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# The $H_l$-index: improvement of $H$-index based on quality of citing papers

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**Abstract** This paper proposes $h_l$-index as an improvement of the $h$-index, a popular measurement for the research quality of academic researchers. Although the $h$-index integrates the number of publications and the academic impact of each publication to evaluate the productivity of a researcher, it assumes that all papers that cite an academic article contribute equally to the academic impact of this article. This assumption, of course, could not be true in most times. The citation from a well-cited paper certainly brings more attention to the article than the citation from a paper that people do not pay attention to. It therefore becomes important to integrate the impact of papers that cite a researcher's work into the evaluation of the productivity of the researcher. Constructing a citation network among academic papers, this paper therefore proposes $h_l$-index that integrating the $h$-index with the concept of lobby index, a measures that has been used to evaluate the impact of a node in a complex network based on the impact of other nodes that the focal node has direct link with. This paper also explores the characteristics of the proposed $h_l$-index by comparing it with citations, $h$-index and its variant $g$-index.

**Keywords** $H$-index · Lobby index · Academic influence

## Introduction

$H$-index (Hirsch 2005) has become a popular metrics to measure the achievement of researchers. The popularity of $h$-index stems from its capability of combining the number

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of publications a researcher generates and the number of citations each publication attracts. *H*-index not only encourages the continuity of producing influential papers (Kelly and Jennions 2006), but also can be a useful tool in assessing the research quality of a researcher (Hirsch 2005). At the same time, the popularity of *h*-index has drawn attentions from academic researchers. They have identified several issues associated using it to evaluate academic researchers (Bornmann and Daniel 2007; Jin et al. 2007; Jin 2007; Liu and Rousseau 2008). And many *h*-index variants have been proposed to address above mentioned issues.

However, while *h*-index and all its variants seek to find an appropriate way to evaluate a researcher, one problem they have is that they all treated the citations a paper receives equally. Being an important component in *h*-index and its variants, number of citations a paper receives has been an important indicator of its academic impact. However, not all citations to a paper contribute equally to the academic impact of this paper. Therefore, the *h*-index could be more precise in evaluating a researcher's research quality if it puts different weights on citations a paper receives based on the academic impact of those papers that cited the focal paper.

On the other hand, after constructing a citation network based on the citation links existed between academic papers, it is possible to evaluate a paper's academic impact based on the academic impact of papers that cite it. The reason is that social network analysis researchers have developed measures to evaluate the influence of a node in a social network based on its neighbors influence in the network. Example measures include the PageRank of Google, Katz Prestige (Katz 1953), eigenvector centrality (Bonacich 1972), lobby index (Korn et al. 2009), *c*-index (Yan et al. 2013) and $c_g$-index (Yan et al. 2013). All these measures measure the importance of a node in network based on the importance of other nodes that have direct links to the focal node in network. We selected lobby index over other indexes in our study due to its high feasibility. The calculation of other indexes depends on the construction of a complete citation network that covers all academic papers, and the construction of a complete citation network could be infeasible. On the other hand, the calculation of lobby index requires only the number of citations a paper that cites a focal paper receives.

We therefore propose to integrate the existing *h*-index method that balance the number of publications and the number of citations each publication receives with lobby index (Korn et al. 2009) that estimate the impact of a publication based on the impact of other papers that cite the publication to better evaluate the research quality of academic scholars. We called the resulted measure $h_l$-index.

The structure of the paper is as follows: "Related literature and background" section reviews related literature on *h*-index, citation networks, and lobby index, while "$H_l$-index" section describes the development of $h_l$-index. "An example of comparison of the citations, *h*-index, *g*-index and $h_l$-index" section conducts a case study to evaluate and compare the $h_l$-index, along with other well-known academic influence measurements: citations, *h*-index and *g*-index. "Conclusions" section presents conclusions.

