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Emerging firms in an emerging field: an analysis of patent citations in electronic-paper display technology

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Abstract USPTO patent data covering the years 1994–2008 is used in this study to examine the citation networks of electronic-paper display technology. Our primary aim is to provide a better understanding of the ways in which emerging firms interact with, and learn from, technology diffusers. Two implications can be drawn from our analysis. Firstly, emerging firms within an emerging industry can enhance their technological capabilities through positive external learning activity. Secondly, despite the fact that technology diffusers have clear technological advantages, with the emergence of a new field, their influence within the network could potentially be decayed if they fail to remain proactive in terms of the absorption of available external knowledge.

Keywords Patent citation · Electronic-paper display technology · Emerging field

Introduction

Flexible electronic technologies have been applied to a wide variety of products, including digital posters, radio frequency identification (RFID) and electronic books (e-books). Nevertheless, whilst it is quite clear that the e-book industry has enjoyed a boom period over recent years, essentially as a result of the successful commercialization of Kindle (the Amazon e-book reader), it may not be widely known that the first ever e-book to be made available to the market had been introduced earlier by Sony.

It was, however, not until after the release of Kindle at the end of 2007, that the market was to become prosperous, maintaining tremendous growth even after the introduction of the iPad in 2010; and indeed, according to Digitimes, by 2009, global sales of electronic book readers had risen to approximately three million units, representing a threefold increase on the level of sales just one year earlier.

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Such a thriving market has therefore attracted considerable interest from other firms keen to enter this lucrative field, including Plastic Logic (USA), Samsung (Korea), Fujitsu (Japan), Foxconn (China), Prime View International and AU Optronics Corporation (Taiwan). However, due to the technological complexities involved, very few of these firms have proven capable of manufacturing the upstream products, electronic-paper (e-paper).

E-paper is a display technology which is an essential element of e-books. In order to duplicate the traditional reading experience, e-paper is designed to imitate the look of actual printed paper. Nevertheless, e-paper differs significantly from conventional flat panel displays since the latter illuminate pixels with electricity, while images on e-paper can remain constant in the absence of power. Furthermore, e-paper provides wider reading angles.

Amongst all of the various e-paper display technologies, the two main technologies in the e-book reader production are 'electrophoresis displays' (EPDs) and 'cholesteric liquid crystal displays' (Ch-LCDs). Thus, in the present study, we examine the behavior of manufacturing firms adapting these technologies, focusing on four of the leading firms in this field, E Ink, SiPix, Kent Display and Bridgestone; these are referred to throughout this study as the 'emerging firms'.

The primary aims of this study are to provide a better understanding of the ways in which these emerging firms in this emerging field interact with, and learn from, technology diffusers. We find that activeness in learning has a significantly positive impact on the relative importance of e-paper display technology within the knowledge network. Firms engaging in intensive patent citation activities with the aim of accruing knowledge from other firms can maintain, or indeed, improve their position within the network. On the other hand, however, the outcomes may not be so attractive for those firms which exhibit less dedication to such knowledge acquisition, despite their previous advantages in various technologies.

The remainder of this paper is organized as follows. "Development of e-paper display technology" section provides a brief introduction to the technological development of the e-paper industry, followed in "Methodology" section by explanations of both the sample selection process and the research methodology adopted for this study. The empirical analyses are provided in "Results" section, along with a discussion of the findings and implications. Finally, the conclusions drawn from this study are presented in "Conclusions" section.

Development of e-paper display technology

The mainstream e-paper technologies used in e-book readers are 'electrophoresis displays' (EPDs) and 'cholesteric liquid crystal displays' (Ch-LCDs). The EPDs account for approximately 93% of the total e-paper market share and are utilized by firms such as E Ink, SiPix and Bridgestone, whilst Ch-LCDs, which account for about 5% of the market share, are used by Kent Display and certain other firms. The development of these two technologies is briefly described below.

Electrophoresis displays (EPDs)

EPDs utilize charged particles such that when electric fields are applied, these particles, which are scattered in clear fluid, migrate to the surface of the container according to their electrodes. Thus, the image which is displayed is changed accordingly. This technology

makes e-paper visible under direct sunlight, whilst also maintaining the page in the absence of power.

