Creative Destruction in Clusters: From Theory to Practice, the Role of Technology Gatekeepers, Understanding Disruptive Innovation in Industrial Districts

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Abstract--**The industrial district (ID) literature assumes that technology gatekeepers (TGs) shape the district learning process and its evolution. However, the analysis of the TGs resilience is absent. Instead, most of the evidence provided is set at a single point in time and considers only one stage of the cluster life cycle (CLC). This paper introduces into the discussion two important influences in order to analyze the dynamics of TGs and the ID evolution: the type of knowledge created (whether it be disruptive or not) in the cluster and the TG resilience across different stages of the CLC. This work responds to the gap that not much is known about the persistence of the TGs across different stages of the CLC. Using qualitative longitudinal case-study research, a world-class ID is analyzed over the last twenty years. The results show that there are new technological gatekeepers when it is a question of bringing in disruptive knowledge. Put differently, incumbent TGs are resilient but unable to create disruptive technologies in order to renew IDs, being more focus on the introduction of sustaining technologies. Results also shed light on the understanding of radical innovation in IDs, a fact almost neglected in the literature.**

I. INTRODUCTION

This paper tells a story about a technology disruption which challenges assumptions in the industrial district (ID, hereafter) literature. The paper attempts to answer the question of how clusters evolve, change and reinvent themselves, focusing especially on the knowledge creation role of technology gatekeepers (TGs, hereafter) and their dynamics. Most works on TGs have been set at a single point in time [71], and little research has been undertaken on gatekeepers over an extended period (with two exceptions, although both focus on the same stage, see [45] and [49]. This is the case despite the existence of a burgoing stream of research analysing the cluster life cycle (CLC, hereafter) (e.g., [82] and [28]. In fact, the majority of studies about technology gatekeepers are not dealing with TGs resilience (e.g., [72]), or are contextualized at central stages of a cluster's life cycle (e.g. [45];[71]) neglecting the TGs dynamics across different CLC stages and their contribution to renew clusters. In addition, literature about innovation in ID is mainly based on the assumption of incremental rather than radical innovation [13], being IDs more capable of dealing with gradual innovation than disruptions ([41], [25],[22]). In this some authors [75] [50] established that comparing types of networks and innovation "when the user industry is mature and the innovation is largely autonomous in that it does not require drastic changes to the product or the production process, then a Marshallian or Third-Italian type of network would be the most appropriate". Crevosier emphasises the importance of understanding how industrial districts "react to or generate radical innovations, to the extent that it is stated that "without making this point clear, it is not possible to make any prediction about the reproduction and the duration of such systems" [37]. Therefore, in this "incremental" paradigm, the role of TGs is perfectly defined and contextualized, being the gatekeepers which orchestrate the knowledge and drive the evolution. Nevertheless, unanswered questions arise: What happens when disruptions change the knowledge bases and networks configurations in IDs? How radical innovations affect TG's centrality? Are TGs resilient? To the best of our knowledge, there are neither articles discussing the role of the TG at the renewal stage of a CLC, nor are there ones that address explicitly the theoretical cross-fertilization between TGs and the CLC. Thus, analyzing the role and dynamics of technology gatekeepers across different stages of the cluster life cycle when facing technological disruptions constitute the goal of this paper.

Most of the literature on IDs assumes that the main providers of knowledge are TGs, i.e. focal firms which orchestrate networks and access external flows of knowledge [10]. TGs carry out two key functions for a cluster's innovation system: sourcing knowledge from outside the cluster, and then diffusing that knowledge within the local system [10][46]. Most of the research conducted on TGs assumes that large leading firms, with high absorptive capacities and high R&D expenditures, shape a district's learning process (e.g. [66], [71]) by making significant investments in searching, learning and diffusing knowledge within their own networks for the purpose of maximizing profits. However, this argument does not hold up when the linearity of such a TG-led learning process is challenged by considering the effects of two important influences, namely: first, the influence of type of knowledge (whether it is disruptive or not) that TGs create, and, second, their persistence across CLC stages. The argument is as follows.

The ID literature (e.g., [13]) assumes circumstances of continuous (i.e. non-disruptive) innovation generation in a context where TGs seek to maintain a central position in inter-firm networks. Most of the works on TGs in the ID literature (e.g., [71], [5]) are focused on clusters that are at a central stage of their life cycle when there are few or none new entrants and when knowledge is more homogeneous, and the context is one where continuous (rather than disruptive) innovation is the norm. In this chain of thought, TGs are supposed to maintain stable and high-quality linkages [66] [45]. In fact, when a TG is dominant in a cluster it focuses research and knowledge creation to its own benefit ([3], and whole networks could be locked-in to a particular knowledge paradigm. Consequently, as [42] point out, cluster firms embedded in stable local networks can be trapped due to the fact that technological breakthroughs or disruptive changes could threaten the existing power of TGs [9]. Radical, disruptive or breakthrough innovations can be based on novel technologies (new to the firm), or on emergent technologies (new to the entire industry) . Two authors [31] defined disruptive technologies as those which "bring to a market new value propositions". This paper posits that TGs mainly create continuous knowledge expanding central stages of the CLC but not renew clusters creating disruptive new technological trajectories. This reasoning is confirmed in the entrepreneurship and strategic management literature, contradicting the economic geography assumption that has characterised TGs as firms which lead and shape learning in IDs (e.g., [62], 64]). TGs, as incumbent firms, are more engaged in providing incremental improvements to existing products while small new entrepreneurial firms are the ones which create disruptive innovations [19], which incumbents are unable to challenge [38].

Thus, this paper addresses an important paradox. While TGs play an important role as knowledge leaders, they have no incentive to alter the status quo by promoting new technological trajectories which potentially threaten their own roles in clusters. In fact, the literature says that new knowledge (technological trajectories) is created by new entrepreneurial firms. Without new knowledge the cluster cannot be renewed, and eventually it may face lock-in and decline in the long term. Through such a perspective we look at the roles of technological gatekeepers in cluster life cycles, in order to better understand the mechanisms which dynamically shape the learning process and how clusters evolve.