## Related literature and background

### *H*-index

*H*-index (Hirsch 2005) was proposed to improve simpler measures such as the total number of citations or publications used to evaluate the research quality of academic scholars. The

$h$-index integrates the number of articles a scholar published and the number of citations each published article received. "A scientist has index $h$ if $h$ of his or her $N_p$ papers have at least $h$ citations each and the other ($N_p$-$h$) papers have $\leq h$ citations each" (Hirsch 2005). Compared with the traditional citation analysis approach, $h$-index concurrently values the quality and quantity of scientific research output of individuals.

Since $h$-index was proposed, the $h$-index and some related bibliometric indices have received a lot of attention from the scientific community in the last few years (Alonso et al. 2009), its theoretical aspects have been thoroughly discussed (Barcza and Telcs 2009; Egghe and Rousseau 2006; Glänzel 2006; Schubert and Glänzel 2007; Ye 2011; Egghe 2010). Through research on the advantages and disadvantages of $h$-index, many scholars put forth a series of derivative indexes, including $g$-index (Egghe 2006), $h_g$-index (Alonso et al. 2010), $A$-index and $AR$-index (Jin 2007; Jin et al. 2007), $R$-index (Jin et al. 2007), $h_I$-index (Batista et al. 2006), $H^{(2)}$-index (Kosmulski 2006), $m$-index (Bornmann et al. 2008), $AR^2$-index (Rousseau and Jin 2008).

From the definition of the $h$-index, it is apparent that the academic impact of each publication plays a crucial rule in evaluating the research performance of a scholar. $H$-index and all its variants use the number of citations a publication receives as the measure for its academic impact. The underline assumption for this is that each citation received contributes equally to the academic impact of a publication. This, of course, usually is not the case. The citation from a paper that itself is cited by hundreds of other papers certainly contributes more to a paper's academic impact than that from a paper that nobody remembers. Citation from a high influential paper help attracts more attention to the paper, while the citation from a not-so-well-cited paper may not bring in any additional attention to the paper. It therefore becomes important to distinguish the citations that bring the paper more attentions than those that do not.

## Citation network and lobby index

The citation network is a complex network that studies the citation relationship between articles (or journal, etc.). For example, the nodes represent different articles. If Article $B$ cites Article $A$, then there exists an edge directing from $B$ to $A$. The citation network has some unique structural features. For instance, the citation network is the directed non-weighted network where edges are unidirectional and there is no ring, etc. In a citation network, the number of citations an article receives is the in-degree centrality of this node, which the number of other nodes with direct links pointing to the node.

Korn et al. (2009) proposed the lobby index (or $l$-index) for the undirected non-weighted network to describe centrality of node based on the centrality of other nodes that have links to the node of interest. "The $l$-index or lobby index ($l(x)$) of a node $x$ is the largest integer $k$ such that $x$ has at least $k$ neighbors with a degree of at least $k$" (Korn et al. 2009). Although lobby index is defined in the undirected network, we can easily extend it to the directed network.

**Definition 1** For a directed network, we define lobby index as follows:

(1) In-lobby index: In-lobby index of node $x$ is the biggest integral $k$ such that node $x$ has at least $k$ neighbor nodes directing at $x$ whose in-degree is at least $k$.
(2) Out-lobby index: Out-lobby index of node $x$ is the biggest integral $k$ such that node $x$ has at least $k$ neighbor nodes directing from $x$ whose out-degree is at least $k$.
(3) All-lobby index: All-lobby index of node $x$ is the maximum integral $k$ such that node $x$ has at least $k$ neighbor nodes whose all-degree is at least $k$.

This is consistent with the node degree centrality is defined as in-degree, out-degree and all-degree in directed network.

## $H_l$-Index

### Definition of $h_l$-index

We propose the measure, call $h_l$-index, to measure the research performance of a scholar. It is the integration of $h$-index and in-lobby index defined above. As discussed above, for a node (article) $A$ in the citation network, if in-lobby index of node $A$ is $k$, then $k$ is the biggest integral such that the article $A$ is cited at least by $k$ articles whose citations are no smaller than $k$. Obviously, the in-lobby index of an article measures its influence more accurately than the citations. Therefore, when using $h$-index to evaluate a researcher's performance, replacing the number of citations a publication receives with the in-lobby index of this publication could have a more precise evaluation. And we call the resulted measure $h_l$-index.