The display technology developed by E Ink involves the application of microcapsules which contain particles and electrolyte, with the white (black) particles being positively (negatively) charged. When a positive electrical field is applied, the black particles flow to the upper surface of the microcapsules and become visible, whilst the white particles are forced to move to the back, such that a particular spot on the screen appears as black; this process is reversed when a negative electrical field is applied. Since the production is relatively simple and less costly, the E Ink technology has been adopted by over 90% of all commercialized electronic readers.

As opposed to microcapsules, the composition of SiPix's electronic ink is a microcup. This is built on a layer of flexible PET (polyethylene terephthalate) plastic containing dielectric fluid 'indium tin oxide' (ITO) which charges the particles; the particles then migrate when an electrical field is applied. If the particles are at the surface, and therefore visible, that area turns to their respective colors.

Both microcapsule and microcup have the disadvantage of long response times; that is, they are very slow in turning the pages and the animations included in the displays. However, SiPix claims that its roll-to-roll technology has a distinct advantage over E Ink's sheet-to-sheet technology in terms of rapid production. Furthermore, microcup appears to be more competitive in the long-run since it has relative advantages in developing colorization. Nevertheless, the production process is currently both difficult and expensive.

Another application of EPDs is a technology developed by Bridgestone, the 'quick response-liquid powder display' (QR-LPD). This technology involves the adoption of electronic liquid powders to replace minute containers, with air substituting for electrolyte fluid, and the overall process facilitating a much more rapid change in the images; however, it has certain disadvantages in areas such as colorization and image-sticking.

Cholesteric LCD (CH-LCD)

When chiral dopant is added to nematic liquid, an optically active substance, its structure becomes spiral; thus, as a result of its resemblance to an actual cholesterol molecule, this type of nematic liquid is referred to as 'cholesteric liquid'. Without any electrical field being applied, cholesteric liquid placed between two horizontal substrates will be arranged in horizontal spiral order and will either be transparent or will reflect color.

When different voltages are applied, the liquid shifts between the three states of 'planar', 'focal conic' and 'hometropic', with these shifts determining the brightness of the displayed images, whilst colorization is achieved in Ch-LCDs when the pitch lengths of the molecules are altered. Although Ch-LCD technology appears to have some attraction, slow response time and high cost are significant obstacles to this technology gaining market share; despite this, firms such as Kent Display and Fujitsu continue to utilize this type of technology in their e-paper products.

Methodology

Data source

We collected data on US patents issued in response to applications submitted between 1994 and 2008, focusing on the patents assigned to four 'emerging firms' (E Ink, SiPix,

Kent Display and Bridgestone), as well as the related citations from the United States Patent and Trademark Office (USPTO) database.

We found that during the period under examination, E Ink had 171 patent counts, whilst SiPix had 101 and Kent Display had 23, with all of these patents being related to e-paper display technology. Bridgestone is, however, widely known for its mainstream involvement in the tire production business, which is obviously quite different from the technology under discussion here; thus, referring to Jang et al. (2009), we used several keywords related to e-paper display technologies to screen for the company's associated patents as shown in the Appendix. As a result, we found that Bridgestone had 56 related patent counts during the sample period.

There was a requirement for us to determine the citation parties of these emerging firms, as well as the associated citation frequencies, in order to build up a picture of their citation network; as a result, we found that only very few parties were cited more than ten times. Thus, after excluding both research institutions and the emerging firms themselves, we found that the three firms that were mostly cited by the emerging firms were Copytele, Xerox and Eastman Kodak. These three firms are regarded as the initial owners of e-paper display technology, and are therefore considered in the present study as the knowledge diffusers of the e-paper display technology.

In all 89 of the patents owned by Copytele, the discussion was directly related to e-paper display technology; however, since Xerox and Eastman Kodak are involved in more diversified technologies, such as copiers and digital cameras, not all of their innovations are directly related to e-paper display. We therefore carried out a search for all of their patents associated with e-paper display technology, defining those patents belonging to the following categories as being e-paper display technology-related: (i) those UPC classes in which the qualified patents of the emerging firms were also situated; and (ii) the three major UPC classes that were most often cited in the patent applications of the four emerging firms.

