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Assessment of Patent Legal Value by Regression and Back-Propagation Neural Network

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Abstract

This study aimed at the basis of patent law and proposed a revolutionary valuation model for the monetary legal value of patents. The damage award of a patent infringement lawsuit was deemed to be the legal value of a patent. 65 Effective samples of infringement lawsuits were extracted from 4,289 patent related lawsuits which were retrieved in the U.S. district courts of Delaware, California and Texas. 17 patent indicators were summarized to quantitatively describe dimensions of patents. The linear regression analysis was applied to discuss the linear relationship between each patent indicator and the damage award; finally 7 significant patent indicators were derived. The Back-Propagation Neural Network was then applied to construct the nonlinear valuation model of patent legal value, wherein the 7 significant patent indicators were the input variables and the damage award was the output variable. The proposed patent valuation model was validated to have the predictive power by error analysis. It accommodated to valuate the possible damage award or to negotiate the settlement fee for disputing patent infringement lawsuits.

Keywords: Assessment, Back Propagation Neural Network, Damage Award, Infringement, Linear Regression, Patent Valuation.

1. Introduction

1.1 Background of the Study

As technologies develop rapidly and the era of knowledge economics arises, intangible assets show their higher significance than before. The patent stands for a leading role among various species of intangible assets. The patent contributes to enterprises by revenue, stock performance, reputation, research and development, so as to be an important factor for evaluating enterprises and nations in aspects of operation, management and innovation.

However, when considering the patent value, especially the monetary value, it is hard to valuate the patent because the patent is not only a kind of intangible assets, but also a kind of rights. When thinking about the asset, the financial experts usually concentrate their attention on patent's financial contribution. This contribution, like stock performance or market success, is not directly generated by patents. It is only partly influenced by patents. When thinking about the right, the legal researchers always focus on the scope of patent right and related legal behaviors.

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There exists an important phenomenon recently that patent infringement lawsuits grow distinctly around the world. Damage award, licensing fee, and royalty become conspicuous parts of income, and even turn into the majority of revenue in some new start-up companies. No matter in negotiations of patent licensing, patent transactions, hypothecation of intangible assets, or shareholding by patent-based technologies, monetary value of the patent is always a critical issue. Meanwhile, a reasonable and reliable patent valuation model is always discussed seriously for making patents become monetary assets. The issue of monetary valuation of patents is concerned by people including employees, chiefs, investors, researchers, and professionals among fields of technology management, financial operation, legal strategy, and business administration.

The existing patent valuation models in practice might be briefly summarized to three approaches (Reilly and Schweihs, 1998), such as the cost-based approach, the market-based approach, and the revenue-based approach. These approaches basically originated from financial methods and modifications of them.

The basic idea, on which the cost-based approach is based, is the idea of replacement. This means the value of a patent is identified as the amount that would be necessary to replace the protection right or the related economic benefit potential. The logic behind this approach is that a prospective buyer acting in a logical way would not be willing to pay more for a patent than the amount he would have to pay to obtain an equivalent protection right. The costs compared could be, for example, historical costs, costs of replacement or costs of reproduction, depending on the valuation method used. One advantage of the cost approach is that the evaluator of patents has little influence on the valuation result.

The market-based approach is based on a comparison with a corresponding transaction between independent third parties. That is, the value of a patent is defined through comparison to a similar patent, the market price of which is known through an earlier purchase or sale. In this market, there has to be a sufficient number of comparative transactions in the recent past, for which the obtained retail price is known. If this information exists, the market approach is easy to apply and leads to a valuation result that is acceptable and easy to comprehend. But the prerequisite of an active market is hardly met for patents. Furthermore, the published licensing rates are not sufficient for an adequate comparison.

The basis of the revenue-based approach is the comparison of the future economic benefit of a patent with the future benefit of an alternative investment. So far, the income approach implements the definition of value most directly. With the application of the income approach, the sum of advantages, i.e. the additional returns or saved costs less accruing costs, that will arise from the patent will be ascertained. These economic benefits are compared to the best alternative investment, which shows the same future payment flows and the same investment risk. With respect to the valuation, the comparison is made by determining the future economic benefit of the protection right and then discounting it with a risk-adapted interest rate to its actual cash value. To put it another way, the income approach answers the question: what sum would have to be invested in another way to achieve identical payment flows with the same risk? The valuation results would be somehow risky since the data employed are only prediction-based values and cannot be determined with certainty.

Unfortunately, the aforementioned financial approaches for patent valuation usually disregard the subject matter of the patent and species of enforcement defined and restricted by patent law. These existing patent valuation approaches are more likely named as the

"Technology" valuation approaches. It has to be emphasized that a vital difference exists in the scope of right between a technology and a patent. The vital difference will result in different valuation outcome. The right of a technology is knowledge-based power to make, use, or sell; whereas the right of a patent is the power to exclude others from making, using, selling or importing.

