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The relationship between a firm's patent quality and its market value — The case of US pharmaceutical industry

Yu-Shan Chen *, Ke-Chiun Chang

Department of Business Administration, National Yunlin University of Science and Technology, 123, Section 3, University Road, Douliu, Yunlin 640, Taiwan

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ABSTRACT

This study examined the relationships between corporate market value and four patent quality indicators – relative patent position (RPP), revealed technology advantage (RTA), Herfindahl–Hirschman Index of patents (HHI of patents), and patent citations – in the US pharmaceutical industry. The results showed that RPP and patent citations were positively associated with corporate market value, but HHI of patents was negatively associated with it, while RTA was not significantly related to it. Thus, if pharmaceutical companies want to enhance their market value, they should increase their leading positions in their most important technological fields, cultivate more diversity of technological capabilities, and raise innovative value of their patents. In addition, this study found that market value of pharmaceutical companies with high patent counts was higher than that of pharmaceutical companies with low patent counts, and suggested that pharmaceutical companies with low patent counts should increase RPP in their most technological fields, decrease HHI of patents, or raise patent citations to further enhance their market value. Furthermore, this study developed a classification for the pharmaceutical companies to divide them into four types, and provided some suggestions to them.

1. Introduction

In the era of knowledge economy, competitive advantages of firms are less based on the allocation of physical assets, and more on intangible assets, such as patents. Although patents are intangible and their value cannot be accurately measured, companies must develop and increase their corporate value by proactively focusing on patents. The disparity between the book value of publicly traded companies and their market value has increased steadily in recent years [1]. Breitzman and Thomas thought that the substantial value of intangible assets is not accounted for on the financial statements of most companies [2]. Thus, the information provided in annual reports about innovative activities is inadequate and increasing the requirements of annual reports would enhance investors' understanding of the financial statements [3]. Estimating the corporate value based on the patent quality may therefore provide insights into the value of companies' intangible assets. There are some literatures that examine various aspects of the influence of patent performance upon the market value of firms, but there is no literature which explores this influence from four aspects of patent quality — leading position, technological capability, concentration of firms' patents, and innovative value. Therefore, this study explored the relationship between patent quality indicators and market value of firms from the four aspects of patent quality to fill the research gap.

Intellectual property rights became an important strategic weapon for pharmaceutical companies nowadays. The average gross sales margins of United States pharmaceutical companies during the past few years are nearly twice those of the semiconductor companies. Such significant differences in gross margins are primarily attributed to the better records of pharmaceutical companies in protecting their innovation by patents. Therefore, the protection of R&D outcomes is a paramount concern for pharmaceutical companies. Since R&D costs of developing new drugs are very high but the costs of manufacturing pharmaceutical drugs are very low, very few pharmaceutical companies are willing to make huge investments in pharmaceutical R&D without

* Corresponding author. Tel.: +886 5 534 2601x5240; fax: +886 5 531 2074.
E-mail address: dr.chen.ys@gmail.com (Y.-S. Chen).

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patent protection. The owner of the technology can ensure not to lose control of his technology through patents, since he can acquire the monopoly position in the market under patent protection. The patent system can help the owner to exclude others from using his technology during the protection term of the patent.

This study was mainly conducted in the pharmaceutical industry in the United States. There are several characteristics for the pharmaceutical industry. First, it is the highest R&D intensive industry in the United States, and thereby has both the highest R&D to sales ratio among all major industries in the United States. Second, patent protection is very strong in this industry and pharmaceutical companies generally recognize that they are in races with other firms to develop innovative new drugs. Finally, there is sufficient data in the pharmaceutical industry and it is possible to obtain finance and patent information of these pharmaceutical companies easily. In addition, success in the US pharmaceutical industry is dependent upon the ability to continually develop new drugs by investing in R&D. New products are especially important in this industry for two reasons. First, the treatment of diseases is continually changing, which makes old drugs obsolete. Second, patents can allow pharmaceutical companies to make their new drugs have high economic margins [4].

In the pharmaceutical industry, the risk of new drug development is highest in the beginning stage. As the time goes by, the risk would get lower and the value and cash flow of the drug would get higher and higher after obtaining the patent. This study thought that the patent quality would positively impact market value of companies, because patents can protect their innovation outcomes. Previous studies argued that the impact of R&D on market value was significant, and some previous researches discussed the influence of patent indicators upon company's market value already, but this study found that these patent indicators mainly represented the quantitative aspect of patents such as patent counts. There is no study exploring the influence of patent quality upon companies' market value from the four aspects of patent quality — leading position, technological capability, concentration of firms' patents and innovative value. Therefore, this study used four indicators of patent quality – relative patent position (RPP), reveal technology advantage (RTA), Herfindahl–Hirschman Index of patents (HHI of patents), and patent citations – to explore the relationship between patent quality and market value to fill this research gap.

The structure of this paper is as follows: Section 2 would outline the literature review and hypothesis development; Section 3 described the methodology and measurement of this paper; Section 4 would discuss the empirical results; the final section was conclusions and implications of this study.

2. Literature review and hypothesis development

2.1. The patent information and patent indicators

With respect to patent information, Griliches et al. explored whether there was additional information on R&D activities, and found out that patent information can provide more information than R&D expenditure data [5]. Besides, Trajtenberg thought that patent indicators can show the information of firms' R&D capabilities which were scarce in financial statements [6]. Previous researches showed that patent information can provide abundant information to financial data when assessing corporate performance. Patents can support technology management in five areas: support of R&D investment decisions, human resource management in R&D and knowledge management, effective protection of products, identification and assessment of sources for external technology creation, and strategic and operational value maximization of the patent portfolio [7]. Effective patent protection has been identified as an important source of competitive advantage, because it provides two major functions: first, a granted patent protects the inventor, at least for a period of time, from imitation; second, patent protection supports the internal use of technology [8]. Patented technology can be used externally to achieve important operational and strategic benefits [8].

