important (Assink, 2006; Charitou and Markides, 2002; Gilbert, 2003; Govindarajan and Kopalle, 2006; Henderson and Clark, 1990).

2.2. Creation and diffusion of innovations in cluster contexts

Clusters present peculiar dynamics regarding the generation and development of innovations. Most of the literature describes how the fact of belonging to a cluster generates a positive effect that catalyses the innovation of those companies who belong to it (Inkpen and Tsang, 2005; Tallman, Jenkins, Henry, and Pinch, 2004). However, as it has been proposed in other different researches, these companies need to combine the close and intense relationships, naturally generated in the cluster, with distant and out-of-the-cluster ones in order to access to global sources of knowledge (Corò and Grandinetti, 1999).

In the attempt of describing the inter-organizational relationships within industrial clusters, the metaphor of the network has been widely used; in this, physical proximity and sense of belonging are key elements that facilitate trust, reciprocity and other common values (Antonelli, 2000). From a relational perspective, the cluster is described as a cohesive and dense network made up of strong contacts. As a result, companies can potentially benefit from a certain efficiency when exploiting the opportunities that have arisen through the exchange of high-quality information, tacit knowledge and cooperative exchange.

On the contrary, following the same logic, the companies in the cluster may have problems to access to new and unique information. For example, Glasmeier (1991) in terms similar to those of Harrison (1994), described how Swiss watchmakers presented weaknesses in responding to disruptive technological changes from outside the district; and thus generated a competitive disadvantage.

In a way, the above argument is controversial, since there are many counterexamples that describe how industrial clusters are able to access new opportunities. In fact, other cases show that the existence of these industrial concentrations benefits the companies that integrate them both in relation to exploitation and exploration advantages. Saxenian (1991), for instance, found out that, in the rapidly changing environment of the information technology industry, especially in Silicon Valley, firms had abandoned the large number of distant relationships with suppliers to establish instead a small and selected number of relationships nearby.

3. Empirical framework

3.1. Context of the research

The present study focuses its research context in the ceramic industry and more specifically in the Spanish ceramic tile cluster. On the other hand, it is based on the analysis of the digital printing technology introduction in the cluster. The digital printing technology could be considered as a disruptive technological innovation as we will expose subsequently.

3.1.1. The ceramic industry and the Spanish ceramic tile cluster

In general terms, the manufacturing tile companies are grouped worldwide in the form of clusters or industrial districts. The ceramic tile industry is considered as a highly dynamic and competitive industry where technological advances, focused mainly on processes and products, are frequent (Russo, 1985). The result is an agile sector which is continuously moving towards high-technical and aesthetical products, quality excellence, efficiency and processes optimization. The strategy of this industry is mainly based on the reduction of energy consumption and environmental impact, the increase of flexibility and reduction of the productive cycle (Budí-Orduña, 2008).

This ceramic sector is also characterized by its intensity in terms of knowledge transmission. Mechanisms such as the constant creation of companies, the mobility of human resources and an informal channel of communication among the members of the cluster community are the basis of this characteristic (Molina-Morales, 2002).

The Spanish ceramic tile cluster is located in the province of Castellón and covers all activities of the ceramic industry value chain. Previous research has identified this territorial grouping as the paradigm of an Marshallian-type industrial cluster (Boix, 2009). This industry includes, on the one hand, the end-product companies —which are engaged in the production of pavements and ceramic tiles— and, on the other hand, a wide range of companies engaged in related secondary activities, such as, distribution of raw materials, manufacturing of frits and enamels, development of chemical additives, manufacturing of machinery, or other services such as, trading services. In addition, this cluster includes a number of public and private institutions as well as a set of organizations and associations that provide technical, logistic and knowledge support. Finally, R&D centres, the local university, local vocational training centres, business associations and trading companies also support and guide production companies towards business excellence and continuous improvement.

The Spanish ceramic tile cluster produced in 2016 the 94% of the total of the ceramic tiles manufactured in Spain. The 80% of Spanish ceramic tile companies are located in this area (ASCER, 2016). It is composed of about 100 end-product companies and over 1000 related-companies that are performing secondary activities. The business volume achieved in 2016 reached 4800 million of euros (ANFFECC, 2016; ASCER, 2016).