Regarding the topics involved the patent law with the patent value, Lanjouw and Schankerman (1997) discussed patent owner's behaviors in patent litigation events. Lanjouw, Pakes and Putnam (1998) used the cost of patent prosecution as the indicator to evaluate patents. Lanjouw (1998) discussed the behaviors in patent prosecution for evaluating patents. Lanjouw and Schankerman (2001) discussed the behaviors in patent infringement lawsuits for evaluating patents. Reitzig, Henkel and Heath (2007) proposed that the patent infringement lawsuit affected the firm's strategies.

According to U.S. patent law 35U.S.C.154 "*Every patent shall contain a short title of the invention and a grant to the patentee, his heirs or assigns, of the right to exclude others from making, using, offering for sale, or selling the invention throughout the United States or importing the invention into the United States, and, if the invention is a process, of the right to exclude others from using, offering for sale or selling throughout the United States, or importing into the United States, products made by that process, referring to the specification for the particulars thereof.*", the right of a patent for the patentee is definitely designated for excluding others from five species of unauthorized behaviors: making, using, offering for sale, selling and importing. Based on the concept of patent law, any patent which can not be enforced the right to exclude others from aforementioned five behaviors would be regarded as legally valueless. The existing patent valuation models in practice usually take this important legal issue aside.

As described above, it's therefore a principal objective of this study to rediscover the patent value in view of patent law by investigating patent infringement lawsuits because the documents of patent infringement lawsuits indicate patents and their momentous, direct and monetary patent values, i.e. damage awards.

It's another objective of this study to construct a monetary valuation model of patents by discussing the mathematical relationship between damage awards and patents.

1.2 Literature Review

Regarding the topic of patent valuation and patent indicators, Cockburn and Griliches (1988) first discussed the relationship between stock performance and patents. Albert, Avery, Narin and McAllister (1991) applied the citation count as the indicator to evaluate patents. Tong and Frame (1994) used the patent claim as the indicator to evaluate national technology outcome. Hirschey and Richardson (2001) suggested that scientific measures of the quality of inventive output were useful indicators to investors. In this literature, the scientific measures of the quality meant the prior arts of non-patent references of patents. Hereof, Schererc and Vopel (2003) suggested that the number of prior arts and citations received were related positively to the patent value; non-patent references were informative about the value of pharmaceutical and chemical patents, but not in other technical fields; patents, which were upheld in opposition and annulment procedures, and patents representing large worldwide patent families were particularly valuable. In this literature, backward citations, forward citations, non-patent references, and worldwide patent families were concluded to be positive to the values of the patent. "Hirschey and Richardson (2004) found a favorable stock-price influence when both the number of patents, the scientific merit of these patents, and the R&D spending were high, where patent citation information could indeed help investors judge the future profit-earning potential of a firm's scientific discoveries". In this literature, backward citations, forward citation, and non-patent references were concluded to be positive to the stock-price. Reitzig (2004) inspected almost all the possible detailed patent indicators with the market value of the patent owner. He concluded that actions of the prosecution were positive to the market value of the patent owner. But legal values of patents in this literature were not considered. Hall, Jaffe and Trajtenberg (2005) used the patent citation count as the indicator and discussed its contribution to market value. Von Wartburg, Teichert and Rost (2005) proposed a methodological reflection and application of multi-stage patent citation analysis for the measurement of inventive progress. In this literature, backward citations and forward citations were concluded to be positive to R&D activities. Choy, Kim and Park (2007) employed patent analysis in cross-impact analysis of syntheses and interactions between various technologies and expected to help practitioners to forecast future trends and to develop better R&D strategies. In this literature, influences of patents were thoroughly analyzed, but legal values of patents were ignored. Hereof and Hoisl (2007) described the characteristics of the German Employees' Inventions Act and discussed which incentives it created with a survey of 3,350 German inventors to test the hypotheses regarding this institution. The study concluded that the law created substantial monetary rewards for productive inventors. In this literature, the patent law was watched and the law-related value of patents was discussed. Silverberg and Verspagenb (2007) focused on the analysis of size distributions of innovations by using patent citations as one indicator of innovation significance. In this literature, backward citations, forward citations, and non-patent references were concluded to be positive to innovations but legal values of patents were not discussed. Van Trieste and Vis (2007) focused on evaluating a patent on the basis of cost-reducing process improvements from the viewpoint of the patent-holding firm by considering the relevant cash flows that resulted from owning the patent, wherein the patent value was determined by licensing fees, royalty income, and the competitive advantage resulting from the patent and patent maintenance costs. In this literature, the law-related value of patents was first discussed, but no relationship was found between this law-related value and patent indicators. Chiu and Chen (2007) proposed an objective scoring system for patents from the licensor side using the Analytic Hierarchy Process to value patents for new products being developed by an actual enterprise. This scoring system was quite interesting; unfortunately, no monetary value was modeled.

The aforementioned literatures discussed lots of patent indicators and their contributions such as market success and stock performance. However, such contributions are not directly generated by patents, but are influenced by patents. Besides, the aforementioned literatures somehow missed an important issue, that is, the patent is a right which given by law. It's more rational to discuss the patent value in view of patent law.