The major contribution lies in the finding that the transition from mature stages to renewal stages of the CLC fosters the establishment of new and complementary TGs, challenging the established assumptions about the role of TGs and their persistence in clusters. This paper focuses on disruptive knowledge which avoids potential knowledge lock-in and promotes a general rejuvenation and reinvention of the cluster. We recognize that creation of incremental knowledge is positive and contribute to extend the CLC central stages. Nevertheless, we leave the latter to others and focus our attention on disruptions and the role of TGs across different CLC stages, facts almost neglected in the ID literature.

This paper is in line with the literature on cluster evolution and its dynamics over time ([16],[28], [82], [68]), focusing on the central role played by firms [82] in order to understand how clusters evolve and avoid lock-in. This paper challenges and discuss previous findings which suggested the key role of technological gatekeepers in the early stages of clusters [45] or in the central phases [71], incorporating into the conversation a dynamic analysis of the technological gatekeepers across different stages. This paper is based on a qualitative longitudinal case-study of how the Castellon ceramics cluster in Spain has evolved over the last twenty years. After this introduction, section II addresses the theoretical treatment of technology gatekeepers the consideration of different cluster life cycles. In a third section, the qualitative longitudinal case study is presented. Finally, the last two sections discuss and conclude, pointing out the implications of the paper for theory, scholars and policy makers.

II. THEORY

A. Technology gatekeepers: knowledge creation and spinoff process

TGs are said to be essential to cluster learning processes by accessing external (to the cluster) knowledge, and conducting a conversion process which deciphers external knowledge and turns it into something locally understandable and useful [21]. The gatekeepers [10] [71] or anchor tenants [3] [17] are focal companies or agents which mobilize knowledge, orchestrate the cluster by attracting investments, provide a vision for nurturing innovation, and supply technological knowledge to local start-ups [17]. Anchor tenants are said to generate new knowledge by combining specific local knowledge with external knowledge components [3]. This is facilitated by having abundant external (to the cluster) ties that enable the exploration of new forms of knowledge [17] [47], through both formal and informal channels (e.g. [44]). In particular, most of the research conducted on TGs assumes that large leading firms with high absorptive capacity and high-intensity R&D activities shape the district learning process [71] [62] [5] [66] [64] [73] [17] [47] by engaging in major investments to search for, acquire and diffuse knowledge within their own company networks in order to maximize profits.

Nevertheless, the literature about technological gatekeepers and their effects on clusters presents certain paradoxes. The technology strategies literature highlights the notion of competence destroying technological discontinuities (or disruptive innovations) [83] with the suggestion that such discontinuities can trigger changes in the competitive landscape in ways that frequently disadvantage incumbent firms. Such new technological changes allow new entrants to establish innovative and dominant designs [1] and incumbents often prove unable to respond [31] [38]. In addition, the literature on entrepreneurship has pointed out that new small entrepreneurial firms are the ones responsible for major revolutionary breakthroughs [19] [88] [58], while the incumbents are more engaged in providing incremental improvements to existing products [19]. Therefore, the assumption that the technological gatekeepers are the incumbents which orchestrate a cluster, provide its dynamism, and are the firms which provide the cluster with knowledge, is only valid as long as there are no disruptive changes. When disruptive knowledge appears the TG incumbents oppose it in order to maintain the status quo and their central positions in the cluster's networks [9].

According to some authors [83], technology evolves through periods of incremental change, punctuated by technological breakthroughs that either destroy or enhance a firm's competences in an industry and especially in IDs. In general, competence destroying discontinuities are initiated by new firms while actions to enhance competence are initiated by existing firms. Leading companies stay closely tuned to their customers' needs and new technologies may either be perceived as (a) presenting different performance attributes, not valued or known, by existing customers or (b), as creating value attributes which may improve at such a rapid rate that the new technologies can threaten established markets [2] [31]. Incumbent firms tend to stay close to their customers, and the processes of identifying customer needs, and forecasting technology trends, as well as the allocating of resources, are centred on current customers and markets, and therefore such firms may not be attracted by new technologies and will probably avoid disruptive technologies [31]. In addition, other authors [81] highlights an incumbent's lack of vision of its market and a desire not to destroy existing assets when serving the market. These point out that not only do small new entrants introduce disruptive technologies, but also large and incumbent firms can be later developers of such new technologies. Incumbents do not consider investments in disruptive technologies a rational financial decision [81].

According to our theory, and as has been pointed out by other authors [19], incumbent TG firms will be reluctant to destroy the status quo, and will be less effective than new entrants in introducing radical or disruptive innovations that threaten their own product portfolio. But what are the characteristics that new entrepreneurial firms need to possess? Such firms have been termed as visionary leaders [81] and they should have disruptive innovation capabilities defined as the "internal driving energy to generate and explore radical new ideas and concepts, to experiment with solutions for potential opportunity patterns detected in the market's white space and to develop them into marketable and effective innovations, leveraging internal and external resources and competencies [14].

Therefore, taking into account that new small entrepreneurial firms can be disruptive agents, the next question is: are those small entrepreneurial firms new start-ups or spin-offs? Put differently, are the new entrants, as opposed to incumbents, from inside or outside the cluster? The literature on clusters, mainly derived from the strategic management perspective, is clear about the answer: knowledge spillovers are related to heredity, that is, knowledge flows from successful incumbents to those organizations with previous experience in the industry. This means that organizations (incumbents in our reasoning) spawn new enterprises through spin-off processes [60] [61]. pin-offs follow from disagreements which arise because incumbent management has a limited ability to recognize superior ideas from employees [61]. In addition, [59], spin-offs are the key reasons to explain agglomeration economies.