A total of 38 patent classes were selected according to the above mentioned criteria, which ultimately provided us with 3,802 patents for Xerox (out of a total patent count of 15,546) and 6,416 for Eastman Kodak (out of a total patent count of 19,013). And all of these selected/screened patents were directly related to e-paper display technologies. The total patent counts for both companies were as at 31 December 2008. With all of the e-paper technology related patent selected both from emerging firms and technology diffusers, we were able to build up the citation network of each sample year using the software UCINET.

Methods

The opportunities for any unit within a network to access new knowledge required for further development are clearly affected by its network position (Tsai 2001), and in order to characterize the position of each firm within the patent citation network within the field of e-paper display, there is a requirement to investigate the direct and indirect linkages between each component. 'Network centrality' indicators are ultimately found to provide us with a useful method of measurement; thus, the following two definitions of network centrality, introduced by Freeman (1979), are adopted for the present study.

Degree centrality

A firm is regarded as being more 'central' to the network if it shares more links with other nodes within the network. This concept, which is known as 'degree centrality', refers to the

importance of each individual firm within the network (Yang et al. 2010) as well as its potential communicative ability (Freeman 1979). This concept has been applied in many studies within the prior literature, including Tsai (2001) and Larson (2008).

With the assistance of the UCINET software, we calculated the frequency of patent citations for each firm within the patent citation network, and then adjusted the results to counteract the effects of network size. The adjustment was made through dividing the frequency value by the total number of nodes minus one. Our calculation of the frequency of patent citations also includes a traditional 15% depreciation, as used in many of the prior studies (for example, Hall and Trajtenberg 2005), based upon the assumption that the value of the patents will decay over time.

Hagedoorn and Duysters (2002) assumed that firms experiment with, and learn from, their contacts. Degree centrality, which represents the direct linkages which a firm has with fellow members, has been applied as a measure of the learning behavior of the firms within a dynamic network; and indeed, their research did indicate that having more contacts with fellow members within the network enhances the probability of developing new capabilities. We therefore assume that the higher the degree centrality of a firm, the more active the firm will be in terms of gaining new knowledge, which will clearly have a positive impact on its future innovative performance.

Betweenness centrality

In addition to direct connections, there will also be some indirect transfer of knowledge from one firm to another; and indeed, those firms falling directly in the communication path between other firms will clearly exhibit strong potential to control the overall process of knowledge diffusion throughout the network. This potential controlling effect, which is known as 'betweenness centrality', is defined as the frequency of a firm falling between pairs of geodesic citation paths (Freeman 1979), and indicates the ability to control and coordinate knowledge within the overall diffusion process (Yang et al. 2010). In the absence of nodes with significant levels of betweenness, the network might well fall apart.

To calculate this indicator, we must first determine the proportion of a firm's involvement in each geodesic knowledge-transference path between other firms, and then sum up the proportions; this will ultimately reveal how much the firm controls the flow of information throughout the network (i.e., its level of 'betweenness'). However, in order to make appropriate comparisons between different networks, we again have to adjust for the effects of network size. According to Freeman (1977), the greatest betweenness centrality within a network of n nodes is:

$$\frac{n^2 - 3n + 2}{2}.$$

The actual betweenness centrality indicator would therefore have to be divided by this number.

Table 1 provides both a brief overview and a comparison of the patenting performance of our four emerging firms in the e-paper display technology, from which we can see that, in terms of both absolute number and relative percentage, E Ink has consistently been the owner of the greatest number of patents. SiPix joined the market in 1999, thus its patenting work is obviously reflected only in the subsequent periods. Although SiPix entered the market relatively late, its performance has not proven to be inferior to that of the earlier

Table 1 The patenting performance of emerging firms in e-paper display technologies

Emerging firms	1994–1999		2000–2004		2005–2008	
	Number	%Share	Number	%Share	Number	%Share
E Ink	34	58.62	91	46.42	46	51.68
SiPix	–	0.00	72	36.73	29	32.58
Kent Displays	11	18.96	8	4.08	4	4.49
Bridgestone	13	22.41	25	12.75	10	1.12
Total	58	100.00	196	100.00	89	100.00

incumbents; indeed, its activeness has apparently outperformed that of both Kent Display and Bridgestone, whose relative proportions declined after 1994–1999.

