The Greater Scattering Phenomenon Beyond Bradford's Law in Patent Citation

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Patent analysis has become important for management as it offers timely and valuable information to evaluate R&D performance and identify the prospects of patents. This study explores the scattering patterns of patent impact based on citations in 3 distinct technological areas, the liquid crystal, semiconductor, and drug technological areas, to identify the core patents in each area. The research follows the approach from Bradford's law, which equally divides total citations into 3 zones. While the result suggests that the scattering of patent citations corresponded with features of Bradford's law, the proportion of patents in the 3 zones did not match the proportion as proposed by the law. As a result, the study shows that the distributions of citations in all 3 areas were more concentrated than what Bradford's law proposed. The Groos (1967) droop was also presented by the scattering of patent citations, and the growth rate of cumulative citation decreased in the third zone.

Introduction

In a knowledge-based economy, the most important output factors are allocating, producing, and using knowledge resources. Technological knowledge has become the engine of competition. Firms and specific technologies owners protect the core knowledge through patents to remain competitive. Patent analysis has become instrumental in evaluating the competitiveness of firms. Company valuation pays close attention to book value as well as the value of patents, one of its intangible and important assets. There are several patent analysis methods that could be applied to different company assessments (Breitzman & Mogee, 2002). Banerjee, Gupta, and Garg (2000) contended that patent analysis draws a set of indicators to measure economic activity and innovation output, using the results to position the research competences of firms and nations. Patent analysis also assists management decision making in firms (Choung, 1998; Griliches, 1984, 1990; Kayal & Waters, 1999).

According to the *World Intellectual Property Indicators* (WIPO, 2011), the number of patents worldwide has increased dramatically. Patent applications numbered 888,200 in 1991 and 1,979,133 in 2010, an increasing rate of 1.23. Hence, identifying core patents through patent analysis is a critical issue for managers. Researchers have developed many models and laws to determine core literatures or to demonstrate bibliometric distributions. For example, Zipf's law, Lotka's law, and Pratt's measure measure the concentration of information distribution, and Egghe (1987) showed that a data set is shown to be more concentrated using Lotka's law than using Zipf's law. Braam, Moed, and van Raan (1991) proposed a bibliometric method that maps subjects of scientific research in a given period by combining cocitation and word analysis methods. In Glänzel and Schubert's (1985) study, they

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found that half of the scientific papers are contributed by few productive authors in the data set. Vinkler (2009) proposed the pi-index to assess the scientific impact of scientists or researchers in similar subject fields. Bradford's law (1934) depicts the scattering of publications and identifies core journals and articles for a specific discipline. In recent research studies, applications of Bradford's law were diverse. For example, Faba-Perez, Guerrero-Bote, and Moya-Angeon (2003) investigated the distribution of linkages from a selected web space and found that the data set did not fit the typical Bradford's law. Regolini, Gentilini, Baligand, and Jannes-Ober (2012) also examined citations of articles from a set of electronic periodical collections in a given discipline, and stated that Bradford's law could be used in libraries to identify journals with high qualitative articles. In this study, we adopted Bradford's law to identify core patents through the patent's citations and the scattering patterns of impact from Bradford's law. In addition to the original law, this study analyzed the scattering of citations and modified the law. In the following paragraphs, Bradford's law, citation analysis, and evaluation with patent citation are further discussed.

Bradford's Law

Bradford's law states that articles on a subject are scattered according to a specific mathematical function: $1{:}n{:}n^2$, meaning that Bradford's law was not only a law of scatter but also a law of concentration (Gordon, 2010). Bradford (1934) found that only 250,000 out of 750,000 articles were published in 300 abstracting and indexing journals. He conducted a study in applied geophysics and lubrication and proposed that scientific research on a specific subject is scattering into three zones, each zone containing the same amount of research articles. Articles in the first zone are highly concentrated in a few core journals in a research field; the second zone contains more journals not in the first zone; the number of journals in the third zone grows exponentially compared with the second zone. That is, the number of journals in each zone, which contains equal numbers of articles, is in a proportion of $1{:}n{:}n^2$, where n is called the Bradford multiplier. Bradford's law was originally a study on geophysics covering 326 journals, and the zones contained nine, 59, and 258 journals, respectively. Numerous researchers have conducted bibliometric studies of science literatures following Bradford's law. Vickery (1948) analyzed 1,600 periodical references and compared the result to the study of Bradford. Vickery designated the scattering of scientific research as "Bradford's law." Leimkuhler (1967) also followed Bradford's law to conduct a study in the mathematics literature. While various studies applying the law resulted in different numbers of core journals and Bradford multipliers, these studies support the scattering patterns across disciplines.

Groos (1967) stated that Bradford's law underestimated the number of journals in the third zone, in which articles scattered droopily rather than linearly. Therefore, the scattering should be an "S"-shaped pattern. Brookes (1973) found similarity between Bradford's law and Zipf's law and combined the two laws to develop the "Bradford-Zipf law." Pope (1975) examined the droop phenomenon proposed by Groos with statistical analysis. Basu (1992) reviewed prior research employing Bradford's law and presented a model for the distribution of articles based on a random and unequal partitioning model. Bookstein (1993) examined implications of Bradford's law in relation to the multidisciplinary character of the journal and developed a model indicating the evolution of journals.

Bensman (1982) analyzed data in Bradford's study of applied geophysics and lubrication subjects and found that when all articles were divided into three zones equally, the ratio between numbers of journals in each zone approximated $1{:}n{:}n^2$. Garg, Praveen, and Lalita (1992) found the scattering of journal articles in the solar power field is similar to Bradford's curve. Coleman (1993) stated that in social science bibliographies, distribution in graphs of Bradford's law showed different patterns between homogeneous and heterogeneous bibliographies. Chen, Chong, and Tong (1995) studied the evolution of Bradford's graphs and identified critical factors contributing to the dynamic behavior of Bradford's law. Heine (1998) applied the article distribution of Bradford's law to show the relationships between journal productivity and journal rankings, and proposed using a specific ranking convention to present Bradford data. Rao (1998) analyzed 12 data sets and suggested a log-normal model which is more suitable to present the law of scattering.