B Cluster life cycles, lock-in and renewal

The burgeoning cluster life cycle literature emphasises the problem of knowledge lock-in [69] [45] [24]. The characterisation of different stages of the cluster life cycle vary, depending on the author [65] [85] [69], but all of them agree that there are distinct "*emergence*", "*growth*", "*maturity*" and "decline" phases. In the first stages of a CLC, knowledge has a more heterogeneous character [69] and clustered firms have higher growth rates than in later stages, and there is a pervasive spin-off process [59] which drives cluster growth. In the growth stage, self-reinforcing processes based on trust and reciprocal interactions are crucial. On the other hand [16] clustered firms have a high innovation rate during the growth phase. By the time of the maturity phase, the competitive shake-up period is largely over, and the cluster has been shaped with leading firms playing a dominant role as TGs. Knowledge has become more stable and homogeneous. Finally, in the latter stages there is a decrease in innovation [74] which potentially leads to knowledge lock-in [29] [32] [33].

There is a diversity of explanations for the emergence of clusters and the development of the decline stage (e.g. [77]). However, what is missing is analysis of a CLC's transition from mature to a renewal stage. How a cluster moves through its life cycle depends on whether there is an increase or decrease of heterogeneity amongst the cluster's organizations [69], and whether there is a renewal of its technology life cycle [11]. The question is how can heterogeneity be increased in order to renew a cluster and initiate a new growth stage? Most cluster studies focus on successful cases at a time when they are in their central life stages. Some studies analyse emergence [34], and a few cluster decline [48], but literature on cluster transition to renewal is scarce. An author [59] showed how radio producers in the USA shifted to making televisions, and other [79] documented the shift from mechanical manufacturing methods to the use of electronics in the accordion cluster in Marche, Italy. But neither of them analysed the role of TGs, nor the processes by which new knowledge is created. The reason to expect that incumbents cannot cope with technological disruption is related to the phenomenon of the learning trap [63] whereby leading organizations foster specialization and inhibit experimentation, and find it difficult to adapt and diversify [67]. Other [4] summarized why it can be so difficult to increase knowledge heterogeneity:

Mature technologies are likely to have highly developed value networks and organizational and extra-organizational assets that are co-specialized with these technologies. These co-specialized assets and networks make subsequent innovations on these existing technologies easier, but may impede experimentation with nascent technologies that require different sets of assets, inputs, and complements.

Our argument can be summarized as follows as a set of predictions. First, the TG orchestrates the networks that control and shape most of the learning process in a cluster, focussing mainly on the creation of non-disruptive incremental knowledge. In this process, a TG's superior resources provide it with centrality and control over the networks. Second, while the TG is able to dominate during the mature or central stages of a CLC when knowledge is more homogeneous and stable, there is no evidence suggesting the TGs will then lead the creation of disruptive knowledge which can move the cluster on a renewal trajectory and thereby avoid decline. On the contrary, it is new entrepreneurial local spin-offs that may threaten the existing technological status quo and thus rejuvenate the cluster .

III. METHODOLOGY

Our approach is both qualitative and case study based. In addition, our study is longitudinal, as it encompasses twenty years of primary and secondary data knowledge sourcing. Capturing the dynamics of technology gatekeepers requires valuable information about the cluster evolution through its different technology stages and the emergence of a new disruptive technology, back to early 90's. Our focus is on understanding the role of the TGs in knowledge creation in a cluster throughout its life cycle. For this purpose, a technology disruption, the inkjet decoration technology development, is used in order to show clear-cut transition from maturity toward renewal. Our interviews and analysis were conducted to the inkjet inventors as emerging technology gatekeepers, (KERAJET firm and its founders), its rivals, facilitators (glazing firms producing the inks and Cambridge firms producing head printers) and other co-related agents in the clusters (associations, Spanish and Regional Government Officials, industry representatives, academics, etc.).

The case study is a key instrument in order to capture all the complex information (e.g., [88]), utilizing secondary data analysis alongside in-depth interviews aimed at understanding the evolution of the Castellon (Spain) ceramic cluster over the last 18 years in order to capture its technology life cycle. Interviewed respondents (fifty three) included: the inventors and followers of a new technology; the lead users of, and improvers of, the technology; the managers of leading firms; Officials of public research laboratories; academics; consultants; and policy officials as well as industry associations representatives in Spain and Italy. Regular visits to the sector European exhibitions such as the Italian international ceramic fair trade CERSAI, the Castellon counterpart CEVISAMA or Technargila (the international showcase of technological innovation for the ceramics industry, Modena) were conducted during the last 12 years in order to complement the information and follow up the new technology (firstly presented in 2000 in CEVISAMA). Interviews were conducted following a structured scheme from 2000 to 2011 by the authors of this paper as a result of participation and leadership of different research projects related to the Castellon cluster and its emergent technology. From 2002 to 2006, the authors participated in a European research project related with the technology, G1RD-CT-2002-00783 MONOTONE (European Commission, 5th FP, Growth Programme), as well as various national projects (supported by the Ministry of Industry, Ministry of Science and Innovation and the National Innovation Agency, CDTI) and regional projects (supported by the Regional Innovation Agency, IMPIVA), all of them related with the Castellon cluster and its technological development. These projects facilitated the organization of technical workshops among industry agents where the sector technical evolution was discussed (see [35]).

In addition, other relevant secondary sources of knowledge accessed are scientific papers about the Castellon cluster [52] [53] [54] [55] [51] and its inkjet technology disruption [6] [7] [8], together with leading ceramic magazines, journals, patent databases (@espacenet) and ceramic industry reports collected in the last 12 years .

Finally, semi-structured interviews with the inventors and other complementary firms have also been carried out, especially during 2011 and 2012. In total, 53 key informants were interviewed over periods of 2-3 hours per person. In addition, the paper achieved triangulation of data through specific questions with interviewees, discussion with experts in the industry and policymakers and also by comparing results with secondary data (following [20] recommendations). As well as carrying out the aforementioned interviews, we have also analysed archival data, internal documents and industry reports, and academic publications to document how the cluster, its anchor firms and the new entrants have evolved over time. This approach is consistent with [87]. For the sake of brevity, a brief summary of the interviews and data analysis is presented (more data available upon request).

