Technology Manager's Radar Screen: Monitoring Competitors' Innovation Performance

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To capture a competitor's innovation performance, both in terms of its productivity and impact, we propose to characterize its patent portfolio, including both cited and un-cited patents, by a pair of numbers. This pair of numbers, one related to the productivity and the other to the impact of the competitor, is obtained from the centroid of a so-called *h*-complement area of the citation distribution of the competitor's portfolio. As such, a large number of competitors' innovation performance embodied in their portfolios can be simultaneously captured and panoramically observed in a two-dimensional coordinate system. In addition to its simplicity and effectiveness, this approach provides us significant insight into where performance difference among these competitors lies, and allows us to track their performance evolution over time.

Keywords –**Centroid, *h*-complement area, *h*-index, rank-citation curve**

I. Introduction

For an organization's technology manager, competitor analysis often involves the assessment of the organization's technological position among its competitors in a market segment, about a product, or within a technology sector. To this purpose, patents assigned to these competitors are considered as an important source of technological intelligence, and patentometrics [1] has offered a wealth of tools among which the *h*-index [2], claimed to have captured both productivity and impact, is a recent entrant.

The *h*-index has already been a de facto indicator in scientific community for research performance evaluation, as evident from the large number of articles devoted to this topic and its adoption by on-line databases such as Scopus and Web of Science. Some recent reviews to *h*-index related research could be found in [3] and [4].

The extension of the *h*-index's application from researchers to patent assignees seems intuitive, yet there are few articles [5][6] dedicated to such an extension. This is probably due to that the adequacy of applying the *h*-index to measure the productivity and impact (jointly referred to as the *innovation performance* hereinafter) of a patent assignee is dubious The *h*-index, on one hand, has been mostly criticized by the scientific community for being insensitive to some exceptionally highly cited papers. On the other hand, the *h*-index is also recognized as being insensitive to the lowly cited and un-cited papers [4], even though it is not really regarded as a disadvantage by the scientific community.

In contrast, the great majority of patents are either lowly cited or un-cited, as indicated by empirical studies [7][8]. Therefore, when applied to patent assignees, the *h*-index may fail to accurately reflect an assignee's innovation performance as a significant portion of the assignee's effort embodied in its lowly cited and un-cited patents is not captured.

The so-called *rank-citation curve* [9] that has accompanied the *h*-index since its origination provides us an alternative. It is a curve manifesting the citation distribution of an individual's decreasingly sorted publications or patents, and has been frequently adopted by *h*-index related researchers in providing geometric explanations to the *h*-index (and related *h*-type indices) and to graphically illustrate their various propositions [3][9]−[13].

Reference [6] suggested that the rank-citation curve of an assignee with smaller *h*-index is located in a two-dimensional coordinate system closer to the origin and therefore may run completely beneath the rank-citation curve of another assignee with greater *h*-index, and this scenario implies that the former is outperformed by the latter. The authors then proposed two shape descriptors, the *c*- and *t*-descriptors, characterizing the segments of the rank-citation curve corresponding to an assignee's *h*-core [14] and *h*-tail [9], respectively. The shape descriptors are then used to verify the geometric relationship among assignees' rank-citation curve segments, and therefore the assignees' relative performance with respect to their *h*-cores and *h*-tails.

Noticing the resemblance of the *c*- and *t*-descriptors to area centroids, [15] further suggested capturing an individual's research or innovation performance by the centroids of its *h*-core area [6] and *h*-tail area [9]. Then, a large number of individuals' research or innovation performance with respect to their *h*-cores and *h*-tails can be simultaneously positioned and conveniently observed in two-dimensional coordinate systems.