**Definition 2** ($h_l$*-index*) The $h_l$-index of a set of articles is $h$ means that $h$ is the biggest integer such that the set of articles has at least $h$ articles satisfying that the in-lobby index is no less than $h$.

In other words, the $h_l$-index of a researcher is $h$ means that the researcher has $h$ articles each of which has the in-lobby index that is no less than $h$ and the researcher does not have $h + 1$ articles each of which has the in-lobby index that is no less than $h + 1$. Also, the $h_l$-index of a set of articles is $h$ means that the set of articles has up to $h$ articles each of which has been cited by at least $h$ articles whose citations is at least $h$ and the set does not have $h + 1$ articles each of which has been cited by at least $h + 1$ articles whose citations is at least $h + 1$.

Figure 1 displays a scholar's papers and those that cite the scholar's papers. As displayed in Fig. 1, a scholar has generated $n$ papers. Paper 1 of this person received $s$ citations. Paper 11 that cited Paper 1 received $c$ citations. And following is the proposed algorithm to calculate $h_l$-index of this scholar:

1) Calculate the in-lobby index of each article this scholar generated. For each article, rank the papers that cited the article in descending order based on the number of citations each paper receives. If the number of citation received by the $k$th paper in the list $\geq k$, while the number of citation received by the $(k + 1)$th paper in the list $\leq k$, then in-lobby index of this article is $k$.
2) Repeat step 1 for all other articles the researcher generated.
3) Rank the scholar's articles in descending order based on the in-lobby index value. If the in-lobby index of the $h_l$th paper $\geq h_l$, while that of the $(h_l + 1)$th $\leq h_l$, then the $h_l$-index of the scholar is $h_l$.

Table 1 presents an example on how $h_l$-index was calculated for a set of articles. In Table 1, the set contains 7 articles. According to the number of citations each paper received and the in-lobby index value for each paper, the $h$-index for this article set is 5, whereas $h_l$-index of this article set is 4.

$H_l$-index should have following property.

**Property** *For any set A containing n articles,* $0 \leq h_l$-index $\leq h$-index $\leq n$. *And* $h_l > 0$, *when and only when this set has at least one article that is cited by at least one article with citations* $\geq 1$.

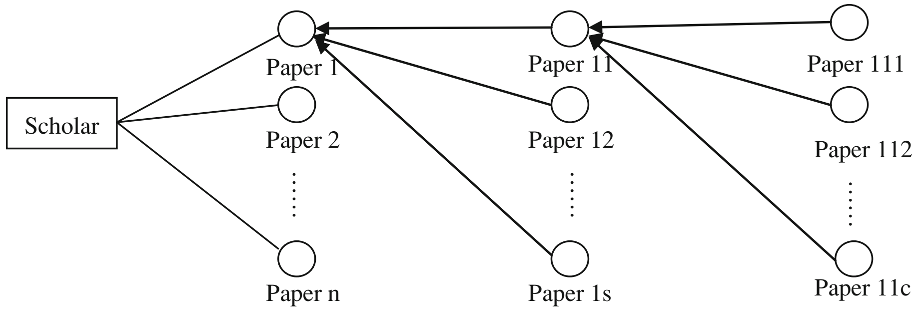


**Fig. 1** An example of a scholar's papers and the citing papers

**Table 1** An example of $h_l$-index computation

| Serial number | Citation | In-lobby index |
|---|---|---|
| 1 | 20 | 10 |
| 2 | 23 | 8 |
| 3 | 15 | 7 |
| 4 | 10 | 5 |
| 5 | 10 | 4 |
| 6 | 5 | 2 |
| 7 | 2 | 2 |