Several studies adopted Bradford's law to plot the scattering of citations across journals (Mishral, Panda, & Goswami, 2010; Deng & Lin, 2012; Jena, Swain, & Sahu, 2012). Barrios et al. (2008) also employed Bradford's law to analyze the distribution of papers. Furthermore, the research showed that the median of citations in each zone also followed the power law, with a ratio of $2^2 : 2 : 1$. The subjects of the aforementioned studies not only covered the number of journals and journal citations, but also the number of papers and paper citations. This study adopts Bradford's law to analyze the scattering of patent forward citation and to identify core patents.

An established law can remain debatable among scholars. For example, some theories proposed departures from the power law, such as "black swans" and "dragon kings." Janczura and Weron (2012) conducted three tests to identify whether there were extremely significant deviations from power law tails in natural disasters, financial crashes, and electricity prices. These deviations were called "dragon kings." Although we cannot overcome extreme outliers existing in power law with more data, some data sets still modulate ideal power models with measurable and consistent patterns (Katz & Katz, 1999).

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Citation Analysis

Citation analysis is a method used to evaluate patents. The citation frequency of patents is an indication of technological significance. A higher citation rate of patents suggests that the patents are more technologically important (Narin, 1994). Patent citation analysis identifies patents with a strong impact on recent technology development (Thomas & Breitzman, 2006). A patent cited by later patents contains innovative ideas that influence later technology development. Patent impact is used to identify the core technological competence of institutions. Lanjouw and Schankerman (2004) developed an index for assessing patent quality by calculating number of claims, cited numbers, citing numbers, and patent family sizes. Other studies considered not only the number of times that a patent is directly cited, but also the number of indirectly cited patents (Atallah & Rodriguez, 2006). Thomas, McMillan, and Abington, (2001) measured and predicted companies' stock market performance with technological indicators based on patent citations and the technology cycle time (TCT) indicator, the median of discrepancies between the ages of patents, and the patents it cited. The TCT was more effective in the study than Standard and Poor's (S&P) 500 index. Pouris (2005) used patent citations to compare the performance of transport research in South Africa and other countries. Patent citation analysis has also been used to study technology flow and R&D spillover. Jaffe, Trajtenberg, and Henderson (1992) conducted research comparing the geographic locations of patents and other patents citing the patent, showing that the knowledge spillovers were geographically localized.

However, citation analysis is not without problems. Citation analysis often fails to differentiate among different citing behaviors and purposes, and citations such as biased citations, self-citation, citation errors, etc., may misinform assessment (Leimu & Koricheva, 2005; MacRoberts & MacRoberts, 1996; Ohniwa, Denawa, Kudo, Nakamura, & Takeyasu, 2004; Van Leeuwen, Moed, & Reedijk, 1999; Van Raan, 1999; Huang, 2011; Chang, 2012). Wilson (1995) studied three reasons for unused relevant information, namely, failure to find, information overload, and nonuse policy. The citing motivation of patent inventor is similar to that of essayists. Bessen (2008) indicated that patent citation statistics are correlated with the value of patents with statistical but not economic significance, meaning that a small portion of variance in patent value can be explained. While patent citation analysis may have shortcomings, this study applied Bradford's law to analyze citation data to find the distribution pattern of patents.

Evaluations With Patent Citation

Narin (1994) observed skewness of citation distribution in the IR100 award. The result shows that a relatively small number of both patents and papers received plenty of citations, and the author established a patent bibliometrics approach to identify productive countries, assignees, or inventors. Hall, Jaffe, and Trajtenberg (2000) suggested that intensity of citations of a firm's patent was highly related to a patent's market value. Furthermore, the use of citations for assessing a patent's impact is supported by theories of probability (Hall & Trajtenberg, 2004). Haupt, Kloyer, and Lange (2007) also used citations to study technology life cycle development. Gambardella, Harhoff, and Verspagen (2008) employed data from European surveys to establish systematic assessments of the patents' economic value. This value from measurement was significantly correlated with the number of patent citations, references, claims, and countries in which the patent is applied. Among these factors, the number of citations was highly correlated with a patent's value, and the result suggested that the top 5% of patents obtaining the most citations were most valuable. As a result, identifying highly influential and valuable patents are important for firms, which offers them critical information on knowledge assets management and investment. However, there was also an opposite research conclusion. Sampat and Ziedonis (2005) indicated that the number of patent citations could be employed to predict whether a patent issued by a university was licensed or not, but this number could not be used to predict the revenue from a licensed patent. Nevertheless, the authors stated that the insignificant relationship between the number of citations and revenue may be due to small sample size. Furthermore, patents assigned to universities had different features than patents assigned to firms, resulting in different result findings.

Bradford's law was adopted in this study to identify the core patents through patent citation. Data were retrieved from three technology areas to study the scattering patterns of impact. The three areas were semiconductor, liquid crystal (LC), and drug. In addition, the Groos droop, the nonlinear shape of the distribution existing in patent citation, was also observed. Based on the patent analysis, company managers are able to assess the value and advantages of their proprietary technologies and gain insights for future R&D investment decisions.

Methods

Research Hypothesis

This study formulated two hypotheses for employing patent analysis. First, in Huang, Chang, and Chen's (2012) research, papers and patents both showed higher degrees of concentration than that of papers. More than 86% of patents were produced by the top five countries, and 50%–70% of papers were published from these countries. Hence, the degree of concentration for patents was significantly higher than that of papers. Furthermore, the concentration of patent citations was even higher than that of paper citations. Therefore, this study supposes that patent's distribution of patent citation scattering is more concentrated than that of papers. In other words, high-impact patents may be comparatively

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small in number. This indicates that the proportion of three zones may be different from the law: the powers of multipliers in the second and third zones may be greater than that of Bradford's.