Focusing exclusively on the end-product companies, its annual production volume has reached in 2016 the 492 million of square meters. They generated in 2016 a turnover of 3,316 million of euros. These companies export the 80% of the total sales volume. The Spanish ceramic tile cluster is the first producer and exporter in Europe and the second exporter in the world. Finally, the Spanish ceramic tile industry is considered the third contributor sector to surplus of the Spanish coffers (ASCER, 2016).

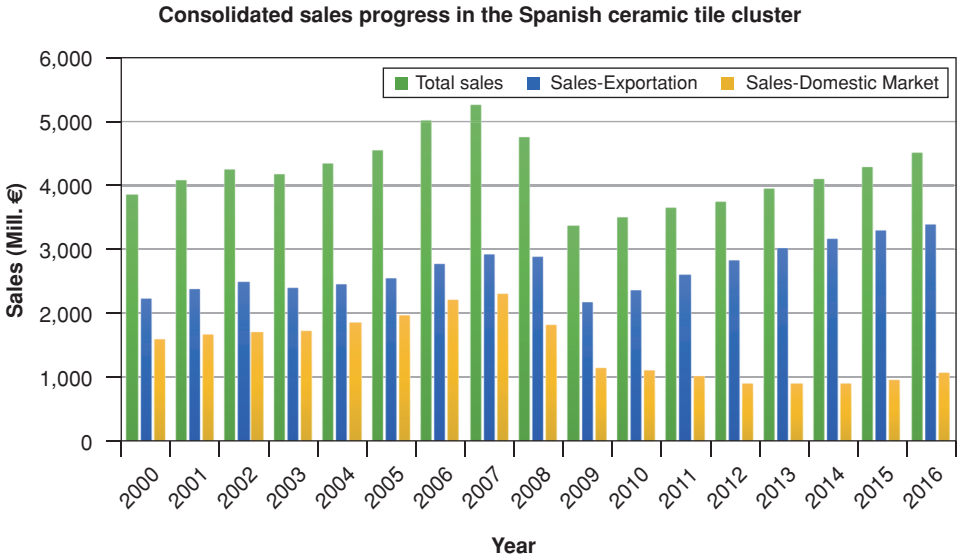
In order to contextualize the innovation in the period [2000-2016], Table 1 and Figure 1 show the evolution of the cluster from a business point of view performed by the end-product manufacturers and by the frits, enamels and digital ceramic inks manufacturers (which are the main secondary industry of the cluster itself). In this respect we must emphasize that innovation was widely introduced in the cluster around 2009-2010. Unfortunately, we are not able to directly infer that the change of trend in the evolution of the business was exclusively due to this fact.

Table 1. Evolution of sales of ceramic tiles manufacturers and frits, enamels and digital ink manufacturers

Total sales of ceramic tile companies (mill. €)					*Total sales of frits and digital inks companies (mill. €)*			
	Total sales	*Exporting sales*	*Domestic sales*			*Total sales*	*Exporting sales*	*Domestic sales*
2000	3.137,50	1.872,10	1.265,40		**2000**	726,20	376,50	349,70
2001	3.302,50	1.987,80	1.314,70		**2001**	789,30	405,80	383,50
2002	3.420,10	2.059,30	1.360,80		**2002**	835,90	458,00	377,90
2003	3.317,50	1.939,10	1.378,40		**2003**	860,00	483,00	377,00
2004	3.477,00	1.977,30	1.499,70		**2004**	885,00	505,00	380,00
2005	3.650,20	2.040,90	1.609,30		**2005**	911,00	532,00	379,00
2006	3.982,20	2.183,10	1.799,10		**2006**	1.033,10	602,00	431,10
2007	4.166,00	2.295,00	1.871,00		**2007**	1.097,50	641,00	456,50
2008	3.671,00	2.210,00	1.460,00		**2008**	1.087,60	700,27	387,33
2009	2.591,00	1.673,00	918,00		**2009**	794,02	529,57	264,45
2010	2.547,00	1.746,00	801,00		**2010**	976,98	640,79	336,19
2011	2.597,00	1.892,00	705,00		**2011**	1.065,73	733,27	332,46
2012	2.656,00	2.082,00	575,00		**2012**	1.109,36	768,55	354,75
2013	2.800,00	2.240,00	560,00		**2013**	1.159,32	792,10	367,21
2014	2.900,00	2.328,00	575,00		**2014**	1.202,16	845,62	356,53
2015	3.095,00	2.452,00	643,00		**2015**	1.194,79	853,77	341,02
2016	3.316,00	2.570,00	746,00		**2016**	1.203,23	843,02	360,22