Results

Despite having already amassed about 15 years of development, the e-paper industry can still be regarded as an emerging field; that is, the industry has already gone through, and is still experiencing, extremely rapid changes, in terms of technologies, competitors and market demand. Hagedoorn and Duysters (2002) indicated that in any environment characterized by rapid change, the current status of firms within a network may not necessarily provide an accurate predictor of their potential; it is therefore essential for us to examine such dynamics if we are to appropriately analyze the extent of knowledge and technology diffusion over time. Thus, our analysis of the development of the e-paper industry involves the following three stages.

Of the four emerging firms examined in this study, Kent Display was the first to be established, in 1994, with none of the other firms having been set up until 1999; we therefore define the period between 1994 and 1999 as the 'emergent' stage. Increasing numbers of patent grants have been observed within this overall field since 2000, with e-paper related products subsequently being commercialized and released from 2005 onwards. Thus we select the year 2005 as the cut-off point, with the 2000–2004 period being defined as the 'development' stage of the e-paper industry, and the 'commercialization' stage being defined as starting in 2005.

Figures 1, 2, 3, and 4 show the respective dynamic changes in the e-paper display technology patent citation network for 1994, 1999, 2004 and 2008. The numbers that appear next to each node in these three figures (i.e., each firm), are the number of occurrences of self-citations. The numbers alongside a line between two firms are the number of occurrences of mutual citations, with the nearer node being the one which cited the patent.

Emergent stage

Of the four emerging firms examined in the present study, Bridgestone was the only one which existed within the network prior to 1994, along with the three knowledge diffusers (Copytele, Xerox, and Eastman Kodak), as shown in Fig. 1.

Although Bridgestone was not officially participating in the e-paper industry, it nevertheless owned several technologies of relevance to e-paper display, and indeed, had

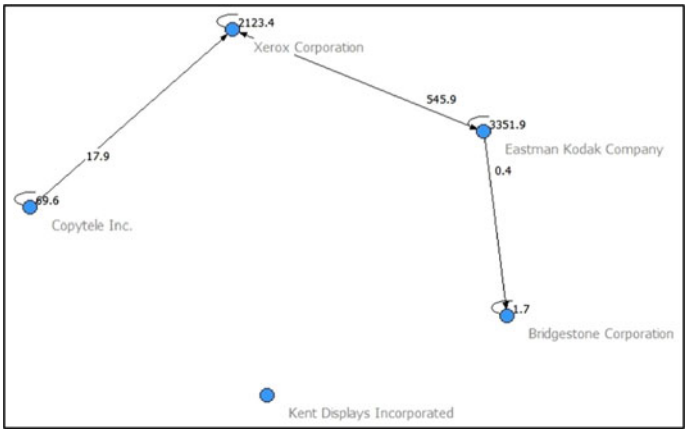

Fig. 1 The patent citation network of e-paper display, 1994

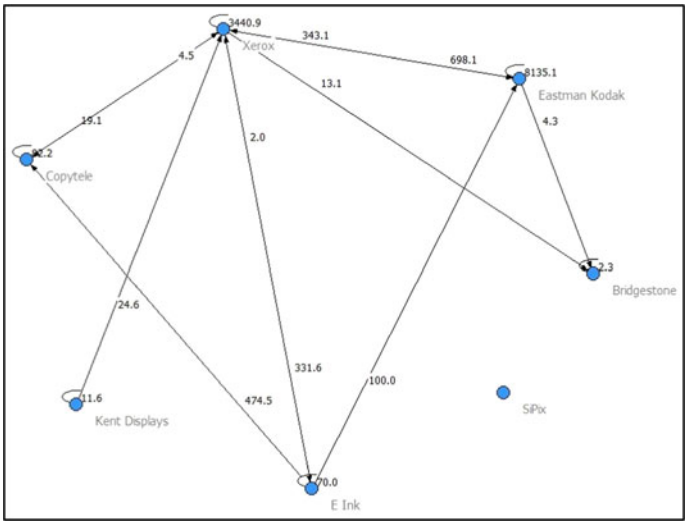

Fig. 2 The patent citation network of e-paper display, 1999

already been cited 0.4 times by Eastman Kodak in 1994. However, according to Fig. 1, its position within the network at that time was merely peripheral, as compared to the knowledge diffusers, where we observe intensive interactions between Xerox and Eastman Kodak.