*Proof* The definition of $h_l$-index shows that $h_l \geq 0$, and $h_l > 0$, when and only when this set has at least one article that has been cited by at least one other article with at least 1 citation. It is not difficult to prove that $h_l \leq h$ too. Since the lobby index value of a node can never be larger than the node degree (Korn et al. 2009), the in-lobby index of the article cannot be larger than the number of citations. Hence $h_l$-index cannot be larger than $h$-index. And $h$-index cannot be larger than the number of the article $n$. □

The definition of $h_l$-index indicates that it can measure the difference that $h$-index cannot. The scholars with identical $h$-index may have different $h_l$-index. Generally speaking, in order to have a high $h$-index value, a researcher needs to generate more well-cited papers. However, in order to have a better $h_l$-index, the researcher also needs to ensure that the citation to her papers come from well-cited papers, which, of course, is more difficult to achieve than to have a high value for $h$-index. Compared to $h$-index, $h_l$-index has higher capability of resisting the impact of self-citations. A person could have a high $h$-index value through self-citations, but it is almost impossible to have a high $h_l$-index value using the same method. The $h_l$-index thus provides a more precise evaluation on the academic impact of researchers.

## The tail behavior of distribution of $h_l$-index

To better understand the characteristics of $h_l$-index, this section discusses the theoretical properties of the distribution of $h_l$-index, demonstrates that $h_l$-index has a power law upper tail distribution under the condition that the underlying publication and citation distributions have fat tails.

Since $h_l$-index is based on in-lobby index, we would like to discuss the property of distribution of in-lobby index in the directed network before the discussion on the property of the distribution of $h_l$-index. In a scale free networks (Barabási and Albert 1999) the distribution of degree centrality of nodes has a power law upper tail. It has also been shown that lobby index has a power law upper tail distribution in a non-directed scale free networks (Korn et al. 2009).

Let $x$ be a randomly chosen node, $d(x)$ is the node degree of node $x$, $l(x)$ is the lobby index of node $x$. Here, let $a_n \approx b_n$ mean that $a_n/b_n \to 1$ as $n \to \infty$ and $a_n \simeq b_n$ mean that there is a $M > 1$ such that $1/M \leq a_n/b_n \leq M$ for all $n$. The constant $\alpha > 1, \beta > 1$, $c$ represents a constant, $c$ in different positions can be different. The following symbols are of identical meanings here.

**Lemma 1** (Distribution of the lobby index) (Korn et al. 2009). *In a undirected network, if the node degrees are independent and $P(d(x) \geq k) \approx ck^{-\alpha}$ for all nodes x, then*

$$P(l(x) \geq k) \simeq k^{-\alpha(\alpha+1)}$$

*for all nodes x.*

Barcza and Telcs prove the power laws distribution of the $h$-index (Barcza and Telcs 2009). Let $x$ be a randomly chosen author, $n(x)$ is the amount of paper of this author, $y$ is a certain paper of this author and $c(y)$ is the citation times of the paper $y$.

**Lemma 2** (Distribution of the $h$-index) (Barcza and Telcs 2009). *Assume that the productivity has an $\alpha$-fat tail: $P(n(x) \geq n) \approx cn^{-\alpha}$, and the citation score has a $\beta$-fat tail $P(c(y) \geq s) \approx cs^{-\beta}$ and assume that all the publication and citation scores are independent, then $P(h(x) \geq k) \simeq k^{-\alpha(\beta+1)}$.*

We can easily know $h_l$-index distribution through Lemma 1 and Lemma 2.