Source: elaborated by authors from ASCER (2016) and ANFFECC (2016).

Figure 1. Consolidated sales of ceramic tiles manufacturers and frits, enamels and digital ink manufacturers

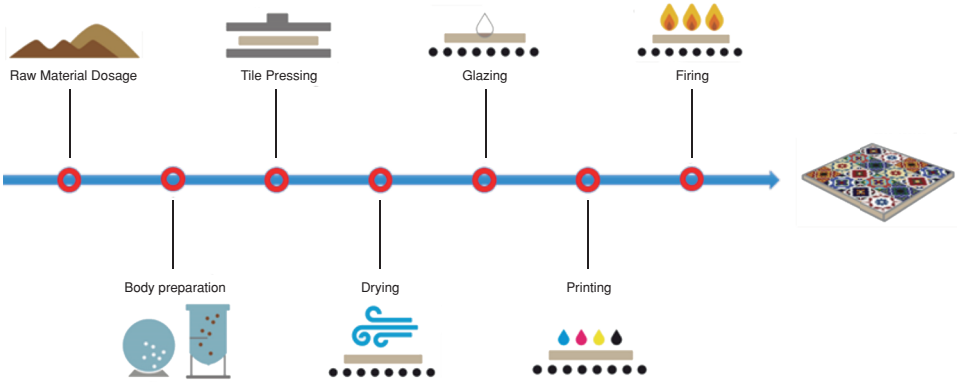


Source: elaborated by authors from ASCER (2016) and ANFFECC (2016).

3.1.2. How new technology impacts on ceramic tile manufacturing process

The disruptive technological innovation described in the present research is based on the introduction of digital printing technology (inkjet technology) as a new technique of tile decoration. In general terms, the ceramic tile manufacturing process consists of seven basic stages (see Figure 2).

Figure 2. Ceramic tile manufacturing process



Source: elaborated by authors.

In this context, it is important to highlight that decoration stage, in the ceramic industry, is one of the most relevant in the business value chain. In fact, decoration is the most important way to differentiate from competitors and to take position in the market. In addition, a significant part of the total manufacturing cost belongs to decoration. It is estimated that decoration cost constitutes from 30% to 50% of the total direct manufacturing cost.

Furthermore, decoration of tiles involves providing them with design and colour by means of a printing technique. For decades, this procedure has been carried out by the screen printing technique. The screen printing technique is a fully mechanical process which is performed by manual adjustments and therefore, it is rigid, inefficient and irreproducible.

3.2. Data source

3.2.1. Participant observation

We understand participant observation as the process that empowers researchers to learn about the activities which are being studied in their natural setting through observation and participating in their activities (Martínez, 2006). In our case, members of the research group have participated for a long period of time in the phenomenon under study being in permanent contact with the most relevant actors of the technological change. Moreover, they have participated actively in the development and diffusion of such change. Our research has benefited from the fact that one of the researchers has developed part of his professional career in one of the leading companies of the Spanish ceramic tile cluster. As a technical manager, taking responsibility of an applied digital inks research department, this author has collaborated in the development of the new technology through his investigations, obtaining information from the phenomenon under study from an internal perspective (Mayring, 2002). In this way, we have been able to observe the phenomenon: (a) in its natural situation; (b) in real time; (c) with a preferential situation to access to information related to the phenomenon (Punch, 2013).