Regarding the topics involved the patent law, Lanjouw and Schankerman (1997) discussed patent owner's behaviors in patent litigation events. Lanjouw, Pakes and Putnam (1998) used the cost of patent prosecution as the indicator to evaluate patents. Lanjouw (1998) discussed the behaviors in patent prosecution for evaluating patents. Lanjouw and Schankerman (2001) discussed the behaviors in patent infringement lawsuits for evaluating patents. Reitzig, Henkel and Heath (2007) proposed that the patent infringement lawsuit affected the firm's strategies.

Though these literatures discussed patents and indicators in view of patent law, there was no corresponding valuation model built yet.

Referring to the issue of a patent's monetary value, Deng, Lev and Narin (1999), Thomas (2001) tried to use multi-regression to model patent indicators and the stock performance. Unfortunately, the R^2 value was too low to explain few. Park and Park (2004) proposed a valuation method that generated monetary value, rather than a score or index, based on the structural relationship between technology factors and market factors. This method of generating the patent's monetary value was more useful in practice than the other indicator-based valuation models. Unfortunately, this method was not in view of patent law.

However, the mathematical relationship between the patent legal value and the aforementioned patent indicators has not been developed yet. A wide gap still exists between the patent and economics while considering the value of patents. In this study, a monetary valuation model for patent legal values is proposed to shorten the gap and link the patent and economics more directly.

2. Methodology

2.1 Population and Sample

This study focused on the patent infringement lawsuits in the U.S. district courts of Delaware, California and Texas. Those lawsuits having final judge determinations with definite patent numbers and damage awards are regarded as effective samples.

2.2 Instrumentation

To describe the possible quantitative dimensions of a patent, 17 indicators are summarized in this study by reviewing previous literatures and authors' own empirical experience in patent engineering, such as patent prosecution, patent search, and infringement analysis.

Samples of lawsuits distribute in different years. The damage award of each lawsuit must be converted to a standard foothold to eliminate the currency revaluation and inflation for consistency of analysis. In this study, the annual interest announced by Federal Reserve System (FED) at the end of each fiscal year is used to convert each damage award to the corresponding value in 2006 by compound interest via engineering economic approach.

By Kolmogorov-Smirnov test, the values of damage awards of all lawsuits are converted by natural logarithm in order to have an approximate normal distribution.

Z-score transformation and Regression analyses are applied for discussing the relationship between each of 17 patent indicators and the damage award, so as to find out significant patent indicators.

Back Propagation Neural Network is applied for modeling the nonlinear relationship between significant patent indicators and damage awards, so as to construct the monetary valuation model.

The Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems. Learning in biological nervous systems involves adjustments to the synaptic connections that exist between the neurons. The key element of the ANN is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements (neurons) working in unison to solve specific problems. The ANN, like human, learns by examples, and is usually configured for some specific applications, such as pattern recognition or data classification. An important issue in ANN design is determining the number of hidden neurons best used in the network. If the hidden number of neurons is increased too much, overtraining will result in the network being unable to "generalize". The training set of data will be memorized, making the network effectively useless on new data sets. The Back Propagation Neural network (BPN) is one of the most popular known neural networks learning technique, which looks for the minimum of an error function in weight space using the method of gradient descent. The combination of weights which minimizes the error function is considered to be a solution of the learning problem.

The reason of utilizing the neural network in this study to model the nonlinear relationship between patent indicators and the damage award is that, the damage award in any patent infringement lawsuit was first proposed by both parties of plaintiff and defendant, then discussed, argued, adjusted, and finally determined by the judge or the jury of court. The process for finalizing the damage award is quite humanly and nonlinear, so that the damage award resulted from its corresponding patents is suitably modeled by the neural network.

The input variables for the BPN in this study are the significant patent indicators of each lawsuit, and the output variable is the damage award of each lawsuit. For constructing the BPN, basically at least two sets of samples are necessary, i.e. a training set and a testing set, for iteratively tuning the BPN by training and testing. Preferably, for validating the constructed BPN to check its predictive power, another validating set is suggested to be introduced into the constructed BPN. Various parameters could be tuned in constructing the BPN. In this study, the convergence of Root-Mean-Squared-Error (RMSE) is observed when training, testing and validating the BPN, and therefore regarded as the performance index of the BPN.

2.3 Delimitation and Limitation

(1) There are several categories of U.S. patents, such as utility, design, plant, defensive publication, statutory invention registration, and additional improvement, etc. The compositions of all these categories differ from each other. This study discusses the utility patent only because the utility patent plays the major part of all U.S. patent categories. The infringement lawsuits of utility patents are much more than the others.

(2) There are sometimes more than one patents included in a patent portfolio which is enforced in a patent infringement lawsuit to win a lump sum of the damage award. Only damage award of the portfolio is discussed. This study doesn't probe into any specific value of the any specific patent in a portfolio.

(3) Only patent infringement lawsuits with final judgment of determination are analyzed. Actually, settlements always exist to terminate patent infringement lawsuits because the defendant might want to reduce possible damage award of the plaintiff. In settled lawsuits, no damage awards will be found, such lawsuits are excluded from effective samples.