A The Castellon cluster in Spain

The Castellon ceramics cluster is a meta-cluster [52] that includes all the activities of the ceramics value chain, as well as various public R&D organisations such as the Institute of Ceramic Technology (ITC-ALICER, hereafter), educational centres such as the Jaume I Universitat and private institutions such as trade associations (including Ascer, Anffecc, and Asebec). The cluster provides 20,000 direct jobs (in 2010) and there are 300 firms in related industries [12].

Within the cluster, glazing is the most important of the auxiliary industries [70] [52] [58]. The Castellon glazing industry is the world leader with 26 firms exporting around 66% of total production valued at 900 million euros; and employing around 3,200 workers in 2010 (Anffecc, 2010). It has extensive operations in other clusters including in Italy and Brazil. The strength of the concentration of companies from different, but interrelated, industries in the Italian and

Brazilian ceramics clusters is reflected in high location quotients for these districts. For example, in the Italian (Sassuolo) ceramics cluster the quotients range from 3.5 to 5.70, which means that the level of concentration for the industry ranges from about 350% to 570% higher than the national mean (depending on the specific municipalities within the cluster) [15] [27]. As in Castellon, the ceramics industry in Italy has a location coefficient of about 4.5 in the cluster, which means that the concentration of the industry in the cluster is 450% above the national average [56]. Institutional support in the Castellon cluster is strong. For example, the local university in Castellon (Universitat Jaume I, UJI) offers a chemical ceramic engineering degree, as well as a masters and a PhD - which are unique in the world. These academic qualifications are offered by UJI jointly with the ITC-Alicer R&D centre. The R&D centre (ITC-Alicer) is the body responsible for transferring knowledge to the cluster through conducting research projects with local firms. It has around 120 researchers. Collaboration between ITC-Alicer and UJI constitutes an excellent example of university-industry knowledge exchange. Lectures in the UJI are provided by ITC-Alicer researchers who have daily contact with the industry. Indeed, inter-organisational interaction is exemplified by that of the ITC with the Jaume I Universitat that is a crucial part of the cluster's "innovation engine" [70] [52], and the true strength of the Castellon cluster lies in its systemic behaviour. The mechanism of innovation diffusion is very difficult to replicate elsewhere – as confirmed in interviews carried out while preparing this paper.

Fig. 1 illustrates the cluster structure and the main knowledge and technology hubs described in the previous paragraph.

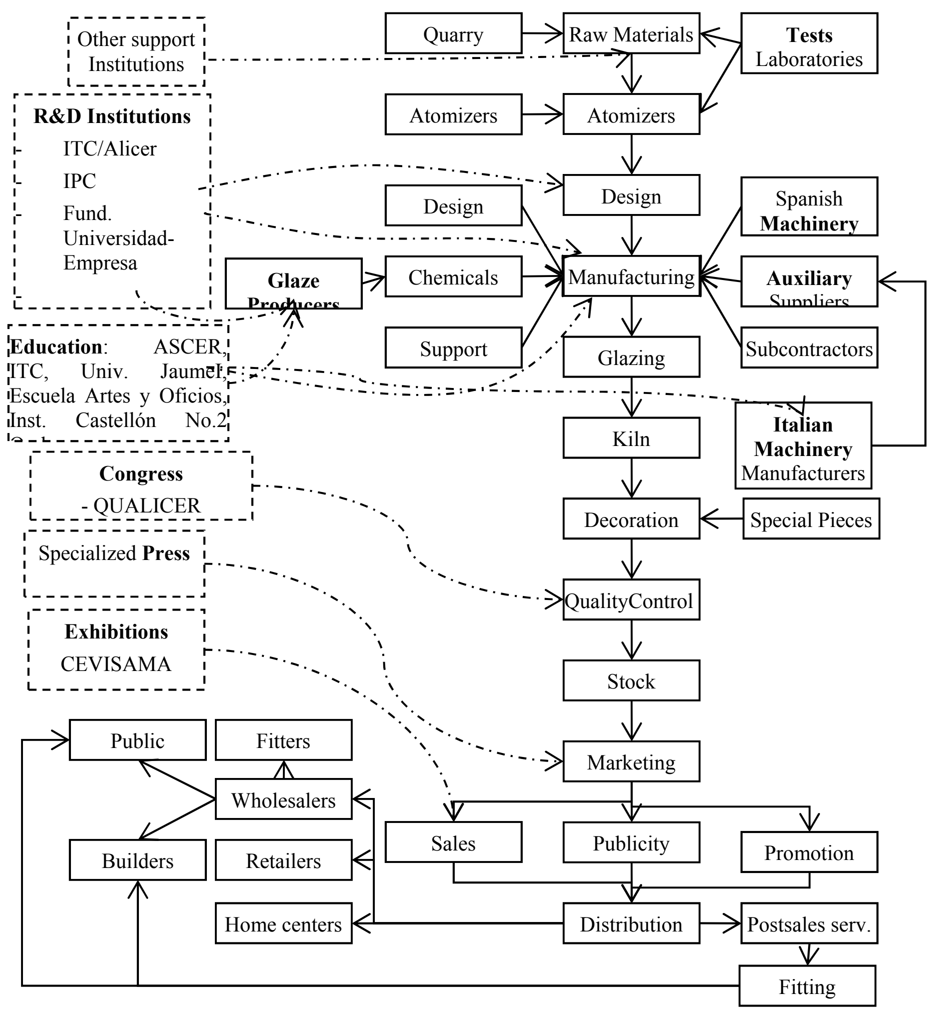

Figure 1 Actors, agents and networking hubs in the Spanish tile ceramic cluster and their connection with the value chain.