From 2002 to 2016, we received the impressions and testimonies of those agents who were directly involved in the establishment, development and promotion of inkjet technology worldwide. We observed from a preferential position the impact that this new technology produced in the value chain of the ceramic tile industry, not only in Spain but also in other countries such as Italy, Brazil, China or India.

On the other hand, we had the possibility of having a constant and durable contact with companies and actors in diverse countries such as Chile, Thailand, Portugal, Italy or Canada which, despite the fact of not being industries linked with ceramic manufacturing, they have been connected in some way with digital printing.

3.2.2. Interviews and other secondary sources

In order to understand and analyse the most relevant aspects of the present study, we have used triangulation techniques (a combination of different methods and data sources). We have conducted numerous interviews, around 50, with actors that have different professional profiles such as company managers, technical managers, commercial managers and manufacturing line managers or laboratory technicians. The interviews were carried out both for members of the Spanish ceramic tile cluster and members of other ceramic tile clusters in different places around the world. We had the opportunity to meet with other relevant figures as well which, not belonging to the ceramic tile industry, are directly linked to the innovation under study. The companies or organizations interviewed are listed below:

- New technology suppliers (digital ceramic printer manufacturers).
- New material suppliers (digital ceramic ink manufacturers).
- Digital components suppliers (electronic components manufacturers for digital printing which belong to different inkjet clusters such as the Japanese or the English inkjet clusters).
- Chemical products suppliers. These components are part of the digital ceramic inks (solvents and additives suppliers).
- Tile manufacturers. These companies used the old printing technology and have assimilated the new technology over the time.
- Companies from diverse industries which adopted the new technology in recent past.
- Companies from diverse industries that were about adopting the new technology. These companies were willing to benefit from the ceramic sector experience in order to rapidly introduce the innovation in their respective sectors.
- Technological institutes, not only those which belong to the ceramic field but also those belonging to other sectors such as textiles, plastics or building materials where digital printing had already been introduced or were about to.

We performed semi-structured interviews where the information obtained was recorded and analysed in order to get a global overview about how, from different points of view (technical and business), the changes in the value chain of the ceramic tile industry were being developed.

Along with this constant and close source of knowledge, data and information were also collected from a variety of secondary sources such as internal industry documents or reports, academic publications and well-informed opinions describing the inkjet phenomenon in all its magnitude.

3.3. Analysis method

Our research is based on a case study as a method of analysis. This method allows us to explore the phenomenon in its own context making use of a variety of sources and data. The data comes largely from documentation, interviews, direct

observations, participant observation and contacts (Yin, 1989). This ensures that our research addresses the phenomenon from different points of view and provides a holistic understanding of it. Through these stories, participants have expressed their own points of view and this has allowed researchers to better understand the actions of the participants (Lather, 1992).

Yin (2003) classifies case studies in explanatory, exploratory, and descriptive. According to this classification, our approach can be categorized as a descriptive case study as it describes a phenomenon as well as the actual context in which it occurs (Yin, 2003).

This approach, has allowed us to know «how and why» this technology has become in one of the most important sources of innovation in recent decades in the ceramic tile industry.

4. Results

4.1. Description of the disruptive technological innovation: digital printing as a revolutionary way of decorating ceramic tiles

We consider the innovation under study as disruptive because it radically changes the way in which the tiles are printed. Tile printing technology shifts from a mechanical technique to a non-contact and digital one. The new printing system (which may be comparable to a home paper printer) is mainly based on software which process images and a digital inkjet system that shoots the ceramic dye on the tile. The basis of the innovation lies in the substitution of a mechanical and non-reproducible technique by a digital one taking into account everything that the digital term means.

The origin of this new technology goes back to 1998, when a Spanish computer engineer —whom we could consider a *visionary agent*— designed and developed a digital tile printing prototype based on a printhead technology which was previously developed in inkjet clusters both from England and Japan. Later, this computer engineer founded Kerajet, a company that nowadays is the world leader in its sector (Albors-Garrigos and Hervas-Oliver, 2013).