Despite that the foregoing shape descriptors and area centroids are proven empirically to be accurate and reliable, there are two major disadvantages. Firstly, both approaches have left the un-cited papers or patents unaddressed. Yet, from a technology manager's perspective, these un-cited patents of a competitor still reveal its degree of commitment in the related technology field, regardless of the citations received. Secondly, both

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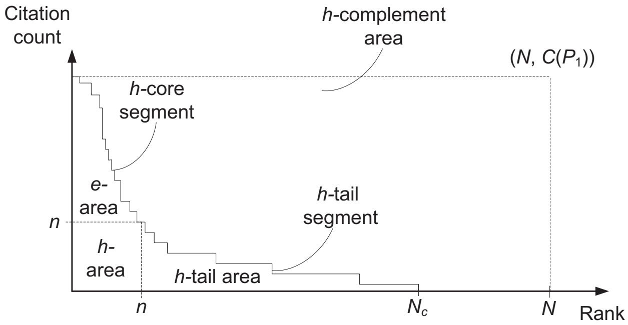

Fig. 1: A fictitious rank-citation curve.

approaches have to deal with the h-cores and h-tails separately and, to make things even more simplified, one would naturally ask: could we combine the two separate analyses in a single one?

We therefore envision a superior approach to be one capable of achieving a panoramic, two-dimensional view to the innovation performance of a number of competitors or patent assignees, including both cited and un-cited patents, as if these competitors are monitored on a radar screen. The approach would be even more valuable when a significant number of competitors are involved or when their performance variations over time are to be tracked. This paper thus describes our endeavor toward such an objective.

II. Notation and Research Data

To test our proposition, the empirical data utilized in the paper are based on the 100 assignees having the greatest numbers of U.S. patents granted in the year 2009 [16]. These assignees' U.S. patents issued between 1976 and 2009 are collected, and the respective h-indices are found to range from 161 (IBM with total 58,185 patents) to 3 (LG DISPLAY CO., LTD. with total 872 patents). The 100 assignees and their respective patent portfolios constitute a representative set of data for our investigation as suggested by their diverse h-indices.

Abstractly, let a patent assignee has a portfolio of N patents $\{P_1, P_2, \ldots, P_{N-1}, P_N\}$ sorted in descending order of their respective citation counts $C(P_i)$, $1 \le i \le N$. The assignee's rank-citation curve is obtained by plotting and connecting the points $(i, C(P_i))$ in a smooth or stepwise manner. A fictitious, stepwise rank-citation curve is depicted in Fig. 1.

As illustrated in Fig. 1, the set of patents $\{P_1, P_2, \ldots, P_{N-1}, P_N\}$ is partitioned by the assignee's h-index n into the set of highly cited n patents $\{P_1, P_2, \ldots, P_{n-1}, P_n\}$ and the set of lowly cited and un-cited $(N-n)$ patents $\{P_{n+1}, P_{n+2}, \ldots, P_{N-1}, P_N\}$, which are referred to as the assignee's h-core [14] and h-tail [9], respectively. The h-tail is further divided into two subsets: (N_c-n) lowly cited patents and $(N-N_c)$ un-cited patents, where N_c is the number of cited patents (i.e., patents having been cited at least once). The segments of the rank-citation curve corresponding to the h-core patents and the h-tail patents are referred to as the h-core and h-tail segments [6], respectively.

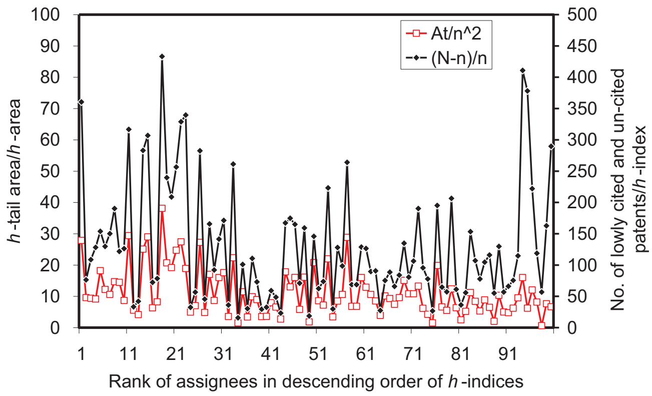

Fig. 2: The ratios A_t/n^2 and $(N-n)/n$ for the 100 assignees.

