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Evaluating the patenting activities of pharmaceutical research organizations based on new technology indices

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ABSTRACT

Several citation-based indicators, including patent h-index, have been introduced to evaluate the patenting activities of research organizations. However, variants developed to complement h-index have not been utilized yet in the domain of intellectual property management. The main purpose of this study is to propose new indices that can be used to evaluate the patenting activities of research and development (R&D) organizations, based on h-type complementary variants along with traditional indicators. Exploratory factor analysis (EFA) is used to identify those indices. By applying the proposed framework to pharmaceutical R&D organizations, which have their patents registered in the United States Patent Trademark Office (USPTO), the following three indices are obtained: the forward citation, impact per unit time, and patent family factors. The ranking obtained from the new indices can represent the productive capacity of the qualified patent, patent commercialization speed, and patent commercialization effort of research organizations. The new proposed indices in this study are expected to contribute to the evaluation of the patenting activities of R&D organizations from various perspectives.

1. Introduction

In the knowledge economy, several technology indicators have been proposed based on patent information, in order to measure the technological impact of R&D organizations (Albert, Avery, Narin, & McAllister, 1991; Karki, 1997). Citations per patent (CPP), patent impact index (PII), and current impact index (CII) are examples of such indicators (Breitzman & Narin, 2001). Recently, the Hirsch index (h-index), which was originally utilized to quantify the research performance of a single researcher or research group in academic publication, has been applied to the patent data (Guan & Gao, 2009; Luan, Zhou, & Liu, 2010; Kuan, Huang, & Chen, 2013).

The h-index was suggested by Hirsch (2005) and combines a measure of the quantity (number of publications) and impact (number of citations). The h-index can be easily calculated and is considered to have certain advantages over other simple citation-based measurements, such as the total number of citations and average citations per paper (Bornmann & Daniel, 2007; Costas & Bordons, 2007).

Although the h-index has generated considerable interest due to its advantages, many researchers have pointed out its disadvantages, such that it may increase even if no new research papers are published, and that highly cited papers are equally considered with less highly cited papers, for the determination of the h-index (Hirsch, 2005; Braun, Glänzel, &

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Table 1
Definition of h-index and its complementary indicators.

Author	Index	Definition
Hirsch (2005)	h-Index	"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"
Egghe (2006)	g-Index	"The highest number g of papers that together received g^2 or more citations"
Hirsch (2005)	m-Quotient	h/y, where h is h-index, and y is the number of years since publishing the first paper
Jin (2006)	a-Index	$1/h\sum_{j=1}^{h} cit_j$, where h is h-index, and cit_j is the citation counts of paper j
Jin et al. (2007)	r-Index	$\sqrt{\sum_{j=1}^{h} cit_j}$, where h is h-index, and cit_j is the citation counts of paper j
Jin (2007)	ar-Index	$\sqrt{\sum_{j=1}^{h} cit_j/a_j}$, where h is h-index, cit_j is the citation counts of paper j, and a is the number of years since publishing

Schubert, 2006; Bornmann & Daniel, 2007; Costas & Bordons, 2007). To complement these disadvantages, various h-type variants, including g-index, a-index, and ar-index, have been proposed (Egghe, 2006a; Jin, 2006; Jin, Liang, Rousseau, & Egghe, 2007). Likewise, the patent h-index can lead to misjudgments with regard to an organization's patenting activities. In order to solve these problems, h-type variants can be applied to the patent data. As many technology indicators have already proposed, finding the meaningful factors of individual indicators is also necessary.

The main purpose of this study is to propose new technology indices, based on h-type complementary variants along with traditional technology indicators, which can be utilized for evaluating the patenting activities of R&D organizations. We conduct an exploratory factor analysis (EFA) with the patent data of pharmaceutical R&D organizations, in order to derive new technology indices. These new indices are applied to rank the research organizations in the pharmaceutical field, and are expected to contribute to the identification of R&D organizations with various types of patenting activities.

Section 2 presents the literature review related to the traditional technology indicators, h-index and patent h-index. Section 3 introduces the data and methodology. The experimental results obtained from the pharmaceutical industry are described in Section 4. Finally, we conclude in Section 5, along with suggestions for future areas of study.