Since the launch of the first digital printer in 2000, tile digital printing has undergone a series of further developments and improvements have been continuous. In fact, the massive adoption of the technology did not take place immediately after the innovation's emergence. A period of eight years elapsed before a real and effective diffusion of technology. In fact, it is estimated that in the period comprising 2000 and 2010, just around 100 printing machines were installed worldwide, while from 2010 to 2015 the number of machines installed (see Table 2) reached approximately the figure of 6,500 (Ferrari, 2016). It was on the first aforementioned period —more specifically between the years 2000 and 2008— when the

innovation appeared and evolved up to the point of being considered as a robust technique, competitive and efficient enough to be massively adopted by the ceramic tile industry worldwide. At this early stage of development, three key factors can be considered as responsible for the innovation's success. These three factors can be summarized as follows:

— The initial resistance to change shown by some of the traditional technological leaders was counteracted by the emergence of new actors associated with emerging technology. They were led by the *visionary agent* who developed the technology in a first place. We are referring to digital ceramic printer manufacturers (led by the aforementioned company called Kerajet) and to digital ceramic ink manufacturers, who quickly developed new skills and specific knowledge related to inkjet technology. Indeed, in the early stages, Italian machinery companies —which were technological leaders at that moment- were very reluctant to adopt the innovation. They faced this threat trying to improve their own leading technology in an effort to persist in a technological environment much more controllable by them.

— The new players, who already had very strong ties within the ceramic tile cluster, because they were members of it, were able to develop new ties with diverse external agents to the ceramic sector. This fact was, from a strategic point of view, a key point in the stage of consolidation for the new technology. Key external agents included printhead manufacturers, colour management software developers, microelectronics manufacturers or manufacturers of ultra-fine grinding systems.

— From a technical point of view, during this period, new technology improved and became feasible enough to be introduced as a reliable substitute of the traditional ceramic decorating process. These advances were crucial for the massive adoption of the technology. They were mainly focused on two fields:

  • *Printhead technology:* printhead manufacturers early realized that the ceramic sector had a big potential in terms of business and decided to adapt their printheads to those new ceramics materials which were not printed before. They modified the printhead design to be more reliable and to increase the printing quality.
  • *Digital ceramic ink technology*: ink formulations evolved from water-based soluble inks to oil based-pigment dispersion inks. This fact led to a reduction in the cost of the inks as well as to an increase of their reliability. Besides, chromatic possibilities were widened as pigments offer a wider colour variety. In conclusion aesthetic possibilities were extended at a lower cost.

In summary, on the early stage of the innovation, some key factors led to the consolidation of the digital tile printing technology making the innovation into a success story. In fact, data in Table 2 shows the successful evolution of the conversion rate to the new technology in the world ceramic tile industry (number of decorative digital lines installed relative to existing decorative lines, digital and traditional). By 2015, the 72% of the world's decoration lines were digital (Ferrari, 2016).

Table 2. Evolution in time of decorative lines conversion rate to digital technology. Number of digital printers installed over the last five years

Year	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
Digital printers installed yearly	—	397	951	2,049	1,537	1,216
Total number of digital printers in operation.	333	730	1,681	3,730	5,267	6,483
Conversion rate to new technology	5%	9%	21%	45%	60%	72%
Total number of estimated decorative lines	—	—	8,000	8,400	8,800	9,000

Source: Elaborated by authors from Ferrari (2016).

4.2. Main consequences of innovation

Although, in a first approximation, this technological innovation may seem subtle or minor (it is simply a matter of evolving from analogue to digital), when analysing the consequences that derive from it, we can talk about a successful case. In fact, this innovation modifies and improves in a great extent different aspects of the ceramic tile industry, beyond the simple technical considerations.

The changes that digital printing has produced in the ceramic industry can be divided into: (a) sectorial leadership; (b) production process; (c) competitiveness and (d) product portfolio.