Kent Display, E Ink and SiPix subsequently joined the industry during the emergent stage, and as we can see from Fig. 2, E Ink, which has proven to be dedicated to citing knowledge diffusers ever since its entrance, has also proven to be the most active learner amongst our sample of emerging firms, having cited Copytele 474.5 times and Xerox 331.6 times. In contrast, the pace of learning has been much slower at both Kent Display and SiPix, as it was not until a few years after their entry into the citation network that they began interacting with other nodes. By 1999, Kent Display had cited Xerox less than 30

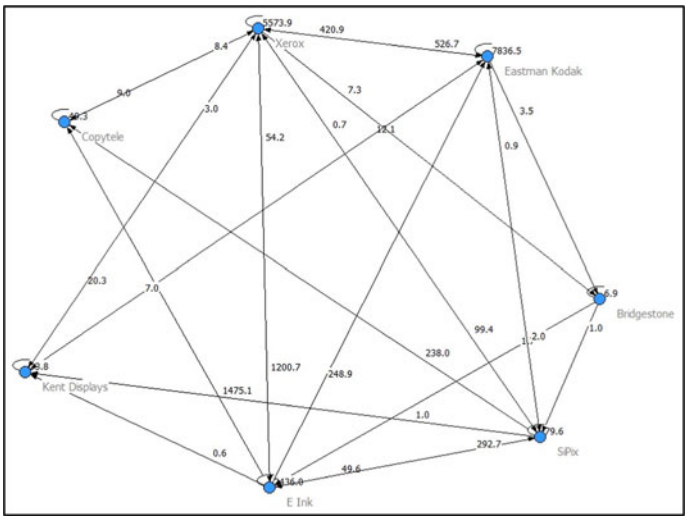

Fig. 3 The patent citation network of e-paper display, 2004

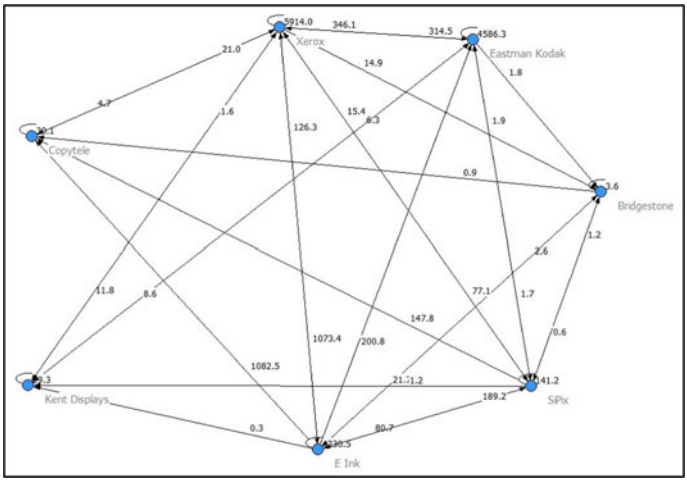

Fig. 4 The patent citation network of e-paper display, 2008

times, and the newly-established SiPix had not even begun citing any of the knowledge diffusers.

The citation relationships between the emerging firms and knowledge diffusers are found to be asymmetric; that is, whilst the emerging firms are found to have regularly cited patents owned by the knowledge diffusers, their own patents are rarely cited by any of the three pre-existing firms, thereby clearly indicating the unidirectional flow of knowledge. This also infers that the technological capabilities of the emerging firms are not as strong as those of the knowledge diffusers, given their long history and considerable numbers of patents.

Development stage

Our findings in this study indicate that citation behavior within this network became more intensive during the development stage (2000–2004), as shown in Fig. 3. Although there has been no discernible change in the general direction of the knowledge flow, there are obvious increases in the number of citations made by the three knowledge diffusers relating to patents belonging to the four emerging firms. This is most obvious in the case of E Ink, particularly with regard to the citations made by Xerox. Although E Ink was found to have cited Xerox more than 1,200 times, Xerox had also made 54.2 citations of E Ink patents over the same sample period.

In contrast to the findings on E Ink, enhancements to the reverse flow of knowledge are shown to be relatively smaller for both Kent Display and SiPix during the development stage. We also find that during this stage, Eastman Kodak was not so frequently cited by the active learner, E Ink, as compared to its citations of Copytele and Xerox patents.