The areas beneath the h-core and h-tail segments corresponding to citations received by the h-core and h-tail patents are referred to as the h-core area [6] and h-tail area [9]. The h-core area (whose sizes is denoted as A_c) is further divided into the h-area (whose size is n^2) and the e-area (whose size is denoted as $A_e=A_c-n^2$) [14]. The size of the h-tail area is denoted as A_t.

To confirm our speculation that the h-index may fail to accurately reflect an assignee's lowly cited and un-cited patents, for the 100 assignees, their ratios of the h-tail area (A_t) to the h-area (n^2) and their ratios of the number of lowly cited and un-cited patents $(N-n)$ (i.e., the size of h-tail) to the h-index (n) are plotted against the left and right axes, respectively, with the 100 assignees arranged in descending order of their h-indices from left to right in Fig. 2.

If A_t and N are correlated with the h-index n in any way, the curves for A_t/n^2 and $(N-n)/n$ should at least reflect some pattern. However, the significant and seemingly unpredictable fluctuations along both curves depicted in Fig. 2 suggest that the h-index indeed does not carry enough information about an assignee's lowly cited and un-cited patents to manifest any such correlation.

III. Methodology

As illustrated in Fig. 1, the h-core and h-tail areas could be considered as consisting of n and (N_c-n) rectangles[1], respectively, where each rectangle has width 1 and height $C(P_i)$ (therefore, area size $C(P_i)$), and has its centroid located at $(i - 0.5, C(P_i)/2)$, $1 \le i \le N_c$. According to geometry, the centroid of a planar shape divisible into a number of smaller constituent shapes can be obtained as the weighted average of these constituent shapes' centroids. Therefore, the h-core area centroid (c_x, c_y) and h-tail area centroid (t_x, t_y) could be obtained as follows:

[1] Actually there are $(N-n)$ rectangles, but the last $(N-N_c)$ rectangles corresponding to the un-cited patents have zero area size.

$$c_y = \sum_{i=1}^{n} \frac{C(P_i)}{2}\left(\frac{C(P_i)}{A_c}\right); \quad (1)$$

$$c_x = \sum_{i=1}^{n} (i-0.5)\left(\frac{C(P_i)}{A_c}\right); \quad (2)$$

$$t_y = \sum_{i=n+1}^{N_c} \frac{C(P_i)}{2}\left(\frac{C(P_i)}{A_t}\right); \quad (3)$$

$$t_x = \sum_{i=n+1}^{N_c} (i-0.5)\left(\frac{C(P_i)}{A_t}\right). \quad (4)$$

Believing that the shapes of the *h*-core and *h*-tail areas/segments more accurately reflect assignees' *h*-core and *h*-tail performance, [15] proposed to use the *h*-core and *h*-tail area centroids obtained according to (1) to (4) as characteristic points and, by plotting these characteristic points in two-dimensional coordinate systems, these assignees' performance with respect to their *h*-cores and *h*-tails could be immediately and conveniently positioned relative to each other.

According to [15], this approach is proven empirically to be accurate and reliable. It however ignores the (N–N_c) un-cited patents and requires two separate analyses for the *h*-cores and *h*-tails, respectively. To achieve a single analysis where both *h*-core and *h*-tail performance is integrated and both cited and un-cited patents are taken into consideration, we may be tempted to use the centroid (r_x, r_y) of the area beneath the rank-citation curve (whose area size is denoted as $A=A_c+A_t$). The point (r_x, r_y) can be obtained similarly as (c_x, c_y) or (t_x, t_y) except that the summation over i is from 1 to N_c and A is used instead of A_c or A_t. Even though a single analysis is achieved, the un-cited (N−N_c) patents are still not taken into consideration.