2. Literature review

Many well-established technology indicators have been constructed based on patent information, including total number of citations, CPP, PII, and CII (Chen, Lin, & Huang, 2007; Chang, Chen, & Huang, 2012). CPP is obtained by dividing the total number of citations by the total number of patents. PII is calculated by dividing the CPP for a specific field by the CPP for all fields. CII measures how often an analytical unit's patents are cited and compared with the average for all patents in the previous five years (Breitzman & Narin, 2001). Moreover, information regarding the patent family is also appropriate as an indicator of the value of patents (Harhoff, Scherer, & Vopel, 2003; Martínez, 2011). The patent family is a patent group that shares the same invention, and is protected by more than one jurisdiction. Further, there are two kinds of patent family data: patent family size and the number of patent families (Harhoff et al., 2003; Martínez, 2011). The patent family size is the number of jurisdictions that protect the same patent family, and the number of patent families is computed as the total number of patents in a patent family.

As a new technology indicator, Guan and Gao (2009) first proposed the application of the patent h-index to evaluate patent assignees. The h-index was introduced by Hirsch in 2005 as a single indicator to measure both the quantity and impact of the scientific performance of a researcher. The definition of h-index is given in Table 1. It can be easily obtained and applied to not only a single researcher, but also to research groups and countries. However, numerous limitations of the h-index have also been found, such as that it fails to compare scientists with different career lengths; it increases, even if no new research papers are published; and it fails to reflect the qualitative difference between highly cited and less highly cited papers (Hirsch, 2005; Braun et al., 2006; Bornmann & Daniel, 2007; Costas & Bordons, 2007). Due to the limitations of the h-index, modified indicators have been proposed in the literature. For example, an m-quotient is proportional to career length (Hirsch, 2005); a g-index (Egghe, 2006a, 2006b), a-index (Jin, 2006), and r-index (Jin et al., 2007) assign more weight to highly cited papers; and an ar-index was devised to fix the problem of an increasing h-index, even if no new research papers are published (Jin et al., 2007). These definitions are presented in Table 1.

Recently, based on the bibliometric h-index, Guan and Gao (2009) have defined the patent h-index as "the number h such that, for a general group of patents, h patents received at least h citations from later patents, while other patents received no more than h citations." They concluded that the patent h-index is an effective indicator in the evaluation of the technological performance of an assignee, by considering both quantity (number of patents) and quality (number of forward citations). Since the introduction of the patent h-index, some studies on the topic have focused on the evaluation of corporate patenting activities (Luan et al., 2010; Chang et al., 2012; Zhang, Yuan, Chang, & Ken, 2012). An example of a study about applying the patent h-index was that of Luan et al. (2010), in which they investigated patent strategy in Chinese universities after the introduction of the "Chinese Bayh-Dole Act," by using the patent h-index. In addition, Chang et al. (2012) explored the relationships between business performance and patenting performance, measured from the patent h-index, essential patent index, and CII in the pharmaceutical industry. Further, Zhang et al. (2012) investigated the nonlinear relationships among the patent h-index, patent citations, essential technological strength, and corporate performance (sales), by using an artificial neural network.

Moreover, there are studies that interpreted the graph of the patent h-index (h-graph) (Kuan, Huang, & Chen, 2011; 2013; Liu, Rousseau, Wang, & Fred, 2013). Kuan et al. (2011) suggested a new geometric interpretation and that the shape descriptors of the patent h-graph represent the relative positions of their ranks and citations. In addition, Kuan et al. (2013) defined an h-complement area by a centroid of the h-complement area, which extended from the patent h-index. Liu et al. (2013) defined five ratios, R_H, R_T, S_H, S_T and S_Z, derived from the patent h-graph (h-core, h-tail, and uncited sources), and applied the ratios to both scientific papers and patents.

Existing studies related to the patent h-index, however, have neither considered the limitations of the h-index, nor applied complementary indicators of the h-index, which treat the disadvantages of the h-index. Furthermore, only a few studies attempted to compare h-type indices to the traditional technology indicators.

3. Data and methodology

To overcome the limitations of prior studies on the patent h-index, we applied the aforementioned h-type variants to the patents of an R&D-intensive field. We derive new technology indices, using the patent h-type variants, and traditional technology indicators, using EFA.