Whilst still mainly citing the knowledge diffusers in the development stage, it is, nevertheless, quite clear that some of the emerging firms had also begun citing their compatriots, with E Ink being the most frequently cited of the four emerging firms during this stage; however, E Ink itself is found to have rarely cited any of the other emerging firms. The case of another of the active emerging firms, SiPix, was found to be quite different, since it cited both knowledge diffusers (Xerox, 99.4; Copytel, 238.0) and the emerging firm, E Ink (292.7).

Commercialization stage

A comparison between Figs. 3 and 4 reveals that during the commercialization stage, the interactions between these firms, with regard to their patent citations, were quite similar to those occurring in the development stage, with Xerox and Copytele maintaining their position as the major knowledge diffusers.

As regards their relative importance to the emerging firms within the knowledge network, there was no discernible widening of the gap identified between the two leading knowledge diffusers and Eastman Kodak during the development stage; nevertheless, Eastman Kodak appears to have done little to retain its position of importance, which is further confirmed by Fig. 2. Furthermore, between the development stage and the commercialization stage, increases in both self-citations and mutual citations were not as obvious for firms within the network as they had been in the previous transition period.

In summary, we find that the knowledge diffusers within the e-paper innovation network, comprising of Copytele, Xerox and Eastman Kodak, have proven to be essential sources of technology for all four of the emerging firms examined in this study; however, with the passage of time, one of these emerging firms, E Ink, has itself also become an important source of technology for its three counterparts.

Although Eastman Kodak had been the most important technology diffuser during the emergent stage, its knowledge flows were basically unidirectional, insofar as its knowledge was spilling over to other firms. Due to its apparent failure to place continuing emphasis on learning, the position of importance within the e-paper patent citation network that had previously been enjoyed by Eastman Kodak has decayed over time. As Fig. 5 clearly illustrates, during the commercialization stage, Eastman Kodak was even surpassed by one of the other technology diffusers, Xerox.

The case of E Ink represents quite the reverse, since it is found to have been quite active in learning ever since it first entered the industry, with the innovation strategy adopted by

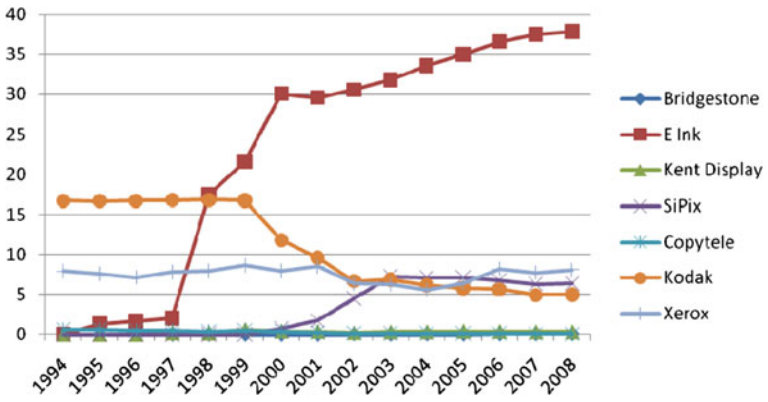

Fig. 5 Degree centrality of firms in the e-paper display patent citation network, 1994–2008

this firm having delivered quite inspiring outcomes. The importance of its relative position within the network has obviously been enhanced over time; and indeed, after several years of such continuing dedication, it seems that E Ink may well have started to play the role of technology diffuser to the other emerging firms.

These findings imply that activeness in learning is one of the key determinants of a firm's future network position in the e-paper industry. Although the technology diffusers did have essential technology on hand initially, this has clearly proven to be no guarantee of their continuing competitiveness. These firms still have to interact and learn from other members within the patent citation network in order to maintain their competitive position.

Conversely, despite the fact that the emerging firms examined in this study lacked critical technologies from the outset, and appeared to be somewhat inferior to the knowledge diffusers, the evidence suggests that this situation can be altered though dedication in the absorption of knowledge through patent citations. The more enthusiastic an emerging firm is, the greater the innovation opportunities they are likely to be presented with, which, as observed in the present study, will clearly have a positive impact on their position within the network.