(4) Only patent infringement lawsuits those involved patents possessed all 17 quantitative patent indicators are analyzed. If a patent infringement lawsuit is too old so that the involved patents do not to possess all 17 quantitative patent indicators, such lawsuits are excluded from effective samples. Besides, qualitative features of patents are not considered in this study.

(5) Patent infringement lawsuits are retrieved in district courts of Delaware and California and Texas. These courts have the accelerated timetable strictly adhered to deadlines, resulting in speedy disposition (McKelvie, 2007). The patent law in the U.S. is a federal law, actions for

patent infringement filed in federal district courts. Either plaintiff or defendant can appeal to U.S. Court of Appeals for the Federal Circuit (CAFC) if either party does not agree with the determination of district court. Studying over a long time, it is found that the suit materials including patent damage award are usually disclosed, discussed, and determined in district courts, while only legal topics and questions of law are argued in CAFC. Hence, the patent infringement lawsuits are retrieved through district courts in this study. U.S. patent infringement lawsuits are filed in quantity in every district court, for example, there is up to 2,865 patent lawsuits from 1944 to 2006 in district court of Delaware. Each lawsuit possesses more than 5,000 documents of miscellaneous issues involved. In order to set up an effective way of modeling, this study only directs to three district courts those are famous in huge quantity and fast judgment of patent infringement lawsuits, i.e. district court of Delaware, district court of California, and district court of Texas.

(6) Patent infringement lawsuits are retrieved in the period of 1944 to 2006 in both district courts of Delaware and California. But because district court of Texas is famous in showing favor to plaintiffs, lots of lawsuits get settlements, only few lawsuits with final judgment of determination are found. Hence, patent infringement lawsuits of district court of Texas are retrieved from 1994 to 2006.

(7) The database for retrieving patent infringement lawsuits is the LexisNexis. The LexisNexis database originated in 1966 and was developed into the first full text retrieval system of legislation in the world by the American Air Forces. It is one of the greatest law resources in the world comprising legal documents, industry information, financial materials, and public news of all levels of U.S. courts, newspapers, magazines, and commercial periodicals.

3. Analysis and Result

3.1 Effective Samples of Patent Infringement Lawsuits

By using the searching keyword "patent" in the LexisNexis database, 4,289 patent related lawsuits are searched from district courts of Delaware, California and Texas. However, not all of these lawsuits are infringement involved, further searching is needed. Thereby, the searching keyword selected from the group consisting of "damage" and "$" is then applied to retrieve documents. The retrieved documents are carefully reviewed and checked by professional manpower. Finally, 65 effective samples (lawsuits) including 163 patents are derived, as shown in Table 1. There are 37 samples including 103 patents are in district court of Delaware; 24 samples including 52 patents are in district court of California; and 4 samples including 8 patents are in district court of Texas. In each of these effective samples, the damage award is clearly indicated, and the patent(s) involved has all 17 patent indicators. If a patent infringement lawsuit is too old or short of some patent indicators, the infringement lawsuit was discarded.

Table 1. Samples retrieved and extracted

Lawsuit resource		District Court of Delaware	District Court of California	District Court of Texas	Sum
Lawsuits retrieved		2,865	1,314	110	4,289
Lawsuits extracted	Lawsuits	37	24	4	65
	Patents	103	52	8	163

In the 65 effective samples, the portfolio size in a lawsuit varies from one patent to 17 patents; the damage award varies from USD 470,084 to USD 2,600,000,000. Table 2 shows the counts of infringement lawsuits from 1989 to 2006. Obviously, infringement lawsuits after 2000 are much more than those before 2000. Since lawsuits with final determinations are only a small part of all infringement lawsuits. The information in Table 2 reveals that patent infringement lawsuit gradually becomes a kind of business in 21 century.

Table 2. Patent infringement lawsuits in each year

Year	Lawsuits	Year	Lawsuits
2006	12	1997	2
2005	7	1996	0
2004	11	1995	1
2003	5	1994	0
2002	6	1993	0
2001	4	1992	1
2000	3	1991	2
1999	3	1990	0
1998	6	1989	2

3.2 Patent Indicators

Based on the view point of patent law, throughout the opinion of court in patent infringement lawsuits in the U.S., a product or a method infringes a patent claim if that product satisfies each of the claim requirements, hence what is claimed is recognized as the invisible boundary of a patent right. Usually, the fewer the number of claims in a patent the wider the protected scope and vice versa. An independent claim usually comprises fewer elements, while a dependent claim certainly comprises more elements than the claim being dependent upon. Independent claims are more important than dependent claims, it's therefore not only the number of claims, but also the number of independent claims is considered in this study. International patent Classification (IPC) and U.S. Patent Classification (USPC) are systems for organizing patents. A patent is designated its IPC and USPC by examiners in patent office. The number of IPC and USPC are considered in this study. In addition, according to the U.S. patent rule §1.75 (d) (1) "The claim or claims must conform to the invention as set forth in the remainder of the specification and the terms and phrases used in the claims must find clear support or antecedent basis in the description so that the meaning of the terms in the claims may be ascertainable by reference to the description." The claimed elements and characteristics thereof must be supported by descriptions and drawings, so the number of drawings is also considered. By reviewing previous studies and authors' empirical information and experiences of patent prosecution, patent search, and infringement analysis, 17 patent indicators are selected as shown in Table 3 and defined below.