TABLE 1. EVOLUTION OF THE PRINCIPAL TECHNOLOGY GATEKEEPERS IN THE CASTELLON CLUSTER.

Gatekeepers in Cluster Rotocolor technology **(1990-1998)**			**Breakthrough and new Gatekeepers in Inkjet technology: emergence stage** **(1998-2004)**			**Current Gatekeepers** **(2005- 2012): growth stage**		
Mechanical Equipment: Based at Rotocolor and traditional screen	Frits and glaze Producers	Inkjet tech manufacturers	Mechanical Equipment	Frits and glaze Producers	Inkjet tech manufacturers	Mechanical Equipment	Pigment Producers	Inkjet tech manufacturers
3 Italian companies co-located in Castellon with headquarters in Sassuolo (System, Sacmi and Barbieri-Tarozzi)	1 Italian producer in Castellon, headquarters in Sassuolo (Coloribbia) Technology: Frits and glazes for Rotocolor and traditional screen	None	0 Sassuolo	0 Sassuolo		3 in Sassuolo cluster (System- Barbieri-Tarozzi, Sacmi) for Rotocolor declining technology Currently, no TGs in inkjet technology	In Italy, since 2010 two minor producers of inks are: Inco and Smalticeram, but no TGs.	Mainly spinoffs from big equipment manufacturers in Sassuolo, Italian cluster Intesa and Tecnoferrari (Sacmi) Projecta (Barbieri) System: laggards, no TGs. Hope, Chinese, no TG.
1 Firm in Castellon (Cretaprint) Technology: Rotocolor	5 world-class frits-glazing firms with headquarters in Castellon (Torrecid, Esmalglass, Ferro and Endeka and Colorobbia) Technology: Frits and glazes for Rotocolor	None	Cretapring in transition from Rotocolor to inkjet by contacting XENNIA, another Cambridge cluster firm in printing technologies, in order to replicate XAAR head-printers.	1 Castellon (FerroSpain, the firm which spawned partially Kerajet) was first developed of inks for the inkjet technology, and specifically for Kerajet machine	1 Castellon (Spin-off firm: Kerajet) Kerajet is the only one in the world market with a Patent and has issued the rest for patenting infringement.	1 Firm in Castellon (Cretaprint) Technology: Rotocolor Follower since 2005 in inkjet with the Esmalglass alliance	3 Castellon firms (Ferro Spain, , Torrecid, Esmalglass) : 80% of the market of inks	2 Castellon (Kerajet, Cretaprint): the world-class TG Cretaprint in 2011 is acquired by EFI, a Silicon Valley firm based on printing technologies. 1 Firm from outside the Sassuolo and Castellon cluster (Durst): new entrant (diversifier) from printing technology field, no spin-offs; early new entrant and TG.

Source: Own, based on Serri, A.,(2008) Ceramic decoration paradigms, Cuaderni di ceramica 2008, 5-1-2008; Dossier Inkjet, Tecnica Ceramica, 369, pp. 1308-1315 (2010) and interviews carried out from 2000 to 2012. Kerajet internal reports. Analysis of archival data.

TABLE 2. EVOLUTION OF CASTELLON CLUSTER. THREE CLUSTER LIFE CYCLES

CLC: central stages (1990-1998). Maturity of the Rotocolor technology	**CLC: Emergent renewal stage (1998-2004)**	**CLC: Growing stage (2005-2012)**
Rotocolor technology dominant paradigm entering maturity; Knowledge heterogeneity reduced and focused around Rotocolor and traditional screen tech. Established TGs (big frits and glazing firms: Esmalglass, Ferro, Torrecid, Endeka, Colorobbia) together with big Italian equipment manufacturers (Sacmi, System, Barbieri). All these companies were TGs maintaining centrality in their networks. |	Knowledge heterogeneity increases when inkjet technology is first presented in 1998 Spinoff process from FERRO and other companies (Porcelanosa) leading disruption New technology gatekeepers Main existing TGs (frits and equipment manufacturers) reluctant to adopt new technology: disruption is not welcome by incumbent TGs and their networks are closed to new concepts Knowledge uncertainty about the new technology, with poor results in the first stages of development (problems with the new inks, processes not optimized, few testers, etc.) Resistance to change to the new technology by the whole industry, except some lead-users (testing the product).	Acceptance of the inkjet technology and a process of paradigm change from Rotocolor towards Inkjet is accomplished New entrants expected, early entrants in 2005 (Torrecid and Durst) and 2008 (Esmalglass with Cretaprint) Sassuolo and Castellon leading clusters adopting new technology up to 50% of the tile production (in 2012). New TGs in the Castellon cluster, plus some of the previous ncumbents Inkjet new TGs (Kerajet, Cretaprint and Durst) market leaders (around 80% of the inkjet market) allied with incumbent TGs producers of inks for inkjet (80% of the new inks market share): exchange of networks and collaboration to establish standards -Torrecid with Durst since 2005 -Ferro with Kerajet: pionnering -Esmalglass with Cretaprint: since 2008 Big Italian equipment incumbent TGs from the equipment Industry also spinoff laggards in the inkjet technology (less than 15% of the market share for inkjet): Intesa and Tecnoferrari (by Sacmi, 2012); Projecta Engineering (Barbieri Tarozzi, 2010); System (2010); Hope (from China, Foshan cluster, 2010).