Hypothesis 1: The distribution (or scatter) of patents is more concentrated than for papers.

Second, since Bradford's law was adopted in the studies with various subjects or disciplines mentioned in the literature review, this hypothesis proposes that the distribution of scattering could also be employed in different industries:

Hypothesis 2: The distribution (or scatter) is similar across industries.

Industry Definition

Computer programming, software, and service; drugs and pharmaceuticals; computers and office instruments, electrical equipment (excluding computers, communications, and transportation equipment) are generally regarded as technology-intensive or R&D-intensive industries (Chan, Lakonishok, & Sougiannis, 2001). A great number of research articles have studied knowledge diffusion and patterns of patents in these technology-intensive industries (Hall et al., 2001; Stolpe, 2002). Thus, the three technological areas are clearly defined in this study. We investigated patent counts by class annually and found that the number of patents granted from 1977 to 2012 in the drug technology area was 99,704 and 86,284 in semiconductors; these two areas held the most patents (Patent Technology Monitoring team [PTMT], 2013). LC accounts for a smaller proportion compared with semiconductors and drugs but plays an important role in the electronic and information industry (Yoon & Park, 2005). Since these three areas are critical to industries but are diverse in number of patents, we compare the scattering patterns across the areas to verify the applicability of Bradford's law.

Definition of the LC technological area for this research was modified from Stolpe's (2002) definition of the LCD technology. Patents of the LCD technology were in Class 349, "Liquid crystal cells, elements and systems," as categorized by the U.S. Patent and Trade Office (USPTO). However, since class 349 did not contain "crystal technology," it is more appropriate to be regarded as an "LC" rather than "LCD" technological area. The definitions of the drug technological area are represented by patents categorized in USPTO Class 424 and 514, as the "Drug, bio-affecting" and "Body treating compositions," respectively (Hall et al., 2001; Lichtenberg & Virabhak, 2002). The scope of the semiconductor technological area is rather broad since it has become one of the biggest hi-tech fields today. The definition of the semiconductor area refers to studies by Weinstein and Huang (1999) and Hall et al. (2001), which includes patents in USPTO Class 257 (Active solid-state devices, e.g., transistors, solid-state diodes), 326 (Electronic digital logic circuitry), 438 (Semiconductor device manufacturing process), and 505 (Superconductor technology: apparatus, material, process).

Data

In this study we collected the number of citations a patent received from other patents. Patent citation analysis can be carried out based on either obtained citations (also called times cited) or references. Some researchers refer to these two types of citations as forward citation and backward citation, respectively (Thomson Reuters, n.d.). For example, a patent's citation referring to a prior patent is called "backward citation" (Gay & Le Bas, 2005); in current technology, the backward citation is related to or derived from the earlier inventions (Ashton & Sen, 1988). In contrast, the forward citation cited by subsequent patents shows the particular patent's contribution to technology development. Both backward citation and forward citation analyses can be used to identify the development trace of a particular technology, especially forward citation analysis, revealing a patent's impact on later technologies and indicating its value and importance.

Since the accumulation of citations requires a long time span, early-issued patents on average have received more citations than later-issued patents. Without a citation window, analyses based on cumulated citations may present biases. Hence, a 10-year citation window is set for citation calculation, considering the different cited half-lives of technological areas. Patents issued during the period 1981–2011 were collected, and the numbers of citations calculated only for patents issued during 1981–2002, taking the accumulation of 10-year citations into account, issued during the period of 1990–2011. The LC industry covered 9,358 granted patents and among all only 9,081 patents received citations, and the total number of patent citations came to 130,761. The drug industry covered 102,121 granted patents and only 82,499 were cited, while the total citations amounted to 612,785. The semiconductor industry covered 106,331 granted patents and only 100,549 patents were cited. The total number of citations in the semiconductor industry was 1,399,462.

Results

Scattering Patterns by Bradford's Law

To explore the applicability of Bradford's law in patent citation analysis, the distribution of patent citations in distinct technological areas is first discussed. The number of patents in each technological area was first sorted by the number of citations. In the LC technological area, the highest number of citations by a single patent was 233, and there were 441 patents receiving only one citation; in the drug technological area, the highest number of citations was 240, with 15,461 patents receiving only one citation; in the semiconductor technological area, the highest

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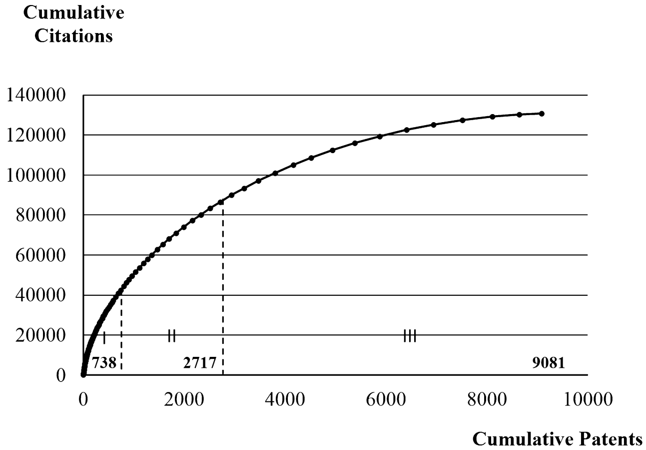

FIG. 1. Patent's citation distributions for LC technological area.