- X_1: "Assignees", is the count of assignees of each patent.
- X_2: "Inventors", is the count of inventors of each patent.
- X_3: "Total claims", is the count of total claims of each patent.
- X_4: "Independent claims", is the count of independent claims of each patent. Total claims comprise independent claims and dependent claims. X_4 is a part, but the most important part of X_3.
- X_5: "US patent references", is the count of US patent documents listed in the field of "References Cited", i.e. prior arts recognized by the examiner, of each patent. Some literatures called "US patent references" as the "backward citations".
- X_6: "Foreign patent references", is the count of foreign patent documents in the field of "References Cited" of each patent.
- X_7: "Non-patent references", is the count of other publications (non-patent literatures, including papers, handbooks and magazines, etc.) in the field of "References Cited" of each patent. Some literatures called "Non-patent references" as the "science linkage".

- X_8: "Forward citations", is the count of citations by the other patents in the beginning of lawsuit of each patent.
- X_9: "International Patent Classifications (IPC)", is the count of IPCs recognized by the examiner of each patent.

Table 3. Patent indicators defined

Evaluation indicator		Mainly discussed by
X_1	Assignees	Reitzig (2004)
X_2	Inventors	Reitzig (2004)
X_3	Total claims	Reitzig (2004)
X_4	Independent claims	Reitzig (2004)
X_5	US patent references	Hereof, Schererc and Vopel (2003) Hall, Jaffe and Trajtenberg (2005) Von Wartburg, Teichert and Rost (2005) Silverberg and Verspagenb (2007)
X_6	Foreign patent references	Hereof, Schererc and Vopel (2003) Hall, Jaffe and Trajtenberg (2005) Von Wartburg, Teichert and Rost (2005)
X_7	Non-patent references	Hereof, Schererc and Vopel (2003) Hirschey and Richardson (2004) Hall, Jaffe and Trajtenberg (2005) Von Wartburg, Teichert and Rost (2005) Deng, Lev and Narin (1999)
X_8	Forward citations	Hall, Jaffe and Trajtenberg (2005) Von Wartburg, Teichert and Rost (2005)
X_9	International Patent Classifications (IPC)	*
X_{10}	US Patent Classifications	*
X_{11}	Worldwide patent family	Hereof, Schererc and Vopel (2003) Reitzig (2004)
X_{12}	US patent family	Hereof, Schererc and Vopel (2003)
X_{13}	Office actions	Hereof, Schererc and Vopel (2003) Reitzig (2004)
X_{14}	Responses	Reitzig (2004)
X15	Examination	*
X16	Drawing	*
X17	Life-span	*

* proposed by this study

- X_{10}: "US Patent Classifications", is the count of USPCs recognized by the examiner of each patent.
- X_{11}: "Worldwide patent families", "is the count of worldwide related patents those claimed at least one same priority of each patent". This count is investigated based on INPADOC database.
- X_{12}: "US patent families", is the count of US related patents "those claimed at least one same priority of each patent". This count is investigated based on INPADOC database.
- X_{13}: "Office actions", is the count of office opinions by the examiner of USPTO of each patent. The office opinions include the selection by restriction, non-final rejection, final rejection, and notice of allowance, etc.
- X_{14}: "Responses", is the count of responses to USPTO by the assignee of each patent. The responses include amendments, response to non-final rejection, response to final rejection, request for continued examination, and appear, etc.
- X_{15}: "Examination", is the time span from filing date to issue date of each patent.
- X_{16}: "Drawings", is the count of drawings of each patent.
- X_{17}: "Life-span", is the time span from filing date to the beginning of lawsuit of each patent.

3.3 Regression analysis

In regression analysis, if the coefficient of determination R^2 value approximates to 1, then the error of the regression model is small and the linear relationship for each indicator corresponding to the damage award is easily explained.

Before the regression analysis, the descriptive statistics of the means and the standard deviations of all these variables which comprising 17 patent indicators and damage award, is performed as shown in Table 4.

Because these variables X_1 to X_{17} do not have the same unit for counting, the means and the standard deviations of all these variables differ significantly. In Table 4, X_3 (Total claims), X_5 (US patent references), X_7 (Non-patent references), X_8 (Forward citations), X_{11} (Worldwide patent families), and X_{12} (US patent families) have higher means and standard deviations than the others. The high variances of all these variables X_1 to X_{17} will ruin any regression model. In order to improve the consistency of analysis, the normalization of all the 17 independent variables (X_1 to X_{17}) is necessary. It is therefore to transform the 17 independent variables into the Z-scores before the regression analysis.