B. Technology Disruption and transition from maturity to renewal in the Castellon cluster

1. Emergence of the new technology (1998-2004)

Knowledge creation

Until 1994, the decorating process in the tile ceramics sector was mainly based on screen printing technology utilising flat or cylinder screens, an inefficient process which required large batch series. In 1994, the Italian company System, produced the Rotocolor machine. This important innovation replaced the screens with laser engraved polyethylene rollers which transferred the design colour patterns to the tiles. Although this technique was a significant improvement, it was not disruptive [40] and it did not solve all the design reproduction problems and implied the need for specialized technicians that would manage the production process. Furthermore, it still required electronic engraving of the rollers and needed large production batches. Similarly, the design transfer process was arduous, lengthy and costly. In the late 90's the Rotocolor technology was the dominant design in the cluster of Castellon and in the world ceramic tile industry. As a result of the Castellon frits and glazing competence, the incumbent TGs located at Castellon (Torrecid, Esmalglass, Ferro, Endeka and Colorobbia) occupied centrality in their networks and disseminated the necessary frits improvements in order to make their customers (tile producers) captive and dependent on frits knowledge for Rotocolor usage. The Italian equipment producers located at Castellon (also incumbent TGs, System, Sacmi and Barbieri-Tarozzi) were also dominating the mechanical knowledge component and maintaining centrality in their networks. All in all, tile producers were inserted in networks controlled by frits and equipment incumbent TGs. See 1990-1999 (maturity) stage of the Castellon CLC in the table 2. From the interviews, all the interviewed agreed with the identification of the TGs in the Castellon cluster. All of them referring to aforementioned frits from Castellon and equipment manufacturers from the Sassuolo cluster . In this vein, our identification of the TGs existence at the maturity stage is empirically sustained. TGs were referred to the frits and glaze and equipment industries in the cluster which are the knowledge-advance firms, and not to the ceramic tile producers which only played a role of adopting the new technology.

In 1998, a local Spanish computer entrepreneur engineer with extensive experience in the tile ceramic industry, along with a chemist working in a leading glaze and pigment multinational firm, began exploring new possibilities for decorating tile ceramics based on digital technologies, and in 1999 they developed a first prototype based on inkjet printing. The initial prototype proved its feasibility and led to the founding of a local spinoff entrepreneurial firm, Kerajet, spawned by a leading frits and glazing incumbent TG multinational firm, FERRO. In fact, the founders (Jose Vicente Tomas, Rafa Vicent y Antonio Querol) were ex-workers of leading TGs (FERRO and Porcelanosa) with extensive ceramic technology experience, that is, the new firm inherited knowledge from successful incumbents. Based on a design consisting of multiple inkjet head systems, control hardware, software design transmission, and inkjet handling subsystems, Kerajet presented their first industrial prototype in the CEVISAMA exhibition in 2000 and also acquired two PCT patent applications. The new technology consisted of four basic subsystems: inkjet print heads; inks or colours to decorate the tile; mechanical parts; and software that ensured the transfer of the design artwork to the printing system, and controlled the process. The third and fourth subsystems continually evolved while the first and second ones had more punctuated evolutions. Inkjet technology constituted a complete breakthrough in tile the decoration process. In effect, a cooking craft process [76] was replaced by a digitized process [10].The Kerajet team needed to solve two particular technical problems, both of which required sourcing knowledge from outside the cluster. First, there was the problem of developing a print head adapted to ceramic tile decorations. The necessary knowledge for this was available in neither the Castellon nor Sassuolo clusters. In fact, this knowledge was new to the entire industry. Kerajet acted as a new gatekeeper by overcoming the district's lack of critical competences by making a bridge to knowledge external to the cluster and the industry when required, thereby confirming the view of the role of a TG to be an access agent to global pipelines. Specifically, research cooperation was carried out with two inkjet print-head manufacturers, one from the Cambridge cluster (XAAR) and another from Japan, SEIKO. This led to the development of customized print-heads for use in the ceramic tile field, and eventually to standardisation of the application. The development of electronics and software for control and management of the equipment was carried out in cooperation with various external research centres and firms. Artwork software selection and training was essential for the transference of designs to the production line. Second, a pigment micro-milling application (company Netzsch) solved the initial phases of organic pigment development (the new inks for the ink jet technology), and was brought in from other external industries such as chemicals from Germany.

The results of the G1RD-CT-2002-00783 MONOTONE technical roundtables and workshops showed that though the problems associated with the previous (Rotocolor) status quo and the limitations of the technology were well known, the attitude of incumbents was rather conservative and a disbelief in the advantages of feasibility of inkjet was well established among the sectors agents. In the interviews, this was confirmed. Incumbent TGs were reluctant to accept a new technology that challenged their status quo. In fact, the point is to understand that FERRO did not want to take the risk and entrepreneurs spinoff. Nevertheless, FERRO contributed to the new venture with research lab facilities and founding part of the enormous investment required initially by the project. At this early stage financial and facilities support from the glazing firm Ferro was crucial. It was agreed that Kerajet would develop electronics and software applications and the decorating machine, while FERRO would focus on the development of inks for the new technology.

Knowledge dissemination

In the early stage of the emergent technology (and the Rotocolor maturity), the rest of the incumbent TGs were opposed to the new technology and no one of them offered support by allowing tile producers of their own networks to test the new concept. In this vein, a problem for the issue of knowledge dissemination was that the early lead users [84] [86] believed they were developing competences that differentiated them from competitors and so this perceived competitive advantage persuaded them to avoid disseminating their new knowledge throughout the cluster. At the same time, there were other lead users who tried the technology but who rejected it because it did not meet the needs of their mainstream customers and this time their knowledge about the rejection was disseminated, due to the experimental stage of the technology. As a matter of facts, one interviewed manifested:

"When our Italian competitors buy it we'll buy it as well"

The lead-users which contributed to refining the Kerajet prototypes were TGs cermic tiles within the FERRO's own network. FERRO was never ready to accept the potential failure of such a risky project but facilitate connections to allow Kerajet to conduct trial and error.