3.1. Data

In order to derive new technology indices, we selected the pharmaceutical field. We did this because this field is R&D-intensive, the benefit of patent protection is large, and its patenting is very active (Mansfield, 1986; Roin, 2008). The patenting activities in this field are considerably more related to market value than are other fields (Mansfield, 1986; Levin et al., 1987; Bettis & Hitt, 1995). Because of these characteristics, patents in this field have been evaluated often (Meyer, Siniläinen, & Utecht, 2003; Chang et al., 2012; Zhang et al., 2012). Among the many pharmaceutical fields, a subfield related to transgenic animals has recently come into the spotlight, and more R&D investment has been made in this area for new or improved products. The patents of this subfield can be more directly related to the pharmaceutical invention ability of an organization than can those of other subfields because the research on transgenic animals is closely associated with producing vaccines and antibodies (Houdebine, 2009). We gathered patents in this subfield to propose indices. Further, we employed the patent data registered at the United States Patent Trademark Office (USPTO) from the FOCUST database, which is managed by WISDOMAIN (http://www.wisdomain.com). WISDOMAIN offers information regarding patents granted by the USPTO, including the number of patents, forward citations, publication date, applicant, title, and international patent documentation (INPADOC) patent.

Search formulae are formed by compiling the pharmaceutical terms related to transgenic animals, and are presented in Appendix A. Patent data without applicant information were eliminated. To evaluate the current patenting activity, we extracted patents that were not expired. As the h-index is not effective for small units of analysis, the data were restricted to applicants with more than 20 patents. A total of 79 major applicants, with a total of 3244 patents, were collected, including only those with registration years that fall within the range of 1996 to 2014. The applicants consist of national research organizations, universities, and pharmaceutical corporations including non-practicing entities (NPEs).

We calculated six traditional technology indicators and six patent h-type indices for each applicant, using their patent data: total number of patents, total number of citations, CPP, CII, average patent family size, average number of patent families, patent h-index, patent g-index, patent m-quotient, patent a-index, patent r-index, and patent ar-index. In this study, we utilize these 12 indicators to devise our indices. When calculating the patent m-quotient and patent ar-index, we changed the concept of "the number of years since publishing the first paper", to the number of years since the registration of the first patent of an applicant. Application list and values of these 12 indicators for each of the 79 applications are included in the supplementary material.

3.2. Methodology

In order to identify the relationship between traditional technology indicators, h-type variants, and the patent h-index, we first use Pearson correlation analysis among the 12 indicators. Next, we conduct the EFA to identify the latent structure as a few factors out of the 12 indicators mentioned above. EFA reduces the dimensionality of the dataset to uncover the underlying structure of the dependencies in a dataset of variables. Moreover, EFA has often been used to identify the relationship among bibliometric indicators (Bornmann, Mutz, & Daniel, 2008; Schreiber, Malesios, & Psarakis, 2011, 2012). Varimax rotation is used and factor values are set, so that the eigenvalue of factors is above 1, and the cumulative proportion of variance, accounted for by the current and preceding factors, is above 80%. Prior to the EFA, we checked a Kaiser–Meyer–Olkin measure of sampling adequacy test to evaluate the suitability of the data for the EFA (Kaiser, 1974; Williams, Brown, & Onsman, 2012).

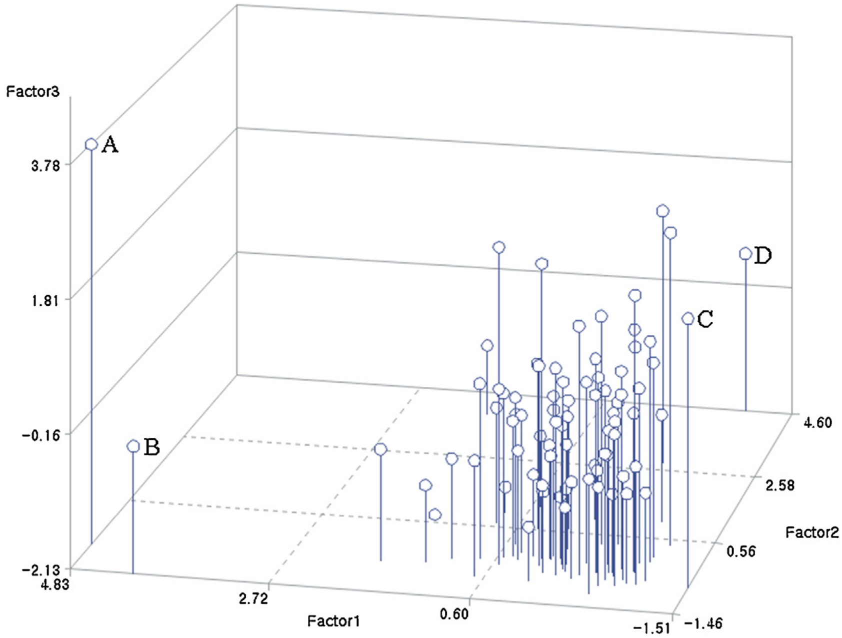

Fig. 1. 3D plot of factor patterns for factors 1–3.