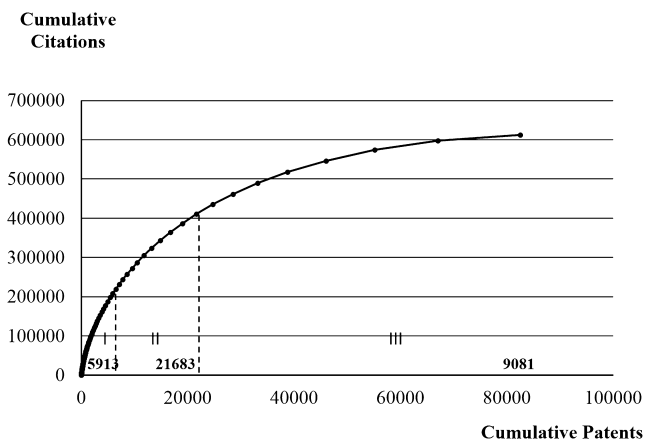

FIG. 2. Patent's citation distributions for drug technological area.

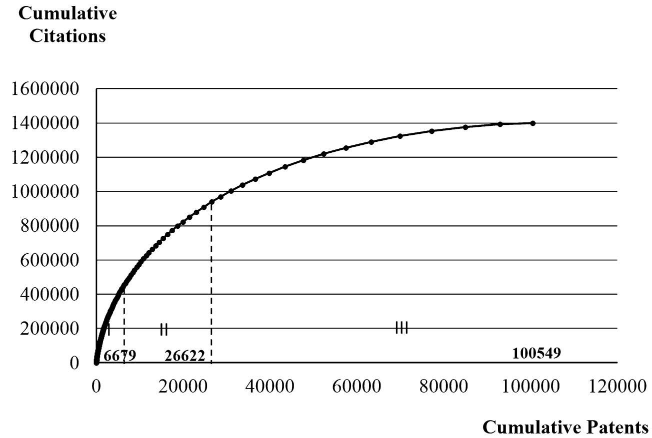

FIG. 3. Patent's citation distributions for semiconductor technological area.

number of citations came to 583, and there were 7,625 patents receiving only one citation. The cumulative patent counts and the cumulative citation counts for each technological area are illustrated in Figures 1–3.

In the three figures, all curves rose rapidly at the beginning, while the growth rate of cumulative citation counts decreased as the patent number count accumulated. This suggests that the scattering of patent citations corresponded with the features of Bradford's law.

We formulated the relations between the number of patents and the number of citations based on Bradford's law. The law suggests that, in a given area, a small set of patents in zone I receives as many citations as a larger set of *n* patents in zone II and an exponentially larger set of n^2 patents in zone III. In this study, patents were first arranged in descending order by the number of citations for each technological area, and each zone contained the same number of accumulated citations. The number of patents in each zone (R_i, $i = 1, 2, 3$) was supposed to show a relationship as $R_1{:}R_2{:}R_3 = C(1{:}n{:}n^2)$, where *C* was a constant and *n* was the multiplier, which indicated the proportionality of patent numbers in each zone.

Patents that account for one third of cumulative citations are defined as patents in the first zone. The number of patents in the first zone is the constant value (*C*) of Bradford's law, and the multiplier is then calculated for the law. The proportion of patent numbers in the three zones, following Bradford's law, should be $1{:}n{:}n^2$.

$$C(1{:}n{:}n^2) = T \tag{1}$$

T equals to the total number of patents in the specific technological area. Based on formula (1), we derived the *n*. Table 1 shows the *n*, the number of patents, and the citations of each zone. As shown in the table, the multipliers (*n*) of the three zones varied. In fact, based on Brooks's (1990) and Hubert's (1977) research, the multiplier of Bradford's law is not a constant. It varies depending on the number of zones adopted by different studies. When the number of zones increases, the multiplier decreases. Even though the multiplier is not constant, we can still compare the numbers when patents are divided into the same zone number. If a multiplier is larger, its field is broader in scope than others; on the other hand, patents in the first zone are more concentrated than others. Hence, in the LC area, *n* (2.68) was the smallest among the three areas; the *n* (2.67) in the drug area was the greatest. The *n* (2.99) in three areas show that the number of patents in zone I from drug area was the most concentrated one of all.

Table 1 shows that the number of cumulative citations did not correspond to Bradford's law. According to the law, the citation numbers in each zone should be identical to one another. Furthermore, the amounts of patents in the three zones should follow Bradford's law. In fact, the numbers of patents in the third zone in our study were much larger than the numbers following Bradford's law distributing by the proportion in $1{:}n{:}n^2$. For example, the cumulative patents in the third zone should be 8,016 in the LC, 63,853 in the drug, and 86,360 in the semiconductor if following Bradford's law. This finding indicates that the scatterings of patents and

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TABLE 1. Number of patents and citations in each zone for the three technological areas.

Zones	LC (n = 2.68)		Drug (n = 2.67)		Semiconductor (n = 2.99)	
	Number of patent (log)	Cumulative citation	Number of patent	Cumulative citation	Number of patent	Cumulative citation
First (I)	738 (2.87)	42,389	5,913 (3.77)	207,636	6,679 (3.82)	464,783
Second (II)	2,717 (3.43)	86,577	21,683 (4.34)	410,278	26,622 (4.43)	939,143
Third (III)	9,081 (3.96)	130,761	82,499 (4.92)	612,785	100,549 (5.00)	1,399,462

TABLE 2. Patent's citations in the three zones for the three technological areas.

Zones	LC		Drug		Semiconductor	
	No. of patents / No. of citations	Average	No. of patents / No. of citations	Average	No. of patents / No. of citations	Average
First (I)	738 / 42,389	57.44	5,913 / 207,636	35.12	6,679 / 464,783	69.59
Second (II)	1,979 / 44,188	22.33	15,770 / 202,642	12.85	19,943 / 474,360	23.79
Third (III)	6,364 / 44,184	6.94	60,816 / 202,507	3.33	73,927 / 460,319	6.23

their citations did not follow Bradford's law. In addition, as shown in Table 1, the distributions of patents are more concentrated than that of journals, articles, investigated in previous studies. Hence, the study further examines the scattering distribution in the paragraphs below.