2. Transition stage towards growth (2005-2012)

The mid 2000s marked the development of inkjet technology as a dominant design. The frits and glaze incumbent TGs followed the path of Kerajet and started to develop and market for the inkjet technology new inks, after realising that they provided much higher added value. The new technology offers extraordinarily sharp image resolutions, fast line speeds and heightened productivity. Kerajet-FERRO alliance was challenged by new entrants, basically from within the Castellon cluster frits and glaze industry. The first follower was a pigment producer, Torrecid, which partnered with Durst (an Italian diversifying printing machinery firm) to offer on the market in 2005 the second inkjet printer using organic pigments. It was followed later by Cretaprint, a small Rotocolor manufacturer in Spain which allied with a major incumbent TG Esmalglass. The other frits incumbents TGs (Colorobbia and Endeka) and the rest of the industry were laggards, entering around 2011 and sharing a small proportion of the new industry, alike the Italian equipment manufacturers which started around 2009-2010.

Print head producers, pioneered by XAAR, began to develop inkjet print-heads adapted for tile decoration. After five years, ceramic tile inkjet print heads became a standardised product, with three international firms accounting for 99% of the market (XAAR, Seiko, Fuji). Organic pigmented inks (necessary for the new technology) also became a standard, and in 2012 most of the Castellon frits and glaze producers have them in their catalogues, while 3 of them (FERRO, Esmalglass and Torrecid) account for 80% of the international market. Three inkjet printer manufacturers (also based in the Castellon cluster) dominate the international market, with a combined 80 % share . The Spanish Castellon cluster dominates the new technology and concentrates around 80% of the world production of inkjet technology (accounting for the machinery, plus around 80% of the world inks).

During the early years (2000-06) the pioneer firm (Kerajet) dominated completely the market with printer sales going to leading customers. Even now, according to interviews with leading firms, Kerajet still has a strong penetration, accounting for an estimated 50% of global purchases of the technology. The evolution of printer sales has followed an exponential curve, and the technology still seems to be in a growth phase. In Castellon and the Italian cluster the new technology is observed in around 50% of the production, and the old technology (Rotocolor) still functional for low value-added products but diminishing. In the rest of the ceramic world (Brazil, China, Turkey, India, etc.), the penetration of the new technology is in its infancy (2%-5% estimated), according to informants.

All in all, the three coalitions of new TGs and the incumbent TGs control the majority of the new tech market (inkjet printers and the inks). Two of the incumbent TGs (Endeka and Colorobbia) entered the new industry too late. As a result, not all incumbent TGs were resilient but three of them. In addition, Kerajet, Cretaprint and Durst are the new TGs in coalition with the former three ones. Incumbent Italian ceramic equipment TGs (Sacmi, Barbieri-Tarozzi and System) spawned new spinoffs or new branches to compete in the inkjet industry in 2010, being now minor players in the new industry and loosing centrality in their networks [80]. As a result, the TGs landscape changed and the new disruptive technology allowed the entrance of new firms which created knowledge and fostered the transition from maturity toward renewal. Again, all the interviewees agreed with the TGs identification in the growth stage. See table 1 for the growth stage and for a general review of the case study.

IV. DISCUSSION OF RESULTS

Our results confirm our predictions developed in the theoretical section. First, Kerajet overcome the district's lack of critical competences by making a bridge to access to external (to the cluster) knowledge, sourcing from Japan and the Cambridge cluster. This fact confirms the view of the role of a TG to be an access agent to global pipelines. All in all, the evidence presented supports the view of the importance of external linkages [18] in order to improve the availability of resources and avoiding myopia or lock-in [(Maskell and Malmberg, 2006). Put differently, the new TGs supplanted the incumbent TGs, creating knowledge and avoiding lock-in in the ID.

Second, the incumbent technology gatekeepers cannot be the ones which introduce disruptive technologies, confirming the disruptive technology literature [38]. Applying the findings to the cluster real, that role belongs to new entrepreneurial firms [16] which have spun off from incumbents taking (heredity) knowledge from them [59] [30]. In addition, incumbents oppose to new disruptions in order to maintain status quo and network centrality, confirming [9]. In fact, the spin-offs which introduce disruptive knowledge into the cluster act as new technology gatekeepers and make possible the transition towards emergent/growth (renewal) stages, supplanting some of the incumbents TGs while allowing others to be resilient in the new technologies. The reason is, as [81] highlights, the incumbents' lack of vision of its market and a desire not to destroy existing assets when serving the market. Nevertheless, as [81] points out, incumbents can be later developers of new technologies, as Esmalglass, Ferro and Torrecid did. These companies foster alliances with the new TGs in the new industry in order to keep controlling networks and enter the new industry, confirming the [45] idea that TGs prefer to exchange knowledge with other TGs. In fact, the incumbent TGs have played a key role developing the new inks and thus complementing the inkjet technology platform. Put differently, once the new technology has become more established the incumbent TGs also become adopters in order to keep pace with the new technological trajectory, and thus trying to maintain their previous TG role.

Third, the role of TG accessing to external (to the cluster) sources of knowledge presents additional implications. In our argument the novel result obtained in this study is the fact that the new knowledge was sourced from different industries and knowledge domains, specifically from the printing industry (from within the Cambridge cluster) and from the micro-milling industry (from within the chemical industry in Germany). This confirms [57] assertion that the provision of winning solutions to problems is positively related to increasing distance between the solver's field of technical expertise (in this case printing, and micro-milling) and the focal field of the problem (in this case ceramics). The importance of "marginality" or technical and social distance from the focal problem field [57] is supported by studies in the sociology of science which stress that:

"Inventions are usually made by outsiders, that is, by men who are not engaged in the occupation which is affected by them and are, therefore, not bound by professional customs and traditions" [23].