Dynamic analysis of network centrality in e-paper display technology

Over the sample period examined in this study, a trend towards degree centrality by the firms within the e-paper display patent citation network is clearly demonstrated in Fig. 5, with this figure facilitating a close examination of the trend towards centrality for each firm over time.

We begin with an examination of the performance of the emerging firms in terms of 'degree centrality', where the elevated status of E Ink, in terms of its essential presence within the network, is most obvious, and indeed, the most rapid. Although SiPix also demonstrates an upward trend, the magnitude of growth in this firm is clearly much smaller than that of E Ink. However, both Kent Display and Bridgestone reveal much poorer performance in terms of upgrading their overall positions within the technology network.

As regards the technology diffusers, we find that there has been some decay in the level of importance within the network for both Eastman Kodak and Xerox, although the decay rate for the latter is found to be much less severe. The trend curve for Copytele, with regard to its degree centrality, appears to be downward, but much flatter. We suggest that this is

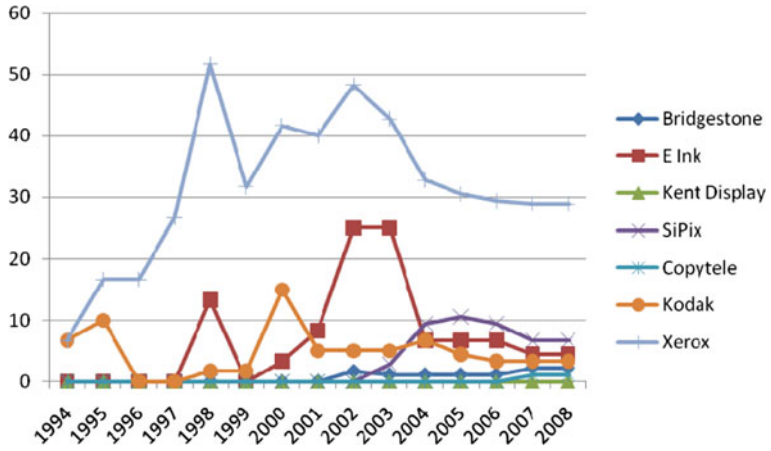

Fig. 6 Betweenness centrality of firms in the e-paper industry, 1994–2008

because Copytele has never really represented such an essential element of the network as its two counterpart technology diffusers, Eastman Kodak and Xerox.

The time trend of 'betweenness centrality' is further examined, in relative terms, in Fig. 6, which illustrates that Xerox and E Ink are the two most indispensible transmitters in the e-paper display technology patent citation network. It should be noted here that the role of 'technology transmitters' differs from the role defined for 'knowledge diffusers' in the previous sections. These two firms actually represent the media channel of the citation network, and indeed, without them, the citation network may well have fallen apart.

We observed earlier, in Fig. 5, that despite its reduction in essential presence, Eastman Kodak has continued to play a major role in overall knowledge flows; however, it is clear that if Xerox were to be removed from this network, the role played by Eastman Kodak would cease to have such importance. From our observations of the citation networks over time (Figs. 1, 2, 3, 4), we find that Eastman Kodak has never had as many direct linkages as the other knowledge diffusers, such that indirect channels are an essential element of its knowledge transfer, and this may well partly explain why Xerox has become a crucial intermediary. As regards the emerging firms, the three firms (excluding E Ink) have become heavily reliant on E Ink for their e-paper-display technologies, thereby elevating the latter's position, with this firm actually becoming a new knowledge diffuser itself.

Although the results of the *t* test in Table 2 do not reveal any significant differences in the level of 'degree centrality' between the emerging firms and the knowledge diffusers between 1994 and 2008, there are distinct differences between their positions and level of importance during the three sub-periods. As their name suggests, the knowledge diffusers have played the role of distributors of new technologies during the entire sample period; however, it seems clear that they have also been playing the role of information media, whereas the emerging firms have tended to play the role of receptors.