Table 4. Descriptive statistics of patent indicators and damage award

Patent indicator	Nomenclature	Mean	Standard deviation
X_1	Assignees	2.4000	1.7302
X_2	Inventors	5.2615	4.6579
X_3	Total claims	61.9231	66.8104
X_4	Independent claims	12.4923	14.4462
X_5	US patent references	51.8769	70.0280
X_6	Foreign patent references	6.2615	9.6926
X_7	Non-patent references	31.5077	84.8908
X_8	Forward citations	41.7385	66.6364
X_9	IPC	3.4000	2.8218
X_{10}	USPC	9.3538	7.9440
X_{11}	Worldwide patent families	103.2154	202.7878
X_{12}	US patent families	36.4154	79.6653
X_{13}	Office actions	7.5385	6.7061
X_{14}	Responses	5.4000	5.6397
X_{15}	Examination	5.8531	4.5862
X_{16}	Drawings	15.9077	18.2000
X_{17}	Life-span	21.5538	20.4122
Damage award		16.0695	1.8963

According to the basic idea of the regression analysis, it is suggested to have at least 25 samples for one independent variable. For the cases of 17 independent variables, 425 samples are needed preferably. Since there are only 65 effective samples in this study, the regression analysis will fail. It's therefore to have 17 simple linear regression analyses performed in this study, wherein each normalized patent indicator is the independent variable and the damage award is the dependent variable. Via the tool of SPSS V8.0, the linear coefficient, R^2 and significance for each normalized patent indicator are shown in Table 5.

Table 5. Regression analysis of the 17 normalized independent variables

Normalized patent indicator		Linear coefficient	R^2	Significance
X_1	Assignees	0.154	0.007	0.521
X_2	Inventors	0.314	0.027	0.188
X_3	Total claims	0.205	0.012	0.392
X_4	Independent claims	0.460	0.059	0.052
X_5	US patent references	0.197	0.011	0.411
X_6	Foreign patent references	0.204	0.012	0.393
X_7	Non-patent references	0.599	0.100	0.010*
X_8	Forward citations	0.682	0.129	0.003**
X_9	IPC	0.113	0.004	0.636
X_{10}	USPC	0.094	0.002	0.696
X_{11}	Worldwide patent families	-0.094	0.002	0.696
X_{12}	US patent families	-0.116	0.004	0.629
X_{13}	Office actions	0.202	0.011	0.399
X_{14}	Responses	0.230	0.015	0.336
X_{15}	Examination	0.353	0.035	0.138
X_{16}	Drawings	0.360	0.036	0.130
X_{17}	Life-span	0.342	0.033	0.150

* Significant at 10% level, ** Significant at 5% level

Either the R^2 or the adjusted R^2 in these regression analyses are too low to have enough explanatory ability. However, it's still interesting to have some inferences.

There are two negative patent indicators which negatively affect the damage award and the other 15 positive patent indicators which positively contribute to the damage ward. The two negative ones are X_{11} (Worldwide patent families) -0.094 and X_{12} (US patent families) -0.116. In previous literature, Hereof, Schererc & Vopel (2003) concluded that worldwide patent families were positive to patent values. But in the present analyses, X_{11} (Worldwide patent families) and X_{12} (US patent families) both get the relative values to negatively affect the damage award. It tells that the increase of the worldwide patent family size won't get the corresponding increase of the damage award. Because worldwide patent families cost lots of money, the present analyses suggested that carefully consideration should be taken while planning the patent portfolio strategy.

Besides, Hirschey & Richardson (2001), Hereof, Schererc & Vopel (2003), Hirschey & Richardson (2004), Von Wartburg, Teichert & Rost (2005), and Silverberg & Verspagenb (2007) proposed that citations include backward, forward citations, or non-patent references contribute to the value of patents. In Table 5, X_5 (US patent references), X_6 (Foreign patent references), X_7 (Non-patent references) and X_8 (Forward citations) all have positive values to indicate positive contribution to damage awards. The result echo the observations of previous literatures. In particular, X_7 (Non-patent references) and X_8 (Forward citations) get the highest two positive values among all patent indicators.

In the present regression analyses, X_2 (Inventors) 0.314, X_4 (Independent claims) 0.460, X_{15} (Examination) 0.353, X_{14} (Responses) 0.230, X_{16} (Drawings) 0.360 and X_{17} (Life-span) 0.342 get higher positive values than X_5 (US patent references) 0.197 and X_6 (Foreign patent references) 0.204. It means that these patent indicators contribute more to damage award than X_5 (US patent references) and X_6 (Foreign patent references) do. Hence, this study provides a new vision for reconsidering the influences of patent indicators.

3.4 Back-Propagation Neural Network

Though there are 17 patent indicators proposed in this study, base on the results of aforementioned 17 simple linear regression analyses, the patent indicators with linear coefficients below 0.3 are discarded. Therefore, only the following 7 significant patent indicators were used as the input variables for the proposed BPN study. They are X_2 (Inventors), X_4 (Independent claims), X_7 (Non-patent references), X_8 (Forward citations), X_{15} (Examination), X_{16} (Drawings) and X_{17} (Life-span), while the output variable is the damage award. Meanwhile, the input variables are normalized to z-scores to be within the interval of 2 times the standard deviation for eliminating the affection of some abnormal values; while the output variable is scaled to 0.2 to 0.8.