Adapting Bradford's Law to Patent Citations

To investigate the distribution of patents, followed by Bradford's law, cumulative citation of the zone II showed double the number of citations in zone I and found the corresponding number of patents. Table 2 presents the number of patents and citations and the average citation of each zone in the three areas.

Table 2 shows the patent and citation numbers of the three zones in the three technological areas. In the LC technological area, the number of patents in the three zones (R_i, i = 1, 2, 3) were R_1:R_2:R_3 = 738: 1,979: 6,364 = 738 (1: 2.68: 8.62). The average number of citations per patent in each zone was 57.44, 22.33, and 6.94 for zone I to III, respectively. In sum, each zone received the same amount of citations, and the patent number of each zone indicated that the second zone with a larger number of patents possessed the same number of total citations as the first zone; the third zone also had a larger number of patents than the first and second zones. Bradford's constant C was 738, and the multiplier n was around 2.68 in the LC technological area. We can see that the proportion in zone III (8.62) was much higher than the square of multiplier (n^2 = 7.18). Although the proportion was not consistent with Bradford's law, it still indicated that patents in zone I had a relatively high impact compared to zone II and zone III.

Both the proportion in the drug and semiconductor technological areas presented discrepancies in Bradford's law and showed the high influence of zone I. In the drug technological area, the numbers of patents in the three zones were R_1:R_2:R_3 = 5,913: 15,770: 60,816 = 5,913 (1: 2.67: 10.29). The average number of citations was: 35.12 for the first zone, 12.85 for the second zone, and 3.33 for the third zone. Bradford's constant C was 5,913 and the multiplier n was around 2.67. Again, the square of multiplier (n^2 = 7.13) showed inconsistency with Bradford's law, which was much smaller than the proportion of zone III (10.29). In the semiconductor technological area, the number of patents in the three zones were R_1:R_2:R_3 = 6,679: 19,943: 73,927 = 6,679 (1: 2.99: 11.07). The average number of citations for each zone were 69.59, 23.79, and 6.23, respectively. Bradford's constant C was 6,679, the multiplier n was around 2.99, and the square of multiplier (n^2) was 8.94, which was smaller than proportion in zone III (11.07).

The proportions of patents in the three zones showed a discrepancy with Bradford's law, employed first in the distribution of journals. The proportions of the third zone in the three technological areas were all higher than the square of the multiplier. We calculated the power of n to the third zone. The powers of n were ~2.19, 2.37, and 2.20 for the LC, drug, and semiconductor technological areas, respectively. The three powers were slightly different. Compared to $1{:}n{:}n^2$ from Bradford's law, the proportion of patents was more concentrated in zone I. The new proportion of modified Bradford's law shows that patents in both zone I and zone II were more concentrated. The percentage of patents in each zone in the three technological areas is presented in Table 3.

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TABLE 3. Percentage of patents in the three zones for the three technological areas.

Zones	LC Patent %	Drug Patent %	Semiconductor Patent %
First	8.13%	7.17%	6.64%
Second	21.79%	19.12%	19.83%
Third	70.08%	73.72%	73.52%

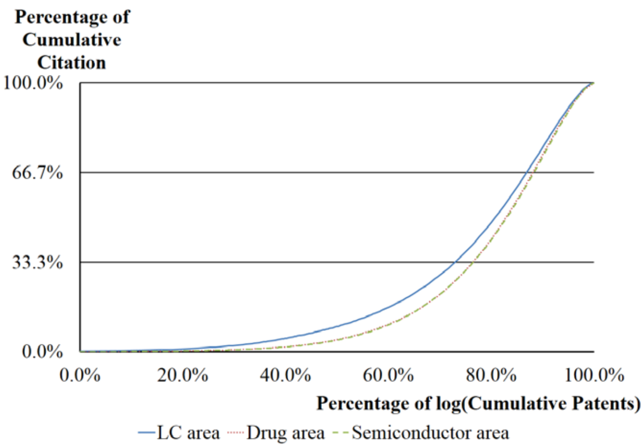

FIG. 4. Curve fitting of the Bradford curve to the three areas. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

The two hypotheses were verified through this concluding discussion. First, Hypothesis 1: The scattering of patents is more concentrated than that of paper's when it was revealed through the proportion of three zones. The original ratio of Bradford's law was $1:n:n^2$; however, the results from our study came to $1:n:n^{2.19}$, $1:n:n^{2.37}$ and $1:n:n^{2.20}$ for the LC, drug, and semiconductor technological areas, respectively. The new powers of the third zone showed that the proportion of patent numbers in the third zone was greater than the original proportion. In other words, the degree of scattering for patents was more concentrated than for papers. Second, Hypothesis 2: Scattering was similar across industries. The scattering of the drug technological area was perfectly consistent with that of semiconductor using a graph-oriented approach as in Figure 4. In addition, the distribution of impact scattering in the LC technological areas also approximately matched with the other two. This indicates that Bradford's law could be adopted across different industries even though the proportions of the three areas were not exactly the same.