In terms of sectorial leadership, as we have introduced in the previous section, technological leaders faced innovation in different ways. This fact led to a major shift in leadership positions within the cluster. While some leaders —Italian machinery manufacturers— lost their dominant position, other actors —the Spanish manufacturers of frits and enamels— followed with interest the innovation since its appearance. As soon as they perceived the new opportunity that was coming up, they design a strong plan of investment focussed in R&D in order to adapt their business to the new technology. As a result, Spanish manufacturers of frits and enamels became the main producers of ceramic inks to supply the new printers. They soon created new and successful business units, achieving a stronger position and consolidating a technological leadership that still continues today. In relation with cluster roles, the case study shows how some actors that we could consider as *gatekeepers*, due to fact that they behave as focal agents that mobilize the knowledge in the clusters (Agrawal and Cockburn, 2003), lost this intermediation role being replaced by a series of new technological leaders (among them the computer engineer who acted as a *visionary agent* of the new technology). This case reinforces the thesis of some authors who express the difficulty that the traditional gatekeepers have to introduce real new knowledge in the cluster (Molina-Morales, 2002).

Regarding the manufacturing process benefits, the innovation has completely changed the layout of the printing lines as well as the manufacturing speed. The inkjet technology allows not only to shorten the space required for the printing stage but also to increase the celerity of the manufacturing process.

Furthermore, and in relation with competitiveness aspects, the innovation has improved the efficiency of the printing process allowing to increase the average manufacturing quality and to reduce most of the costs associated with the decoration process. In fact, one of the major consequences on this point is the gap reduction between high-quality and low-quality producers. In fact, the new decorative technique stabilizes the quality making it more regular. It is precisely this point the one that has led to a transversal adoption of the innovation by every single category of ceramic tile manufacturers, both those dedicated to low-cost product and those who bet on a differentiated high-end product.

On the other hand, the introduction of the digital printing, has reduced the threshold for an economy of scale as far as manufacturing costs of short lots doesn't increase significantly. In fact, costs associated to traditional ceramic tile decoration are relatively higher than those associated to digital even for large production lots. We are considering costs associated to wastes, the defective finished products (which are undeniably linked to traditional printing technology) and fruitless time consumption due to a continuous need of re-adjustment of the traditional machinery to avoid manufacturing defects (line breaks and workforce requirements). Digital decoration reduces these costs to virtually zero which makes it a much more competitive technology.

In terms of product portfolio, the digital printing technology has, somehow, opened new opportunities. The industry perceives now as feasible what was thought to be impossible with the traditional technique. Large tile formats, a wide variety of designs and a new and broad range of colours are the main elements that have favoured the expansion of the company portfolios.

4.3. Implications of the innovation in the basic strategic lines of the companies and the consequences on the overall strategy of the Spanish ceramic tile cluster.

The consequences regarding the adoption of the digital printing technology have a two-level impact on business strategy. On the one hand, there is an impact on basic business strategy for cluster firms but on the other hand, there is an impact on the overall strategy of the Spanish ceramic tile cluster.

4.3.1. Impact on companies' basic business strategies

As a result of our research, we may conclude that the disruptive technology allows ceramic tile companies to concurrently address the two basic strategies: product differentiation and cost reduction. Under this new perspective, companies can reconsider their strategic choice, since they can opt for new competitive positions. In accordance with the main strategic options proposed by Porter (1985), we can clas-

sify the main changes derived from the appearance of the digital printing technology based on the impact in terms of product differentiation or cost leadership.

Regarding product differentiation, it is important to emphasize that, as described above, the new technology enhance the aesthetic properties of the manufactured products, as well as the product portfolios offered by the companies. Both the design performance and the development of new products have benefited enormously from this technological change.

There are a variety of examples that could be used to explain the effect produced by the innovation on product differentiation. Tile formats, for example, can now be larger, as new non-contact technology makes it feasible. Products are richer, as well, in terms of graphic detail and amplitude of chromatic range. In addition, new product development process itself has been greatly simplified, allowing design departments to work faster and more efficiently and to expand the number of prototypes. Consequently, time-to-market of new collections has been reduced considerably.