**Theorem 1** (Distribution of the $h_l$-index) *In line with Lemma 2 assume that the productivity of a randomly chosen scholar x has an $\alpha$-fat tail $P(n(x) \geq n) \approx cn^{-\alpha}$, the citation score has a $\beta$-fat tail $P(c(y) \geq s) \approx cs^{-\beta}$of any article (including the articles of scholar x and the articles citing the articles of scholar x), and assume that all the publication and citation scores are independent, then*

$$P(h_l(x) \geq k) \simeq k^{-\alpha(\beta^2+\beta+1)}$$

*Proof* In a citation network, the number of citation of an article $y$ is the in-degree of node $y$ is, whereas the number of citations of articles that cite $y$ is the in-degree of the nodes that have direct links to $y$. The hypothesis indicates that the citations of articles are independent, and $P(c(y) \geq s) \approx cs^{-\beta}$. Therefore, the in-degree of node $y$ in the network and the in-degree of neighbor nodes with direct links pointing to $y$ are independent to each other and in the distribution of $P(d_{\text{in}}(y) \geq s) \approx cs^{-\beta}$. By Lemma 1 the distribution of in-lobby index clearly should satisfy $P(l_{\text{in}}(y) \geq k) \simeq k^{-\beta(\beta+1)}$. Obviously, the in-lobby index of articles and the number of articles are independent. Lemma 2 reveals that $P(h_l(x) \geq k) \simeq k^{-\alpha(\beta^2+\beta+1)}$. □

In reality, the number of articles a scholar (institution, country, etc.) published in a period of time is approximately in the distribution of power tail and the citations of an article also are in accordance with the distribution of power tail (Yuan 2010), the conditions of Theorem 1 are easy to satisfy. The power tail distribution of $h_l$-index suggests that most researchers have low $h_l$-index, while a few researchers have extremely high $h_l$-index values. It certainly is important for those high influential scholars to be recognized. The power tail with exponent $\alpha(\beta^2 + \beta + 1)$ of $h_l$-index is larger than the power tail with exponent $\alpha(\beta + 1)$ of $h$-index, here $\alpha > 1$, $\beta > 1$. This suggests that there are fewer people who have high $h_l$-index value than those who have high $h$-index value in the same citation network.

## An example of comparison of the citations, *h*-index, *g*-index and $h_l$-index

This section discusses the properties of $h_l$-index and its similarities to and differences from $h$-index, $g$-index and the citations by applying them over a real data set.

### Data

We selected journal "*Scientometrics*" as the testbed. We identified fifty scholars each of whom has published five articles on this journal. We set the number of papers to be five such that we have enough number of scholars and each scholar has enough number of articles for this study. We calculated the $h_l$-index of each scholar based on the citation information provided by Web of Science database.

## Results

We conducted correlation analysis of the number of citations and in-lobby index values over 235 articles generated by 50 scholars identified. Table 2 displays the results from three correlation tests, indicating that the number of citations and in-lobby index are strongly correlated. Since the number of citations are the in-degree of node in the citation network, it is consistent with the fact that the degree centrality of nodes in the undirected network is in strong correlation with lobby index as shown in (Korn et al. 2009).

Next, we calculated the number of citations, $h$-index, $g$-index and $h_l$-index for each of the 50 scholars selected. Table 3 lists all the index values for ten scholars who have the highest $h_l$-index values, in the descending order of $h_l$-index. Table 3 indicates that $h_l$-index could result in different ranking among scholars than using other indexes. The scholars with high $h$-index values may have not-so-high value in $h_l$-index.

In Table 4, two scholars, Wouters, P. and Costas, R. both have $h$-index at 4 and $g$-index at 6. These two scholars should have similar academic impact if these two indexes are used to measure academic impact On the other hand, $h_l$-index values suggest that Wouters, P. with $h_l$-index value at 4 is more influential than Costas, R. whose $h_l$-index is at 2. The reason is that the former's papers were cited by more influential papers than the latter's papers, even though these two scholars received comparable number of citations.