"Since there are 65 effective samples as shown in Table 1, wherein the 53 samples from 1989 to 2005 are chosen to be the training set and the testing set for constructing the BPN, and the 12 samples in 2006 are chosen as the validating set to validate the prediction effectiveness of the BPN. Moreover, 35 samples are randomly selected from the 53 samples to be the training set and the other 18 samples left are the testing set".

Figure 1 shows the convergence plot of RMSE versus learning cycle, wherein the vertical axis represents the scaled RMSE, the horizontal axis represents the learning cycle, the upper line represents RMSE of the training set which converging to 0.101 (10.1%), and the lower line represents RMSE of the testing set which also converging to 0.101 (10.1%). Both the RMSE values of the training set and the testing set converge after 600 learning cycles, so the learning process of the BPN is successful. Though RMSE 0.101 (10.1%) is not perfect, it's still acceptably reasonable.

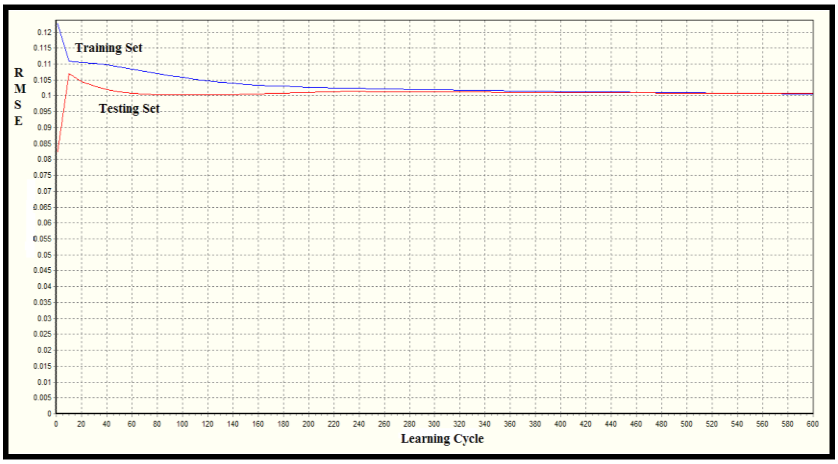

Figure 1. RMSE convergence v.s. learning cycle

In the above-constructed BPN, some optimal parameters used are shown below:

- Neurons in the first hidden layers: 6
- Neurons in the second hidden layers: 2
- Sampling approach for the training set and testing set: random
- Margin for weightings for interconnections: -0.5 to 0.5
- Learning type: batched learning
- Initial value of the learning speed: 1.0

- Decreasing rate of the learning speed: 0.99
- Initial value of the inertia: 0.5
- Decreasing rate of the inertia: 0.99

For validating the evaluation model, the validating set composed of 12 samples in 2006 is then introduced into the constructed BPN to see its RMSE value and check the predictive power of the constructed BPN. Table 6 shows the comparison of RMSE values of the training set, the testing set and the validating set.

After validation, RMSE 0.098 (9.8%) of the validating set is derived. RMSE 0.0.98 (9.8%) of the validating set is superior to RMSE 0.101 (10.1%) of the training set and the testing set, hence the validation is successful. The successful validation means that the valuation model of the BPN constructed by samples from 1989 to 2005 can predict for samples in 2006. The nonlinear relationship between the damage award and the selected 7 patent indicators can be modeled by the BPN with an acceptable error. It proves that the proposed BPN is effective and the valuation model is feasible. Once the significant 7 patent indicators X_2 (Inventors), X_4 (Independent claims), X_7 (Non-patent references), X_8 (Forward citations), X_{15} (Examination), X_{16} (Drawings) and X_{17} (Life-span) of a patent or a patent portfolio are inputted into the BPN valuation model, a possible damage award with an estimated error is outputted.

Table 6. The comparison of RMSE values of BPNt

	Number of samples	RMSE
The training set	35	0.101
The testing set	18	0.101
The validating set	12	0.098

4. Discussion

This study does not claim an unbeatable method to solve the damage award neither in all kinds of patent infringement lawsuits nor in all U.S. district courts. Consequently, this study won't claim the valuation model to solve patent values of non-US patents, such as Chinese patents, European patents and Japanese patents. However, this study tries to combine the knowledge of patent, finance, computation and management, and to provide a brand new concept for analyzing the patent infringement lawsuits so as to propose a monetary valuation model of patent legal value. This study would like to show that the patent infringement lawsuits are not only good for case study but also good for quantitative analysis.

In this study, 17 patent indicators are proposed for quantitatively describing patents. The linear relationship between the damage award and these proposed 17 patent indicators is discussed by regression analysis. It shows that the damage award is not linearly proportional to any one of the 17 patent indicators. The relationship between the damage award and the patent indicators is too complicated to have a linear equation for modeling.