Regarding cost leadership, the shift from an analogue to a digital technology has led to the elimination of two low-efficient sub-stages linked to traditional printing process; the preparation of coloured dye and the colour set-up of the product. This drives to an increase in production efficiency and a reduction in decoration costs. In addition, costs associated with consumable materials (such as traditional silk screen displays) have been reduced. On the other hand, new technology reduces downtimes traditionally associated to ceramic decoration lines. The necessary adjustments to fit the graphic and tonality problems are reduced considerably since they are no longer manual. Generally speaking, downtimes are a major problem in the ceramic tile sector as in other industries operating continuously. They not only reduce the efficiency of the process, but also produce low-quality products, reducing profitability eventually.

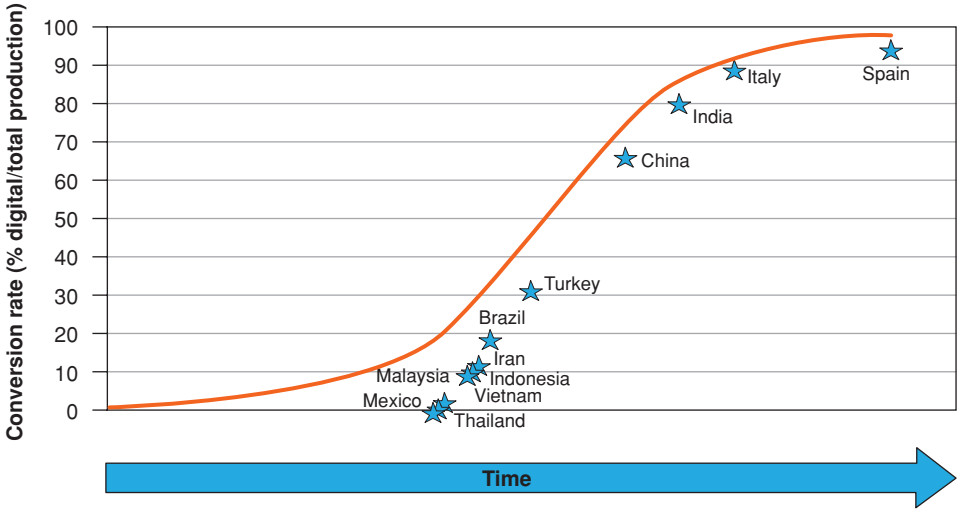
Logistic costs are also significantly reduced. Manufacturing managers can shorten production batches because to switch from one printing pattern to another is, in digital, easier, faster and less costly. As a direct consequence, stocks of intermediate and final products can be limited and the company's response can be adapted quicker to the market demand.

Finally, linked to the aforementioned productive and logistic advantages, firms' financial needs can be reduced. In fact, working capital requirements are lower due to the fact that the stocks of final product, secondary-quality products, raw materials and intermediate products are reduced.

In order to reinforce our conclusion, Figure 3 shows how, in 2015, four countries have fully adopted digital printing technology. They are Spain, Italy, China and India. It is well known in the sector that, on the one hand, Spain and Italy are markets focused on product differentiation strategy while, on the other hand, the strategy of China and India is based mainly on cost reduction. Furthermore, in terms of competition among companies, digital technology has shortened the competitive gap between those manufacturers who were focused on a product differentiation strategy

and those whose strategy was cost reduction. Indeed, in a situation where legal protection of designs is not frequent, imitation is relatively easy, so any company is able to replicate any market-leading product in a reasonable time and without incurring significantly higher costs.

Figure 3. Conversion rate of decorative lines to digital in 2015. Level of digital printing penetration by country



Source: Ferrari (2016).

4.3.2. Impact on the overall strategy of the Spanish ceramic tile cluster

The innovation under study has shown a global strategic value for a cluster as an entity beyond the individual firms' strategic value previously mentioned. The mature Spanish ceramic tile cluster has been renovated and nowadays it is considered as a paradigm of industrial innovation case. The ceramic industry in Spain is currently deemed as a model of dynamism and modernization that is able to compete with many other ceramic tile clusters around the world in terms of cost or quality.