According to the law, each zone should contain ~33% of the total citations in the three technological areas. Table 3 shows that, for all three technological areas, 6.64% to 8.13% of total patents were located in the first zone, while there were 19.12%–21.79% and 70%–73% of the patents belong to the second and the third zone, respectively. This shows

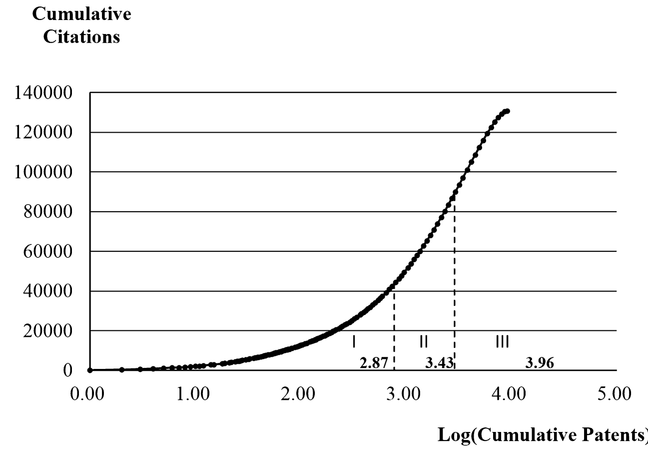

FIG. 5. Bradford curves for LC technological areas.

that there were only around 6%–8% of patents in the first zone containing influential technologies than patents in the other two zones. Patents in the second zone, although with less impact than the first zone, may still contain some practical technologies because technologies without commercial potential may have minimal related patents (Schultz & Joutz, 2010). Furthermore, comparison among the three technological areas showed that in the LC technological area, which is the least concentrated area, patent percentages came up to 8.13% in zone I, 21.79% in zone II, and 70.08% in zone III. In contrast, patent percentages in the semiconductor area came to 6.64% in zone I, 19.83% in zone II, and 73.52% in zone III.

Groos Droop

The logarithm values of the cumulative numbers of patents were calculated and plotted in the figures to discuss whether the Groos droop, which presented a decreasing slope in the third zone of Bradford's curve, exists in the scattering of patent citations. Figures 5–7 show Bradford's curves for LC, drug, and semiconductor areas, respectively.

Based on the cumulative numbers of patent citations, the vertical axis in each figure was divided equally into three sections, each representing separate zones in Bradford's law. For the LC technological area, the log values of cumulative patent counts showed a high growth rate in the first zone from 0 to 2.87; in the second zone, the log values increased from 2.87 to 3.43 showing steady growth; in the third zone, log values ranged between 3.43 and 3.96, with an inflection point in the curve.

The log values of cumulative patent counts in the first zone in the drug technological area ranged from 0 to 3.77; the log values in the second zone were between 3.77 and 4.34; the log values in the third zone ranged from 4.34 to 4.92. For the semiconductor technological area, the log values of cumulative patent counts were from 0 to 3.82 in the first zone; in the second zone, the log values were between

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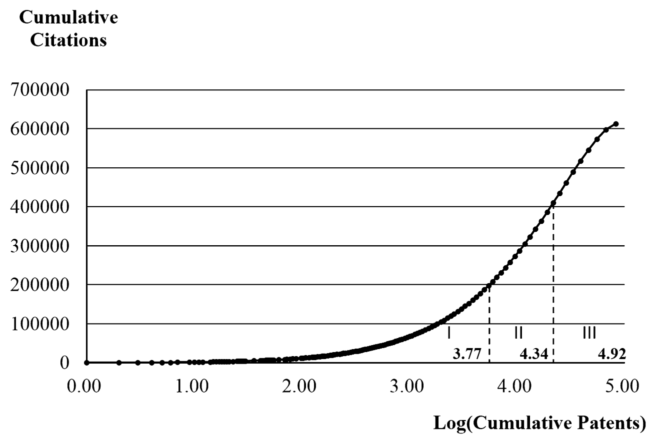

FIG. 6. Bradford curves for drug technological areas.

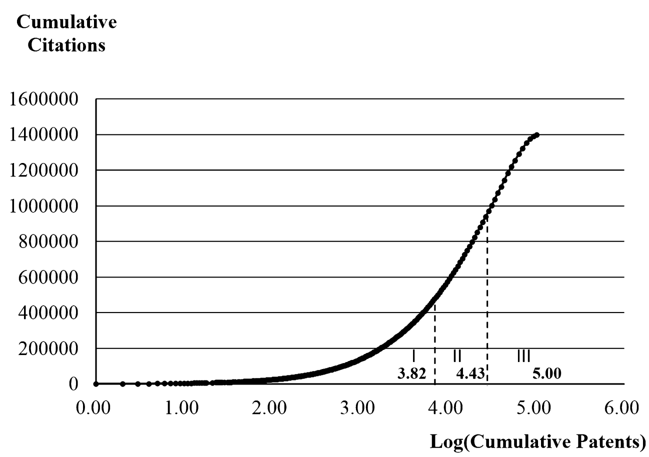

FIG. 7. Bradford curves for semiconductor technological areas.

TABLE 4. Marginal values beyond inflection point for LC technological area.

LC technological area			
Citation	Cumulative citations	Log (cumulative patents)	Δ cumulative citation/Δ log(cumulative patents)
12	101,041	3.58	100353.81
11	105,045	3.62	**100838.25**
10	108,495	3.65	99844.99
9	112,320	3.69	97820.27
8	115,848	3.73	94928.32
7	119,306	3.77	90589.86
6	122,486	3.81	84719.24
5	125,186	3.84	76760.77
4	127,470	3.88	66523.88
3	129,252	3.91	53916.64
2	130,320	3.94	38546.02
1	130,761	3.96	20397.84

TABLE 5. Marginal values beyond inflection point for drug technological area.

Drug technological area			
Citation	Cumulative citations	Log (cumulative patents)	Δ cumulative citation/Δ log(cumulative patents)
8	434,958	4.39	427199.75
7	461,432	4.46	**428970.68**
6	489,086	4.52	425476.84
5	517,056	4.59	413122.41
4	546,104	4.66	389414.19
3	573,626	4.74	348586.70
2	597,324	4.83	280554.21
1	612,785	4.92	171545.61

3.82 and 4.43; in the third zone, the log values ranged from 4.43 to 5.00. Both curves of the drug and semiconductor technological area are similar in shape to the LC technological area. In the first zone, both curves grew rapidly with a positive incremental slope from the starting point, turned to a straight line in the second zone, and finally the growth rate decreased after an inflection point in the curve. Moreover, possessing the same amount of cumulative citations, the second zone had a larger amount of patents than the first zone, and the third zone, again, had more patents compared to the first and second zones.