Usually, it is observed that valuable patents accompany large size of patent family. However, via the present regression analyses, it's found that X_{11} (Worldwide patent families) and X_{12} (US patent families) negatively affect the damage award. These findings may provide a new thinking of the patent portfolio strategy.

Furthermore, lots of previous literatures proposed that citations which including backward and forward citations, or non-patent references contribute the revenue, stock performance, or investor's confidence, but in this study, only X_7 (Non-patent references) and X_8 (Forward citations) contribute superiorly the damage award than other patent indicators. The patent indicators such as X_2 (Inventors), X_4 (Independent claims), X_{15} (Examination), X_{14} (Responses), X_{16} (Drawings) and X_{17} (Life-span) contribute more the damage award than X_5 (US patent references) and X_6 (Foreign patent references). These patent indicators might need more and further investigation.

The nonlinear relationship between the damage award and the 7 significant patent indicators is modeled by the BPN. The valuation model of the BPN is constructed via samples from 1989 to 2005 by training and testing, and then is validated by samples in 2006. By RMSE analysis between these samples, the proposed BPN patent valuation model shows its predictive power and is proved to be feasible.

To be best of authors' knowledge, this study proposed the first successful patent valuation prediction model using BPN and statically regressions. The process involve retrieving samples from patent infringement lawsuits, studying judgments of determination, finding out the patent numbers and damage awards, setting up 17 patent indicators for quantitative patents descriptions, finding significant patent indicators by linear regression analyses, constructing the BPN for modeling significant patent indicators and damage awards, and finally validating the predictive power of the proposed valuation model.

Figure 2 shows the architecture of the patent valuation model. For the application in practice, please see the bold lines in Figure 2, once the 17 patent indicators of a patent or a patent portfolio being in evaluation is described to be inputted in the valuation model as the input variables of the BPN, consequently an output variable is generated to be the possible value of damage award. Referring to the dotted lines in Figure 2, the BPN would be certainly improved by feeding more samples of patent infringement lawsuits from the district courts other than Delaware, California and Texas, so as to refine the patent valuation model. More particularly, because the timing issue is already considered in the patent indicators and the converted damage awards, as years go by and recent samples are fed, the valuation model learns to adjust itself dynamically. A single patent or a patent portfolio via this model can be valuated to distinct prices at different time of valuation. It's a live and growing valuation model for providing the monetary legal values of patents.

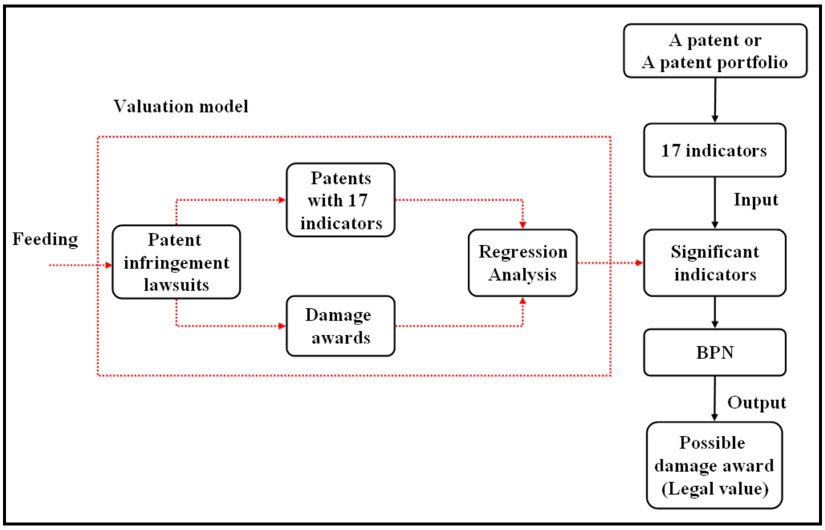

Figure 2. The architecture of the proposed BPN patent valuation model

This proposed valuation model is quite useful in practice. For the patent infringement lawsuit, either the plaintiff or the defendant may use the proposed valuation model to forecast the possible final damage award earned or lost, so as to configure the lawsuit strategy. For technology management purpose, the R&D intensive company may use the proposed model for evaluating the patent assets to distinguish the high value patents from the low value ones. The high value patents should be kept firmly for seeking the chance of lawsuits and "stick license". The low value patents might be used for auction, donation or even abandonment. The proposed model also accommodates to applications of patent transaction deal, patent licensing, hypothecation of intangible assets, and shareholding by patent-based technologies, etc.

5. Recommendation

It is suggested that below topics might be suitable for further studies:

(1) Variance analysis: It speculates that the proposed evaluation model may accommodate to various U.S. district courts, various industries, various technologies, and even various countries. Hence, retrieval of more effective samples and variance analysis are necessary for appropriate adjusting raw patent indicators and optimal parameter settings of the BPN.

(2) Optimal design for patent compositions for maximizing the damage award: It would be possible by setting the damage as the object function while all indicators or indicators as independent variables, so as to get an optimal solution for patent compositions. This would be great helpful to managing R&D, innovation activities, and patent attorneys.

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