Thus, the marginality effect is explained by individuals from outside bringing into play knowledge perspectives different to those held by the focal companies in the problem field (e.g. [43]). The cluster literature has also pointed out this fact, although with the reservation of not specifically referring to new-to-the-industry knowledge. In this vein, two authors have stated [69]:

"Clusters can increase heterogeneity and renew themselves by enlarging their boundaries, either by integrating firms in the same industry, but in other places, or by integrating organisations in spatial proximity, but outside the thematic focus of the cluster"

The transition of the disruptive technology to significant market use was slow, and took almost six years, becoming a functional technology in 2004. As shown in tables 1 and 2, the dynamics of TGs development across the differing stages of the CLC are particularly interesting. Overall, the previously existing TGs have prevailed but now there are also other technology gatekeepers. The most important new TGs are Kerajet, the focal spinoff, Cretaprint (an equipment manufacturer) which successfully completed a transition to the new technology and has been bought by EFI a printing company in Silicon Valley and Durst (diversifying from the printing industry). All these three companies retain around 80% of the market share. Only three incumbents completed the transition by early entrance and now are key actors developing new special inks for the new technology. In addition, and confirming CLC theory, new entrants arrived in the cluster (that is to say, Hope, Intesa, Projecta, Tecnoferrari, among others) during the growth stages (starting mainly in 2010), not when the technology was experimental and emergent (1998-2004). Overall, the incumbent TGs did not renew the cluster. Rather, it was a spin-off company with inherited knowledge from TGs (confirming [59]) which temporarily adopted the main roles, developing external ties and engaging in technology creation and diffusion – which are traditionally supposed to be performed by the incumbent TGs. Nevertheless, incumbent TGs established strategic alliances with the new entrants to ensure access to the latter's products (new inkjet equipment producers are the distribution channel for the new inks developed by traditional frits-glazing firms, i.e., the existent incumbents), and the new entrants also took advantage of the alliances to enter to the incumbent TGs networks. See table 2 for a full description of the TGs formation across the CLC in the last twenty years.

All in all, incumbent TGs orchestrates the networks and enjoy centrality focusing on non-disruptive knowledge creation during mature stages of the CLC, without incentives to create knowledge heterogeneity in order to move the cluster towards renewal and thus avoiding lock-in. In this vein, the assumption [17]that when technology matures, clusters based on anchor organizations may suffer from lock in is confirmed in our study. Behind these results, the cluster excessive focus on non-disruptive (continuous improvement and innovation) knowledge has created this blind spot in the literature. Finally, as a concluding remark, one of the most important lessons manifested from this case study is the fact that TGs, to some extent, are resilient but unable to create knowledge for renewal across all the CLC. In addition, it is also remarkable the fact that incumbent TGs cannot be the ones which introduce disruptive technologies but sustaining ones.

V. CONCLUSIONS

The paper attempts to answer the question of how clusters evolve, change and reinvent themselves in order to prevail. Specifically, the objective has been to dissect the role and persistence of technology gatekeepers across different stages of the cluster life cycle when facing technological disruptions [33]. In order to fulfill this goal, the paper used a qualitative longitudinal case-study research methodology, covering the last twenty years of the cluster technology dynamics. For this, analysis of archival data and interviews with key informants was carried out. The paper has challenged the assumption that technology gatekeepers are large leading firms with high absorptive capacity and high-intensive R&D expenditures which shape the district learning process. Framework in the aforementioned objective, the main questions answered in this paper are: (1) How TGs face disruption in IDs?, and (2) are TGs resilient across differing CLC stages? In addition, this paper's results open a new debate on understanding radical innovation in IDs, a fact not much researched on the literature.

The paper looked at two key aspects: the type of knowledge created by technology gatekeepers and their persistence across CLC stages. Using a perspective based at the economic geography, the entrepreneurship and the management and technology strategy literature, this work has constructed a fertile cross-field framework to study the themes of technological gatekeepers and cluster life cycles in conjunction.

A main finding in the study is that TGs are resilient, confirming [45], but they do not create knowledge in all stages of the cluster life cycle. This contradicts assumptions in the mainstream TG literature (e.g., [71] [62]]5] [66]). Instead, we see the appearance at the point of transition from one CLC stage to another of new technological gatekeepers which take the role of leaders and introduce disruptive knowledge into the cluster. Further, these "new" TGs then become permanent when through alliances they are able to enter into the incumbents' networks, a development which also helps incumbents to maintain their centrality. Consequently, disruption can be expected to be led by new entrepreneurial firms and not from incumbent TGs, confirming previous research in entrepreneurship (e.g., [16]) and technology strategy [19] [88] [58] view about incumbent TGs' rejection of the disruptive technology in order to maintain the status quo and their centrality in their networks [9].

Similarly, the economic geography view [82] [28] is extended by adding new knowledge about the TGs dynamics and their limited role transforming clusters in the transition from maturity to renewal stages. Therefore, it is new spin-offs from incumbent TGs, and not the TGs themselves, which create knowledge for renewing clusters, confirming the management literature perspective which asserts that knowledge is inherited and that the main engine of the cluster (re-)formation is the spinoff process [59] [30], together with agglomeration externalities [30]. Once the new technology has become established the incumbent TGs still retain control of their networks by accessing the new technology and sharing centrality with the new TGs that created the new technology using alliances.

Temporary TGs established global pipelines to access external knowledge, corroborating what is being said in the external linkages debate (e.g. [18]). Nevertheless, our findings have gone one step further: the type of knowledge necessary to challenge incumbent TGs must be new to the industry and to the cluster, that is to say disruptive ideas must come from other industries. If this was not so, the incumbent TGs would have an advantage and a new entrepreneurial firm can be blocked. In addition, this paper showed how disruption is also common in IDs which are well endowed with superior knowledge capable of absorb external knowledge, that is, absorptive capacity [39].

This study contributes to the open innovation literature [36], but also highlights the multiplier effect [21] that the cluster atmosphere exerts on the knowledge creation and diffusion process. The paper has important implications for scholars, who should also research the resilience of TGs and their relationship with the dynamics of cluster life cycles. These insights open up new research avenues, including the need for more empirical evidence to support theory building regarding technology gatekeepers and their relation to cluster evolution. The paper's findings are limited in the first place by the fact that the study needs to be extended to other type of IDs in other industries in order to generalize results. For future research, this longitudinal analysis needs to be replicated in other IDs in order to generate verifiable hypothesis and thus build robust theory.

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