Therefore, instead of (r_x, r_y), we propose to utilize the centroid (r_x', r_y') of an *h-complement area* to characterize an assignee's innovation performance embodied in its entire portfolio. The *h*-complement area, as illustrated in Fig. 1, is above the rank-citation curve but bounded by a rectangle whose upper right corner is located at (N, $C(P_1)$) and whose area size is denoted as $A'=N\cdot C(P_1)–A$.

Since the rectangle consists of the two areas beneath and above the rank-citation curve and has its centroid located at ($N/2$, $C(P_1)/2$), the two areas' centroids (r_x, r_y) and (r_x', r_y') satisfy the equations below:

$$\frac{C(P_1)}{2} = \frac{r_y A + r_y' A'}{A+A'} = \frac{r_y A + r_y' A'}{N \cdot C(P_1)}; \quad (5)$$

$$\frac{N}{2} = \frac{r_x A + r_x' A'}{A+A'} = \frac{r_x A + r_x' A'}{N \cdot C(P_1)}. \quad (6)$$

Then (r_x', r_y') can be easily obtained using (5) and (6) after (r_x, r_y) is determined.

Intuitively, if (c_x, c_y) and (t_x, t_y) faithfully characterize the shapes of the *h*-core and *h*-tail segments/areas, and therefore the *h*-core and *h*-tail performance, as suggested by [15], we would naturally expect (r_x', r_y') to play the same role and to faithfully characterize the shape of the entire rank-citation curve (including the segments corresponding to the highly cited n patents, the lowly cited (N_c−n) patents, and the un-cited (N−N_c) patents) or the entire *h*-complement area, and therefore the overall innovation performance embodied in the assignee's portfolio.

Reference [15] also pointed out that the *x*-coordinates, c_x and t_x, represent the respective productivity sides of an assignee's *h*-core and *h*-tail (that is, how good the assignee is at producing highly cited *h*-core patents and lowly cited *h*-tail patents), and the *y*-coordinates, c_y and t_y, represent the respective impact sides of an assignee's *h*-core and *h*-tail (that is, how good the assignee's highly cited *h*-core patents and lowly cited *h*-tail patents are at attracting citations). We therefore would naturally expect that r_x' and r_y' should have similar functionality.

Additionally, we can imagine that, if an assignee is continuously granted with new patents and these new patents are not cited yet, r_x' would increase and (r_x', r_y') would move towards the right as N increases and the *h*-complement area extends laterally. Similarly, if an assignee continuously receives new citations whereas its N and $C(P_1)$ remain the same, we can imagine that r_y' would increase and (r_x', r_y') would move upward as A increases and the *h*-complement area shrinks vertically. With the reasoning above, we can generally and quite comfortably consider that r_x' and r_y' have reflected the productivity (including both cited and un-cited patents) and impact of an assignee's portfolio, respectively.

IV. Panoramic Performance Snapshot

The centroids of the 100 assignees' *h*-complement areas are obtained according to (5) to (6) and plotted in Fig. 3 with log-scaled *x*- and *y*-axes, respectively.

For comparison's sake, the centroids of the 100 assignees in Fig. 3 are plotted with different markers depending on their ranks by *h*-index[2]. For assignees ranked from the 1st to the 25th places, from the 26th to the 50th places, from the 51st to the 75th places, and from the 76th to the 100th places, four different markers, solid circles, hollow triangles, solid diamonds, and hollow squares, are used, respectively. The centroids of the assignees ranked at the 1st (IBM with *h*-index 161), 26th (MITSUBISHI with *h*-index 82), 51st (NORTEL NETWORKS with *h*-index 60), 76th (HON HAI PRECISION with *h*-index 36), and 100th places (LG DISPLAY CO. LTD. with *h*-index 3) are specifically labeled with their respective ranks.

As illustrated in Fig. 3, for assignees with greater *h*-indices, their *h*-complement area centroids are roughly positioned to the upper right of those assignees with smaller *h*-indices. However, these centroids are so intermingled, again suggesting that their *h*-indices indeed do not carry enough information about the lowly cited and un-cited patents, in contrast to the distribution of *h*-core centroids obtained by [15] for the same set of data.