The EFA cannot be used if the Kaiser–Meyer–Olkin measure for data is below 0.5 (Kaiser, 1974). All analyses were conducted using SAS version 9.4.

4. Results

Table 2 shows the correlation of all possible pairs of the 12 patent evaluation indicators. Two meaningful relationships were identified. First, the total number of citations was shown to be more related to the patent h-index and patent h-type variants, excluding the patent m-quotient, than to the traditional citation-based indicators such as CPP and CII. Second, a high correlation was seen between CII and the patent m-quotient, both of which are related to unit time. The patent m-quotient, which is qualitative and quantitative impact (patent h-index) per unit time, implies the speed of commercialization. CII, which is the degree of the patent citation in the previous five years, represents the degree of recent patent citations. The high correlation between CII and the patent m-quotient can infer that the degree of the recent patent citation is closely related to the speed of commercialization.

Results of the EFA are depicted in Table 3, where loading values above 0.7 are indicated by a "*". Factor 1 is the combination of indicators proportional to the total number of citations, or "forward-citation factor". The forward-citation factor is interpreted as pure technological performance. Because the main indicators for Factor 2 are the CII, which evaluates the impact for the past five years, and the patent m-quotient, which is a measurement of the impact per year, we labeled Factor 2 as "impact per unit time factor;" it can reflect the commercialization speed. Factor 3 consists of the average patent family size and the average number of patent families; it is considered the "patent family factor." The patent family and patent family countries stand for the internationalization of inventions and the range of patent rights. To increase these indicators, it is required that the enormous cost is undertaken and the effort into securing a patent grant is put forth (Harhoff et al., 2003; Martínez, 2011). Therefore, we interpret the patent family factor as the effort to commercialize patents.

The forward-citation factor was different from both the total number of patents and the total number of citations. It represents both quality and quantity by combining several indicators including the total number of patents, total number of citations, and patent h-type variants. For example, Amgen Inc. ranked seventh in the total number of patents and 13th in the total number of citations, but 10th in the forward-citation factor. Another example is that Kimberly Clark Worldwide Inc. was 16th in the total number of patents and ninth in the total number of citations, but 15th in the forward-citation factor.

Next, we evaluate the applicant organizations in terms of these three indices. A list of the major research organizations (applicants) is shown in Table 4, by decreasing factor values for each of the three factors.

By plotting the factor pattern for all factors presented in Fig. 1, four notable research organizations were discovered. Genentech (A in Fig. 1) attained a top research organization in the forward-citation factor and the patent family factor, but obtained a low value for the impact per unit time factor, in the subfield of transgenic animals. This result implied that the Genentech had good quality and quantity on patents in this subfield, and effect to hold the patent family. However, this result implied that their commercialization speed was slow.

Table 2
Pearson correlations among the traditional technology indicators, patent h-index, and patent h-type variants.

	Total number of patents	Total number of citations	CPP	CII	Average patent family size	Average number of patent families	Patent h-index	Patent g-index	Patent m-quotient	Patent a-index	Patent r-index	Patent ar-index
Total number of patents	1	0.80	−0.00	0.04	−0.03	0.35	0.66	0.69	0.30	0.39	0.59	0.60
Total number of citations		1	0.52	0.35	−0.06	0.45	0.88	0.93	0.57	0.77	0.92	0.82
CPP			1	0.44	−0.11	0.10	0.57	0.58	0.51	0.80	0.75	0.60
CII				1	−0.13	0.06	0.48	0.42	0.81	0.29	0.44	0.47
Average patent family size					1	0.41	−0.03	−0.06	−0.03	−0.13	−0.09	−0.04
Average number of patent families						1	0.39	0.39	0.24	0.21	0.34	0.34
Patent h-index							1	0.92	0.73	0.61	0.90	0.99
Patent g-index								1	0.62	0.80	0.97	0.90
Patent m-quotient									1	0.40	0.63	0.72
Patent a-index										1	0.89	0.61
Patent r-index											1	0.89
Patent ar-index												1

Table 3
Varimax-rotated loading matrix for 12 technology indicators (n = 79).