**Table 2** Correlation of citation and in-lobby index of papers

| Pearson correlation | Kendall's tau_b | Spearman's rho |
|---|---|---|
| 0.889** | 0.795** | 0.910** |

** Correlation is significant at the 0.01 level (2-tailed)

**Table 3** Citations, $h$-index, $g$-index and $h_l$-index of the top ten scholars of $h_l$-index

| ID | Author | Citation | $H$-index | $G$-index | $H_l$-index |
|---|---|---|---|---|---|
| 1 | Aksnes, DW | 196 | 5 | 14 | 5 |
| 2 | Chiu, WT | 99 | 4 | 9 | 4 |
| 3 | Diospatonyi, I | 49 | 5 | 7 | 4 |
| 4 | Klavans, R | 200 | 5 | 14 | 4 |
| 5 | Melin, G | 155 | 5 | 12 | 4 |
| 6 | Wouters, P | 39 | 4 | 6 | 4 |
| 7 | Yitzhaki, M | 46 | 4 | 6 | 4 |
| 8 | Archambault, E | 101 | 5 | 10 | 3 |
| 9 | Balaban, AT | 38 | 3 | 6 | 3 |
| 10 | Dore, JC | 43 | 4 | 6 | 3 |

**Table 4** An example ($h$-indexes and $g$-indexes is identical, but $h_l$-indexes is different)

| | | | | | | Total |
|---|---|---|---|---|---|---|
| Wouters P | | | | | | |
| Serial number | 1 | 2 | 3 | 4 | 5 | |
| Citation | 11 | 10 | 10 | 8 | 0 | 39 |
| In-lobby index | 7 | 6 | 6 | 5 | 0 | |
| Costas R | | | | | | |
| Serial number | 1 | 2 | 3 | 4 | 5 | |
| Citation | 20 | 11 | 7 | 5 | 2 | 45 |
| In-lobby index | 8 | 5 | 1 | 0 | 0 | |

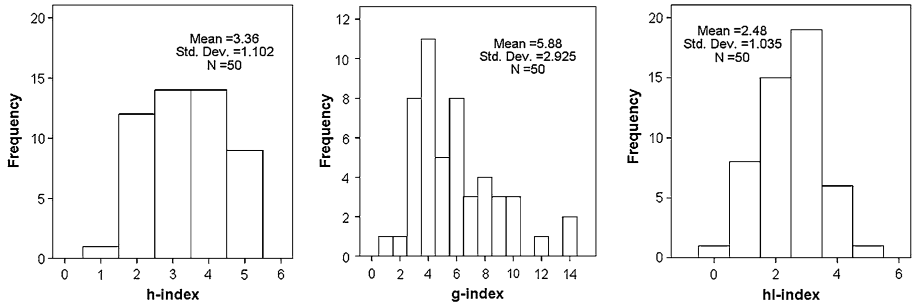


**Fig. 2** The distribution of frequencies of $h$-index, $g$-index and $h_l$-index

Figure 2 presents the frequency distribution of the three academic influence measurement indexes, namely, $h$-index, $g$-index and $h_l$-index, obtained from our selected data. We make the one sample Kolmogorov–Smirnov test for the distribution of the three with the results listed in Table 5. All these three indexes have passed in the test of Poisson distribution in signification level $\alpha = 0.05$, suggesting that all the three indexes have Poisson distributions in the data we collected.

Figure 3 displays the scatter diagram of $h$-index and $h_l$-index. On the diagram, one dot represents one scholar. The dots on the line in the diagram are those with the same $h$-index

**Table 5** One sample Kolmogorov–Smirnov test

| | *H*-index | *G*-index | $H_l$-index |
|---|---|---|---|
| Kolmogorov–Smirnov Z | 0.929 | 0.838 | 0.788 |
| Asymp. Sig. (2-tailed) | 0.353 | 0.483 | 0.564 |