[2] For assignees of the same *h*-index, they are further sorted by their respective total citation counts (A).

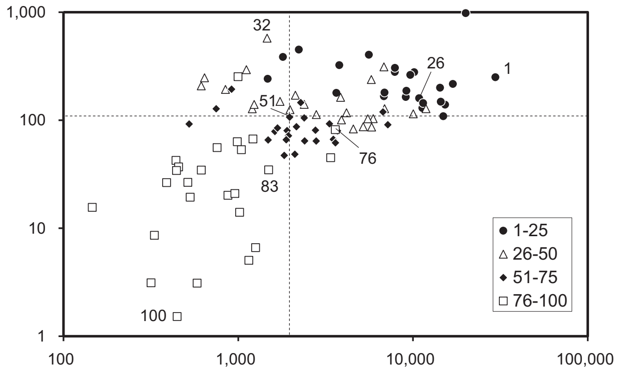

Fig. 3: Distribution of *h*-complement area centroids of the 100 assignees.

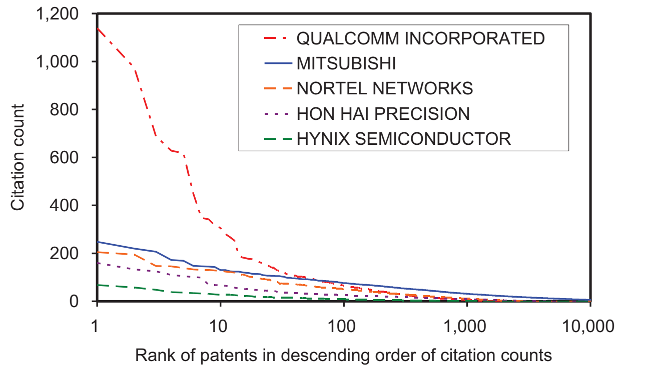

Fig. 4: The rank-citation curves for the 5 sample assignees.

TABLE I

RELEVANT DATA FOR THE 5 SAMPLE ASSIGNEES

Assignee	Quad.	Rank	$C(P_1)$	N	N_c	A	A_c	A'
MITSUBISHI	1	26	248	23,243	19,894	191,800	8,680	5,572,464
QUALCOMM INC.	2	32	1,139	2,898	1,966	35,610	13,874	3,265,212
NORTEL NETWORKS	Ref.	51	205	3,810	3,030	36,414	5,483	744,636
HYNIX SEMICON.	3	83	68	2,930	1,304	4,674	615	194,566
HON HAI PRECISION	4	76	160	7,061	4,328	27,968	2,218	1,101,792

Fig. 3 provides a panoramic view to the innovation performance of a large number of assignees at a point of time. To utilize this panoramic view for competitor analysis, imagine that we are working as technology managers for NORTEL NETWORKS (ranked at the 51st place by its *h*-index 60). Then, by treating the *h*-complement area centroid of NORTEL NETWORKS as a reference point, the centroids of the rest of the assignees (i.e., competitors) are partitioned relative to the reference point into four quadrants as outlined by the crosshair.

For the assignees whose *h*-complement area centroids are located in our 1st quadrant, they can be considered to have both superior productivity and impact and, for those whose *h*-complement area centroids are located in our 3rd quadrant, they can be considered to have both inferior productivity and impact, relative to us. As to those whose *h*-complement area centroids are located in the 2nd (or 4th quadrant), they can be considered to have inferior productivity but superior impact (or superior productivity but inferior impact), relative to us.

To see the foregoing inference is valid, we pick one assignee from each quadrant (i.e., the assignees ranked at the 26th, 32nd, 76th, and 83rd places) and their relevant data are summarized in Table I. The rank-citation curves for the four assignees as well as that of NORTEL NETWORKS are plotted altogether in Fig. 4. For better readability, only the first 10,000 patents in their decreasingly sorted portfolios are included in Fig. 4 and the *x*-axis is log-scaled.