	Factor 1	Factor 2	Factor 3
Total number of citations	0.94*	0.26	0.09
Patent g-index	0.90*	0.37	0.06
Patent r-index	0.88*	0.45	−0.04
Total number of patents	0.85*	−0.19	0.19
Patent h-index	0.82*	0.47	0.14
Patent ar-index	0.79*	0.49	0.11
Patent a-index	0.75*	0.34	−0.23
CII	0.08	0.90*	0.00
Patent m-quotient	0.35	0.83*	0.15
CPP	0.43	0.66	−0.25
Average patent family size	−0.13	−0.02	0.84*
Average number of patent families	0.39	0.05	0.74*

-Loading values of 0.70 or greater are indicated by a "*".

Table 4
High-ranking applicant organizations with respect to individual factors.

Rank	Factor 1 forward-citation factor	Factor 2 impact per unit time factor	Factor 3 patent family factor
1	GENENTECH Inc.	ETHICON ENDO SURGERY	GENENTECH Inc.
2	NIH US DEPT OF HEALTH AND HUMAN SERVICES US GOVERNMENT*	NUVASIVE Inc.	JANSSEN BIOTECH Inc.
3	NUVASIVE Inc.	ANTHROGENESIS Corp.	IMMUNOMEDICS Inc.
4	UNIVERSITY OF CALIFORNIA*	3M INNOVATIVE PROPERTIES Co.	ARENA PHARMACEUTICALS Inc.
5	NEKTAR THERAPEUTICS	DSM IP ASSETS BV	REGENERON PHARMACEUTICALS Inc.
6	UNIVERSITY OF TEXAS*	ALNYLAM PHARMACEUTICALS Inc.	ANTHROGENESIS Corp.
7	DSM IP ASSETS BV	KIMBERLY CLARK WORLDWIDE Inc.	DSM IP ASSETS BV
8	GENZYME Corp.	OHIO STATE UNIVERSITY*	HOFFMANN LA ROCHE Inc.
9	PURDUE PHARMACEUTICAL PRODUCTS LP	INTREXON Corp.	JAPAN TOBACCO Inc.
10	AMGEN Inc.	PURDUE PHARMACEUTICAL PRODUCTS LP	ORTHO MCNEIL PHARMACEUTICAL Inc.

Non-corporate research organizations are indicated by a "*".

National Institutes of Health (NIH) US Department of Health and Human Services (B in Fig. 1) both conducts its own scientific research and provides biomedical research funding to non-NIH research organizations. This institute ranked as one of the highest in the forward-citation factor, while its value for the patent family factor was low. It could be interpreted that NIH focused only on pure patenting activities, but did not put much effort into commercializing its patents related to transgenic animals.

Regeneron Pharmaceuticals (C in Fig. 1) had a low value for both the forward-citation factor and impact per unit time factor, but a high value for the patent family factor. We could interpret that its effort to commercialize its transgenic animal patents was higher than its corresponding technological performance.

Ethicon Endo Surgery (D in Fig. 1) scored low on the forward-citation factor, whereas it had the highest score on the impact per unit time factor. It implied that Ethicon Endo Surgery had high patenting activities per time in the transgenic animal subfield, although it was evaluated low in terms of total technological performance.

There were differences among the rankings of the research organizations per factor. This difference becomes obvious if major research organizations are distinguished from non-corporate research organizations (e.g., government research organizations and university research organizations). In our data, the applicants with more 20 patents related to transgenic animals consisted of 61 corporate research organizations (77.22%) and 18% non-corporate research organizations (22.78%). While non-corporate research organizations accounted for three of the top 10 research organizations for the citation-related index factor, they only accounted for one research organization with regard to the impact per unit time factor and patent family index factors. In addition, there were three universities that achieved high-ranking performance. The University of California Regents and the University of Texas at Austin attained high values for the forward-citation factor, and Ohio State University ranked high in the patent family factor.

The corporate research organizations showed distinctive results, which is in contrast with the non-corporate research organizations. These results inferred that corporations did better at the commercialization of patents, and put more effort into securing patents families, when compared to non-corporate research organizations. In other words, we could observe that many corporations had strong tendency to form family patents, bearing somewhat significant costs in an effort to protect their technology from other countries, while the non-corporate institutions showed relatively less interest in family patents and commercialization.