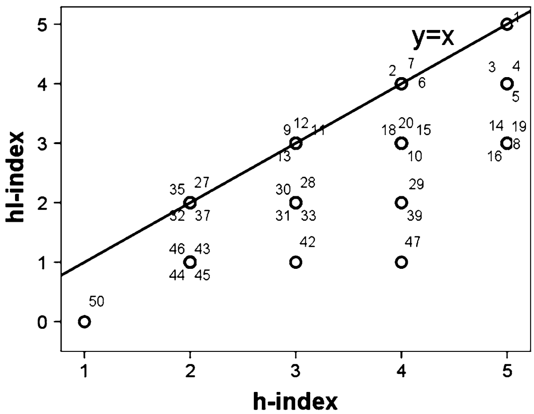


**Fig. 3** The scatter diagram of *h*-index and $h_l$-index

**Table 6** Correlation test

| | Citation | *H*-index | *G*-index | $H_l$-index |
|---|---|---|---|---|
| Pearson | | | | |
| Citation | – | | | |
| *H*-index | 0.694** | – | | |
| *G*-index | 0.973** | 0.767** | – | |
| $H_l$-index | 0.693** | 0.758** | 0.761** | – |
| Kendall's tau_b | | | | |
| Citation | – | | | |
| *H*-index | 0.684** | – | | |
| *G*-index | 0.947** | 0.702** | – | |
| $H_l$-index | 0.642** | 0.681** | 0.671** | – |
| Spearman's rho | | | | |
| Citation | – | | | |
| *H*-index | 0.814** | – | | |
| *G*-index | 0.990** | 0.800** | – | |
| $H_l$-index | 0.772** | 0.762** | 0.775** | – |

** Correlation is significant at the 0.01 level (2-tailed)

and $h_l$-index values. Figure 3 suggests that *h*-index is always larger than or equal to $h_l$-index and the two indexes are positively correlated.

To measure whether the different indexes are correlated to each other, we did a correlation analysis between citations, *h*-index, *g*-index and $h_l$-index and the results are presented in Table 6. All the indexes are strongly correlated to each other.

**Table 7** Partial correlation test

| | *H*-index | $H_l$-index | *G*-index |
|---|---|---|---|
| *H*-index | – | | |
| $H_l$-index | 0.534** | – | |
| *G*-index | 0.556** | 0.522** | – |

Control variables: citations

** Correlation is significant at the 0.01 level (2-tailed)

Table 7 gives the partial correlation analysis of *h*-index, *g*-index and $h_l$-index. There into, the control variable is the citations. The results make it clear that with the influence of the citations wiped out, the correlation of *h*-index, *g*-index and $h_l$-index lowers but is still moderate.

## Conclusions

This paper proposes $h_l$-index as an improved index of *h*-index taking into consideration of the influence of papers that cite a focal paper. We firstly constructed a citation network based on the citation relationships existed among academic articles. We then utilized idea of lobby index (Korn et al. 2009) and promotes the concept of lobby index in the directed network, gains the concepts of in-lobby index, out-lobby index and all-lobby index and adopted in-lobby index to depict the influence of a node (an article). Based on the influence of neighbor nodes of the node with which it has direct link from neighbor node to the node. The proposed $h_l$-index was calculated in the same way in which the *h*-index was calculated, but replacing the number of citations a paper receives with its in-lobby index. By doing so, $h_l$-index provides a more precise way to evaluate the academic impact of researchers.

$H_l$-index is the improvement based on *h*-index and inherits corresponding advantages of *h*-index. Since the calculation of $h_l$-index uses the citations of the citing papers, it is more difficult for $h_l$-index to expand through self-citation than *h*-index. The analysis on the properties of the $h_l$-index demonstrates that the $h_l$-index value is between 0 and *h*-index. If the distributions of the citations and the number of articles in the set of articles are with power tail and independent to each other, then the distribution of $h_l$-index is with power tail. If we adopt $h_l$-index to evaluate the academic influence of the scholars, then this conclusion indicates that only a minority of scholars boast high $h_l$-index values while most scholars have low $h_l$-index values. In the case analysis in "An example of comparison of the citations, *h*-index, *g*-index and $h_l$-index" section, we have explored the similarities and differences between $h_l$-index and the academic influence indexes namely the citations, *h*-index and *g*-index.

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