By examining the developmental dynamics during the three distinct stages, we may be able to gain a clearer picture of the whole process over time. During the 'emergent' stage (1994–1999), the three knowledge diffusers reveal tighter linkages with the other nodes within the network (the four emerging firms) as indicated by the *t* value of −6.8321 in the second row. However, in the 'development' stage (2000–2004), the emerging firms are found to be significantly more active in terms of patent citations than the knowledge

Table 2 *T* test of centrality indicators between emerging firms and knowledge diffusers

Evolutionary stages	Null hypothesis (H_0)[a]	Test results	
		Degree centrality	Betweenness centrality
1994–2008	$\mu_E = \mu_D$	0.2748	−10.3130***
Emergent stage (1994–1999)	$\mu_E = \mu_D$	−6.8321***	−5.9629***
Development stage (2000–2004)	$\mu_E = \mu_D$	3.7400**	−6.9372***
Commercialization stage (2005–2008)	$\mu_E = \mu_D$	59.7532***	−25.7968***

** Significance at the 5% level; *** Significance at the 1% level

[a] μ_E refers to the values for the emerging firms; and μ_D refers to the values for knowledge diffusers

diffusers, given the *t* value of 3.7400. Furthermore, the gap had widened even more over the 'commercialization' stage (2005–2008), as evidenced by the *t* value of 59.75.

However, each of the *t* statistics relating to 'betweenness centrality', shown in the fourth column of Table 2, reveals a negative value, thereby indicating that in terms of playing the role of information distributors, the emerging firms were not as important as their counterparts. In our earlier discussion, we recognized the presence of E Ink within the network as being essential; it is, however, clear that each of the remaining emerging firms have not kept pace with the success of E Ink.

Conclusions

We have carried out an analysis of the innovative activities and network dynamics of e-paper display technology, with particular emphasis on the emerging firms in this field comprising of E Ink, SiPix, Kent Display and Bridgestone. Given their lack of sufficient knowledge base, the emerging firms in this emerging field are required to strengthen their position through learning activities. The exploration of knowledge can be both internal and external, with the former including in-house R&D investment, and the latter involving citations of external patents or the acquisition of firms with critical technologies.

Firms may actually follow both channels to improve their innovative capability, the complementarity of which is suggested in Cassiman and Veugeler (2006) and several earlier studies. Thus, in any proposed analysis, both of these channels of R&D activity should be covered wherever possible; however, data availability confines the discussion in the present study to external R&D sourcing, that is, an examination of the patent citation behavior of firms. We identified another group of firms, defined in the present study as 'knowledge diffusers', which provide e-paper display technologies to the emerging firms within the industry through patent citations.

Following the concept of social networks, we observe the ways in which seven firms within the e-paper display industry interact with each other in the patent citation network, and discover that in the 'emergent' stage, the knowledge flows were mainly unidirectional; that is, emerging firms tended to acquire knowledge from knowledge diffusers, although with varying degrees of involvement. Thereafter, differences in devotion and application within this field led to widening gaps in innovative performance. We note that the greater activeness of the emerging firms has led to them gaining greater importance in the citation network, with E Ink's 'degree centrality' even surpassing that of the knowledge diffusers.

There are two implications which may be drawn from our findings in the present study. Firstly, we find that emerging firms in an emerging industry can enhance their technological capability through activeness in external learning, with the success of E Ink providing inspiring evidence of this. Secondly, despite the technology diffusers, such as Eastman Kodak, having initial technological advantages, their influence within the network can rapidly decay if they do not remain proactive in the absorption of external knowledge. Thus, we argue that in order to achieve and maintain technological competitiveness, and to remain influential in an emerging field, activeness in learning, as measured by a firm's centrality within the patent citation network, plays an indispensible role.

It must, however, be emphasized that in the present study, we make the implicit assumption that patent citations represent inter-firm knowledge spillover. According to Hal et al. (2001), patent citations do allow researchers to study knowledge spillovers; however, many other scholars also point to certain problems that may arise as a result of such an assumption.

Firstly, patent citations are not the only channel of knowledge spillover, since knowledge is diffused through the acquisition of firms, as well as licensing or recruiting experts from other institutions. Secondly, the patent citations included were decided by the examiner; therefore, some patents cited by the examiner will not actually have any direct ties with the patent discussed (Jaffe et al. 2000).

Although these limitations may place some restrictions on the findings of the present study, as noted by Jaffe et al. (1993), it is generally regarded as being reasonable to draw inferences on knowledge spillover effects based upon patent citations.

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Appendix

Keywords used for searching Bridgestone's patents related to e-paper display technology

Patent's information sources	Keywords
Patent title, claims, abstract and specification	Display, display panel, paper-like, electronic paper, liquid powder display.

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