As shown in Fig. 4, MITSUSHI in our 1st quadrant clearly outperforms us both in terms of productivity and impact, as its rank-citation curve is entirely above ours. Similarly, we obviously outperform HYNIX SEMICONDUCTOR in our 3rd quadrant, as its rank-citation curve is entirely beneath ours. These observations are verified by comparing the portfolios of MITSUSHI and HYNIX SEMICONDUCTOR against ours.

As to HON HAI PRECISION in our 4th quadrant, even though it appears that its rank-citation curve runs completely beneath ours in Fig. 4, actually its curve basically coincides with ours after the 1,848th patent, runs above ours after the 2,063rd patent, and extends farther to the right. Since the two curves cross each other, we cannot immediately tell which one has better performance, but HON HAI PRECISION's falling in our 4th quadrant indicates that it should have superior productivity yet inferior impact relative to us. We can see from Table I that this is indeed the case. Despite its greater number of cited and un-cited patents, HON HAI PRECISION's portfolio receives much fewer citations than our smaller portfolio does.

We can also see from Table I that QUALCOMM INCORPORATED has a smaller number of patents and receives fewer total citations than ours. However, its being positioned in our 2nd quadrant suggests that it should have inferior productivity but superior impact relative to us. The productivity side is clearly true. As to the impact side, we can easily see from Fig. 4 that it has some very highly cited patents and, due to the way the *h*-complement area centroid is calculated, these patents are so exceptionally that its centroid is raised above ours. This scenario reflects a property of our approach that a smaller number of highly cited patents, even though with fewer total citations, may be considered to produce greater impact than a larger number of mediocre patents do. This property seems to be a reasonable one, especially considering that patents are rarely highly cited.

As the technology mangers for NORTEL NETWORKS, we can immediately determine our position among a group of competitors from the panoramic view offered by Fig. 3. Not only that we can tell who outperforms or is outperformed by us in terms of productivity and impact, but also that we can see where the performance difference lies (i.e., in productivity or in impact or in both). Additionally, the two-dimensional approach actually allows us to see the degree of difference between competitors' performance, instead of simply ordering them in a linear list as many patentometric indicators do. For example, by the distance between two competitors' *h*-complement area centroids, we can infer whether they have comparable or different or significantly disparate performance.

V. Tracking Performance Evolution

Another major advantage of the proposed panoramic approach is that it could be extended to track the performance evolution of a number of competitors over a period of time, in addition to providing a static view at a specific epoch.

To illustrate this application, the five assignees of Table I are again used as example and their patent portfolios since 1976 are obtained for each year between 2000 and 2009. Then, these portfolios' *h*-complement area centroids are produced according to (5) and (6), plotted in a two-dimensional coordinate system, and connected into trajectories as shown in Fig. 5. Since the trajectories in Fig. 5 are not spaced too far apart, the *x*- and *y*-axes are not log-scaled.

As mentioned in Section III, if an assignee's portfolio continuously increases with newly granted patents and the portfolio continuously receives more citations, it is very possible that its *h*-complement area centroid (r_x', r_y') would move towards the upper right as r_x' is related to productivity and r_y' is related to impact. This speculation is indeed reflected in Fig. 5.

The historical view manifested in Fig. 5 provides us a great deal of insight into how the portfolios of these assignees change over time. The trajectories shown in Fig. 5 generally develop gradually over time and reveal a rather smooth trend. Even though HON HAI PRECISION's trajectory undergoes some abrupt change between 2005 and 2007, its trajectory resumes a smooth trend between 2007 and 2009. These smooth trends provide us some forecasting capability to the assignees' future performance by extrapolation.