The scatterings in all three technological areas showed similar patterns and formed S-shaped Bradford curves. The Groos droop was also revealed in the third zone. Figures 5–7 show that the growth rate of cumulative citation decreased in the third zone. We further explored it in Tables 4–6. The number of cumulative citations and the log of the number of cumulative patent around and beyond the inflection points in the three technological areas are presented in the tables, and the inflection points are marked in bold.

The tables show the inflection points by dividing the delta of cumulative citation by the delta of log value of cumulative patents. Before these points, which are at the peak of the distribution, patents cumulated citations at an increasing rate, with a marginal value greater than previous points; after these points, patents cumulate citations at a slower rate. Tables 4–6 reveal that the inflection points presented at citation equal to 11 in the LC, 7 in the drug, and 12 in the semiconductor area, respectively. Consistently decreasing marginal values shows that the Groos droop is present in patent's citations in these three areas and verifies the theory that the third zone needs much more patents to cumulate citations.

Because the modified Bradford's law for patents tends to have more concentrated distribution of citations, companies are encouraged to find and evaluate patents with potential economic value. Companies with highly cited patents will perform better in the product and capital markets (Den, Lev, & Narin, 1999). Therefore, citation analysis based on Bradford's law can be used to identify core patents scattering in zone I within each technological area. In addition, the

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TABLE 6. Marginal values beyond the inflection point for semiconductor technological area

Semiconductor technological area			
Citation	Cumulative citations	Log (cumulative patents)	Δ cumulative citation/Δ log(cumulative patents)
13	1,036,761	4.53	966903.87
12	1,072,353	4.56	**969796.77**
11	1,108,026	4.60	967560.44
10	1,144,036	4.64	958325.31
9	1,182,403	4.68	943825.66
8	1,219,179	4.72	920523.13
7	1,255,586	4.76	884326.09
6	1,290,572	4.80	834119.44
5	1,323,737	4.84	766754.59
4	1,352,533	4.89	677068.33
3	1,375,921	4.93	559566.07
2	1,391,837	4.97	409333.47
1	1,399,462	5.00	222628.65

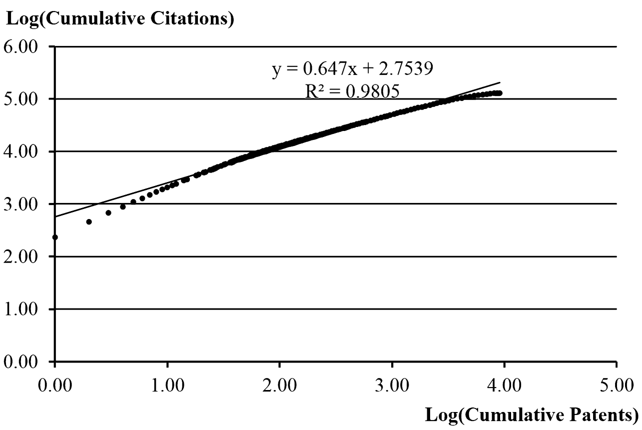

FIG. 8. Log–log relation for LC technological areas.

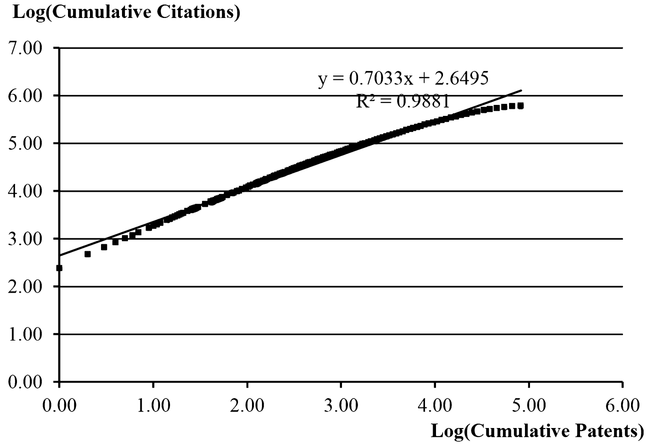

FIG. 9. Log–log relation for drug technological areas.

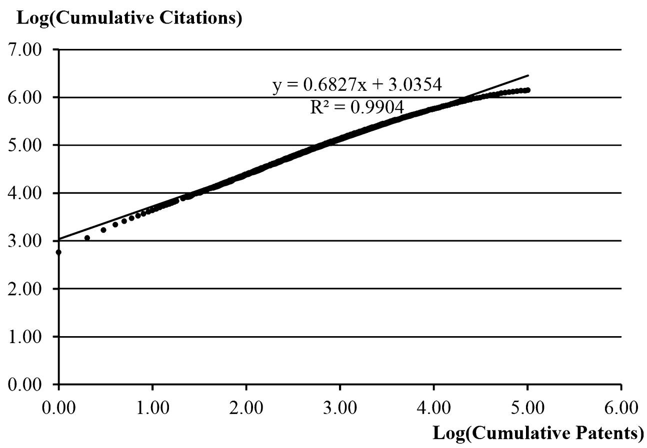

FIG. 10. Log–log relation for semiconductor technological areas.

law can further measure firms' innovativeness and pinpoint important inventions from R&D. It can also assist firms acting as technology acquirers in identifying patents with economic potential.