In addition, this important value is not only perceived by other ceramic tile districts but also by other different industries which are using traditional printing and are willing to carry out a technological transformation as well. The use of printing as a method for adding value to the final product is a paramount aspect for many industries, not only for ceramics. Different industries, such as wood panelling, fibercement boards, glass, corrugated boards or the textile industries, among others, entrust an important part of their competitive strategy on design and, therefore, on printing. Nowadays different sectors are benefiting from the ceramic technological leaders' expertise to reduce uncertainty and accelerate the technological shift.

In conclusion, industrial digital printing has given the Spanish ceramic tile cluster the opportunity to open new diversification strategies. Significant firms from different subsectors such as ceramic printer manufacturers, ink producers or peripheral equipment manufacturers are successfully penetrating other industrial sectors.

5. Results and conclusions

This work addressed the processes which lead to creation, development and diffusion of a disruptive technological innovation in the context of an industrial cluster. At the same time, we wondered if it is possible to create such kind of innovations in a mature cluster beyond the usual incremental ones. Findings of the case study revealed that the usual cluster dynamics may prevent present *gatekeepers* from leading these radical changes. Lack of a distant vision from the cluster itself, limited resources, or the fact of being focused on short-term challenges can be inhibiting factors of more radical solutions.

In this context, the new actors, or *visionary agents* —which may come even from outside the clusters— are called to play a decisive role as sources of innovation. These actors are able to supply clusters with new ideas or original visions far from the clusters' state of the art. In our opinion is interesting to highlight how in this case, innovation was created by a *visionary agent*, an actor that did not belong to conventional *gatekeepers* (companies, local institutions or support organizations) (Molina-Morales and Martínez-Cháfer, 2016).

Findings of this case revealed that disruptive innovations can be generated in other contexts that are different to large companies where organizational structures usually are able to perfectly align R&D resources towards an innovative idea. In clusters as entities this point is more difficult as there isn't an articulated hierarchy or a coordination in the actions.

This research work has addressed the analysis of the innovation consequences from two different perspectives: (a) the ceramic tiles industry's value chain; (b) the role played by cluster members. In our opinion, the success of a disruptive innovation in a cluster will be influenced by these two elements. In other words, a deep impact of the innovation on the industry value chain alongside a close cooperation among relevant actors (gatekeepers) will be a good recipe. When this happens, the cluster's internal and external relationships are reconfigured and, as a consequence, not only the individual firms' strategies are reconsidered, but also the overall clusters' strategy.

Renewal of industrial clusters through disruptive technological innovations is shown in this research. In our opinion, the case study contributes to the present discussion on the future of industrial clusters. Radical innovations, by increasing the competitiveness of firms and by opening up new opportunities, may become key elements to rejuvenate those clusters which are considered to be at the end of their life cycle. In addition, as opportunities may be opened not only in the same industry, but

also in different sectors, radical innovations can be considered as powerful levers for industrial clusters' diversification.

In our opinion, our paper's findings mainly contribute to two different academic research lines. On the one hand, the group of studies which are focused on radical or disruptive innovations analysed by authors such as Christensen (1997), Markides (2006) or Tellis (2006) among others. These authors emphasize the importance of this type of innovations that allow the creation of new markets, beyond the mere incremental improvement of existing ones. On the other hand, this work supports the authors who have raised the need to redefine the internal and external relations of the clusters (Biggiero, 2006; Sammarra, 2005).

Finally, this paper presents a series of limitations, some related to the peculiarities of the case and others due to the descriptive approach we have used. We have performed a case study based on the specific conditions of this case. Therefore, we appeal to caution in generalization of conclusions, which might be suitable to other clusters or industrial realities. This research attempts to take a first step towards a more ambitious and broader analysis. To explore a comparative analysis of different disruptive technological innovations in the context of other clusters should be a potential future challenging research.

ACKNOWLEDGEMENTS

Financial support provided by the Spanish Ministry of Economy and Competitiveness (Project number ECO2015-67122-R) is gratefully acknowledged.

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