Therefore, when there is some abrupt change in the trend, such as the jump of HON HAI PRECISION's trajectory between 2005 and 2007, such a scenario entails

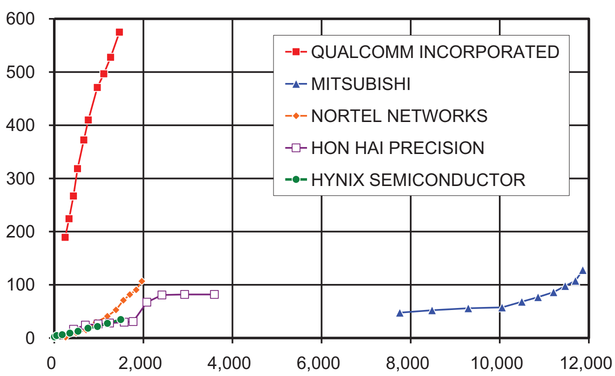

Fig. 5: The trajectories of *h*-complement area centroids from 2000 to 2009 for the 5 sample assignees.

our further investigation. After examining HON HAI PRECISION's data, we find that some of its patents received unusually more citations in 2006 (e.g., D431825's citations increased from 51 in 2005 to 131 in 2006). We as technology managers of course should pay special attention to these patents.

Additionally, we can see that QUALCOMM INCORPORATED's trajectory has been rather consistently showing a trend that the achieved impact of QUALCOMM INCORPORATED grew at a much faster rate than the other assignees over the years. On the other hand, the trajectories of MITSUBISHI and NORTEL NETWORKS both present a similar trend suggesting increased impact in the last few years. Then, HYNIX SEMICONDUCTOR's trajectory has such a steady trend that requires no special attention of us, and HON HAI PRECISION was very productive in producing patents, yet its fast-growing portfolio did not generate much impact.

We can also see that, from NORTEL NETWORKS' perspective, HYNIX SEMICONDUCTOR and MITSUBISHI have always been located at its 3rd and 1st quadrants, respectively. However, QUALCOMM INCORPORATED was in NORTEL NETWORKS' 1st quadrant initially but shifted to the 2nd quadrant in recent years. We can immediately identify that this is because NORTEL NETWORKS caught up on the productivity side over the years. Similarly, we can see that, as NORTEL NETWORKS caught up on the impact side, HON HAI PRECISION moved from the 1st quadrant finally into the 4th quadrant of NORTEL NETWORKS.

VI. Conclusion

Based on the citation distribution of a competitor's decreasingly sorted patent portfolio, we define an *h*-complement area whose lower boundary includes the *h*-core segment, *h*-tail segment, and the segment corresponding to the un-cited patents. We then propose to use the centroid of the *h*-complement area, which accurately reflects the shape of the *h*-complement area or the shape of the entire rank-citation curve, to characterize the innovation performance, including both cited and un-cited patents, embodied in a competitor's patent portfolio.

A large number of competitors' innovation performance as such can be simultaneously depicted in a two-dimensional coordinate system, thereby achieving a panoramic view to these competitors' relative performance. With this panoramic view, a technology manager can immediately determine the affiliated organization's position among a group of competitors. The technology manager can also determine where the performance difference relative to these competitors lies and the degree of such difference.

We have also shown that the two-dimensional approach can be a valuable tool for tracking and monitoring how competitors' innovation performance evolves over a period of time. The trajectories of the competitors' *h*-complement area centroids within the time window can provide a technology manager significant insight into the patterns of competitors' performance evolution. When there is some abrupt pattern change, the technology manger should be alarmed to conduct further investigation. A steady pattern, on the other hand, could provide some forecasting capability as to where a competitor's performance may evolve.

In additional to competitor analysis, the intelligence we gain from analyzing the static and historical views of the *h*-complement area centroids is valuable in making various business decisions. Taking Fig. 5 as example and assuming that we are considering a company from the 5 assignees for acquisition, if the value of intellectual property is a major concern, then clearly QUALCOMM INCORPORATED should be our first target. Alternatively, if we are the owner of QUALCOMM INCORPORATED and we are putting our patent portfolio on the market for sale, Fig. 5 then could be used to justify the hefty price tag we put on the patent portfolio to the potential buyers.

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