Discussion

The model following Bradford's law only calculates the log value of patents to show the distribution patterns. The log values of the cumulative citations in this section are further calculated to show the log–log distribution pattern. Figures 8–10 present the log–log relation of patents and citations. As the figures show, the relation of the log values was almost linear in all three areas with R^2 larger than 0.98. In addition, the end points of the distribution were all slightly below the line. Hence, citations of patents can be predicted through the log–log relation but with different slopes and intercepts in different technological areas.

Narin (1994) indicated that there are similarities between literature bibliometrics and patent bibliometrics (patentometrics) in distributions of national productivity, inventor productivity, referencing cycles, citation impact, and citation preferences within countries. However, based on our results, the distribution of information impact in patents is skewed more concentratedly than in papers. Therefore, the discrepancy is investigated here.

One justification could be due to the differences in citation motivation and behavior between paper and patent. A citation, either from patent or paper, can reveal a scholar's achievements. Citation analysis could be used to track the development of scientific innovation (Cronin, 1984). Meyer (2000) indicated that both patent and paper citations were indicators of the impact of previous work. However, much has been debated regarding the differences between patent and paper citations. Garfield (1964) and Weinstock (1971) stated that the motivations of citation behavior vary. Generally, citing previous work either credits (agree) or criticizes (disagree) pioneers and related work. Furthermore, Vinkler (1987) categorized the motivations into two:

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professional motivations and connectional citing behaviors. Professional motivations refer to the theoretical and practical content of the cited work; connectional citing behavior is motivated by the intention of building social relationships in the scientific community. Shadish, Tolliver, Gray, and Sengupta (1995) conducted an investigation that sampled several hundreds of citations from papers in psychology journals and then surveyed the authors of these papers on their motivations for citing. Six factors emerged: exemplar citations, negative citations, supportive citations, creative citations, personally influential citations, and citations made for social reasons.

Nevertheless, the motivations for citing in patents are very different. For example, references can be provided by the inventors to show novel inventions. Furthermore, an inventor could cite prior works to identify the invention as a priority application, co-pending application or continuation, etc. (Garfield, 1984). Collins and Wyatt (1988) mentioned that patent citation is a legal responsibility for applicants to cite relevant previous work. An applicant's citation is also used to differentiate previous work and to recognize its novelty. Meyer further mentioned that the main difference between paper and patent citations is that papers cite other articles contributing to the same subject, while patents cite previous works that are related to its application. The citation would also be different depending on the characteristics of patents. Innovative patents cite relevant works and patents about general background, but receive fewer citations. On the other hand, some patents work to solve a concrete problem, hence try to avoid existing patents (Meyer, 2000).

The patent examination process also influences patent citations. Not only inventors and applicants cite prior art in their patent, examiners also add related works during the examination process. The examiner citation, which is cited by the examiner, is related to prior works and is used to narrow the original application. Therefore, examiner citation is different from literature citation. The citations decided by examiners are pertinent to the subject matter. The examination processes vary among different patent offices. Thus, the frequency of citation is different among different patent offices. For example, patents from the USPTO have higher citation frequency (Hall et al., 2001; Meyer, 2000). It is because USPTO embraced the "duty of disclosure," and the citation references are asked to include all relevant work. Another reason is that it could be a consequence of the open race among universities or academic laboratories in science. In contrast to more concentrated and secure R&D performed in enterprises, knowledge (papers) created by universities is often regarded as public goods (Fischer & Varga, 2003). That is, knowledge created by academic institutions can diffuse more widely than knowledge created by enterprises. Nevertheless, Seglen (1992) reported that the average number of references per article in a specific field is one of the main variables that affect the number of citations that an article receives. Fewer citations per patent are likely to influence the concentration of the obtained-citation distribution.

Although there is disagreement as to whether there is a correlation between the frequency of cited reference and technological and economic development, inventor citation is still used for value evaluation indicator (Hall et al., 2001). Furthermore, Criscuolo and Verspagen (2008) supposed that the examiner adds citations that are novel but missed by the applicant. Hence, both examiner citations and applicant citations are adequate as indicators for citation analysis. In more recent research studies, paper and patent citations were no longer considered independent citations to literatures. Several researchers have taken notice of "science-technology interaction," also called "science linkage." That is, in some scientific publications, there are increasing numbers of references citing patent documents. On the other hand, a great number of patents are further developed based on scientific theories, hence citing the relevant scientific publications in their reference. Recently, many studies have been conducted on the density of and difference in the interactions between patents and scientific articles across fields (Looy et al., 2003; Tamada, Naito, Kodama, Gemba, & Suzuki, 2006).

Conclusion

This research explored the scattering patterns of patents and their citation distributions for three distinct technological areas: LC, drugs, and semiconductors. The study also attempted to verify whether the three patterns followed Bradford's law. Patents in the technological areas were divided into three sets with the same accumulated patent citations. Among the three sets of patents, the first zone has the least but most important patents. Only a few patents in the area contained potential profit for the firm. While the patents in the three areas are relatively concentrated, the proportion of patents in each zone did not match that proposed by Bradford.

In the study, patent citations presented a higher concentration than the proportion suggested by Bradford's law, $1:n:n^2$. This finding suggests that Bradford's law, in which the smallest set of journals received a high proportion of related papers, is applicable in analyses of patent citations. Based on this result, the two hypotheses were verified, showing that patent citation has more concentrated distribution than does paper citation, and the distributions were similar across the three industries. Moreover, the scattering pattern of patent citations showed smaller sets of patent in zone I and zone II in comparison to that suggested by Bradford's law. Patents in the first zone of the three technological areas were around 6%–8%; 19%–21% in the second zone, and 70%–73% in the third zone. There are differences in concentration level among the three areas. The semiconductor area was more concentrated than the other two areas, with LC area being the least concentrated. Although there is debate about the use of patent citation analysis as an evaluation indicator, these findings should help company managers identify profit-making patents and make sound decisions about resource allocation

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to technologies within those patents in order to maintain competitive.

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