Among high-ranked research organizations, in terms of all factors, DSM IP Assets is an NPE that held a patent to earn, or plans to earn, its revenue from the legal enforcement or licensing of its patents. As NPEs want to acquire more rights of patent and purchase patents, which were highly cited, DSM IP Assets tends to have high values for all factors.

5. Conclusion

Although there are a number of studies related to the patent h-index and h-type variants, no efforts have been made to identify the underlying structure (latent structure) between patent h-type variants and traditional technology indicators. This study is the first attempt to propose new technology indices based on the underlying structure among the patent h-type variants and traditional technology indicators, by using EFA. These new technology indices were developed to evaluate the patent activities of research organizations. We applied the new indices to research organizations that have dealt with patents related to the transgenic animals.

Before uncovering the underlying structure, we observed that the patent h-index and patent h-type variants were correlated to each other, except for the patent m-quotient, which showed closer relations with CII than did the others.

As a result of the EFA of the 12 technology indicators (six h-types and six traditional ones), we found three reduced factors: forward-citation, impact per unit time, and patent family. The forward-citation factor is interpreted as the measurement of pure technological performance. The impact per unit time factor indicates the commercialization speed. The patent family factor is interpreted as the degree of effort put forth to commercialize patents. Distinctions were observed between corporate and non-corporate research organizations, with regard to the ranking of each factor. In the case of non-corporate research organizations, the value for the forward-citation factor was relatively high when compared to those of corporations, while the values for the impact per time and patent family factors were relatively low. With the application of patent h-type variants, in addition to the patent h-index, more analyses can be done and meaningful conclusions can be drawn.

There are advantages and disadvantages of using factors instead of individual indicators. An advantage of using the latter could be that they are more transparent and easier to understand than the factors. In addition, the selected factors cannot fully explain the characteristics of all individual indicators. However, the selected factors can convey the meaning more effectively than the indicators. That is, the factors can save us the trouble of using all individual indicators separately, while they still utilize all individual indicators.

There were studies that economic outcomes (e.g., patent-related income, patent licensing period, and litigation) were correlated with patent h-index (Chang et al., 2012; Zhang et al., 2012), and other patent h-type variants (Hu & Rousseau, 2015). To further develop the proposed indices as frequently used technology indicators, future research should prove that the economic outcomes are more correlated with the proposed indices than with the existing technology indicators, such as CII, CPP, and patent h-index. Since we intuitively interpreted and labeled the resulting factors of EFA, our interpretations should be corroborated in further studies. The limitations of this research lie in the fact that, instead of collecting data for all patents, only transgenic animal patents were taken into account, and various technology indicators, such as science linkage (SL), technology cycle time (TCT), and technology strength (TS), were not considered in depth. Further studies that account for these indicators are expected to provide advanced indices.

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Appendix A. A search query that formed a compilation of the pharmaceutical terms related to transgenic animals in this study

(((transgen* OR transform*) NEAR/10 (animal* OR non-human* OR nonhuman OR mammal* OR pig OR swine OR chick* OR avian* OR egg OR hen OR cock OR rooster OR cow OR bovine OR ungulate*)) AND (produc* OR generat* OR express* OR secret* OR mammary OR lactat* OR milk OR screen* OR evaluat* OR assay OR test* OR analys* OR ovumuco* OR saliva*)) OR ((transgen* OR transform* OR transcript* OR express* OR transfer*) AND (promot* OR enhanc* OR insluat* OR barrier OR silenc* OR mars OR (matrix NEAR/2 attch*) OR cis-act* OR regluat*) AND ((organ OR tissue OR cell) NEAR/2 (specif*)) NOT plant*) OR (((antibod* OR Immunoglobulin* OR miniantibod* OR scFv) NEAR/20 (therap* OR pharmaceut*)) AND (sleeping OR Trypanosoma OR gambia OR autoimmun* OR diabet* OR HCV OR helicobact* OR HIV OR influenza OR AIDS OR ((cancer* OR tumor*) NEAR/10 (liver OR hepat* OR stomach OR gastric OR lung OR pulmon* OR breast))) NOT marker NOT imag*)

Appendix B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.joi.2015.10.006.

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