Moreover, patents contain important information for technology management. The value of patent information can be attributed to a variety of reasons: first, patent data are available even for companies that are not required to report R&D data; second, they can be analyzed under several sub-fields (e.g. business units, products, technological fields, or inventors), and this enables a more precise competitor analysis [9,10]. Furthermore, a large amount of technological information is contained in patents, and they are classified according to standardized schemes. In comparison with other information sources, patents are often considered to be the best source for the timely recognition of technological changes [11]. Because the decreasing or increasing of a firm's patent activity in a technological field can be interpreted as changing levels of R&D activity, important patent indicators can be used to analyze companies' patenting strategies [7,10,12]. Hence, patents can provide important information of firms' R&D capabilities and strategies and enable to capture accurate strategic R&D information.

In the past, the number of patent counts is an important indicator to measure the R&D outcomes, but it can't calculate the entire and precise R&D capabilities of companies. For example, Trajtenberg thought that the number of patent counts is a biased indicator to measure the value of innovation activities which varies very much in economic value and scope [6]. Therefore, several scholars proposed other patent quality indicators to measure accurate R&D capabilities of companies. For example, CHI Research, Inc. has built up a database, called Tech Line database, and uses 7 indicators – number of patents, cites per patent, current impact index (CII), technology strength (TS), technology cycle time (TCT), science linkage (SL), and science strength (SS) – to investigate the R&D competence of companies [13]. There are several studies applying CHI Research's Tech Line database to explore the technological capabilities of companies. For example, Hicks and Breitzman used CHI Research's Tech Line database to investigate the shifts of the US innovation system and found out that there was an extraordinarily dynamic innovation in information and health technologies accompanied by a shift in the center of US innovation from the East to the West Coast [13]. Besides, Breitzman applied CHI Research's Tech Line database to introduce a method for identifying technologically similar organizations, industries, or regions by applying the techniques of information science and international patent classification [14]. Furthermore, Breitzman et al. utilized CHI Research's

Tech Line database to examine patent analysis techniques for evaluating the technological strength of merger candidates, and explored the notion that the technological quality of the merged company may be diluted rather than enhanced [15].

2.2. The importance of patents for the pharmaceutical industry and the selection of patent indicators

The pharmaceutical industry is one of the most productive and profitable industrial sectors; however, the drug development process remains risky and expensive. Therefore, effective intellectual property protection is the key to maintain innovation for drug development [16]. The American pharmaceutical industry is one of the most successful sectors in the world. Among the main reasons for its success is an intensive commitment to R&D which in turn yields sustainable competitive advantages. Like other industries, such as the computer software industry, a major portion of the industry's cost is incurred in the R&D stage. Intellectual property protection is a cornerstone for the success of the pharmaceutical industry [17]. The pharmaceutical industry is so dependent on the adequate patent protection, because it is only through enforceable patent protection that drug companies can generate sufficient revenues to undertake the expensive and risky R&D that makes the introduction of new products possible [18]. Hence, patent protection is beneficial to inventions in the pharmaceutical industry [19]. In addition, market exclusivity in the pharmaceutical industry acquired through patents can yield higher prices and profits for pharmaceutical products, so pharmaceutical companies can try to obtain more patents to increase market exclusivity of their products [20]. Some studies claimed that patents played a more important role in protecting companies' R&D outcomes in some industries, such as the chemical industry and the pharmaceutical industry, than in others, such as the motor industry and the rubber industry [21–23]. For example, when a drug of a pharmaceutical company loses its patent protection, the sales of this drug would drop dramatically in the following year [20]. Moreover, many researchers used patent indicators to explore the pharmaceutical industry and thought that patent information in the pharmaceutical industry was more important than in other industries [21,24–27]. Therefore, this research was conducted in the American pharmaceutical industry.

The patent indicators of many previous researches can only reflect the quantitative aspect of patents, such as patent counts. It is important to explore the influence of "quality" of the patents upon firms' market value. However, Hirschey and Richardson thought that the number of patent counts is an imperfect indicator of inventive activities because it can't capture the true economic value of inventive activities, because they can't measure the patent value very well which exhibit a very large variance [28]. It means that the distribution of the patent value is highly skewed with a long and thin tail [6]. Previous studies posited that innovation varies enormously in its technological and economic importance or value, and the distribution of such value is extremely skewed, and thereby patent counts are inherently limited because they can't remove such heterogeneity of the distribution of the patent value [29–31]. Furthermore, this study used four patent quality indicators – RPP, RTA, HHI of patents, and patent citations – to explore their influences upon corporate market value. There are three reasons to choose these four patent quality indicators. First, the definitions and measurements of these four patent quality indicators were well defined by previous studies; second, the novel managerial implications of these four patent quality indicators were not well discussed yet; and third, these four patent quality indicators are complementary.

Previous studies widely applied the four patent indicators – RPP, RTA, HHI of patents, and patent citations – in several industries including the pharmaceutical industry as follows. With respect to RTA, Granstrand et al. applied RTA to measure the technological competencies of 440 large companies including pharmaceutical ones [32]. In addition, Patel and Pavitt used RTA to classify companies' technological competencies, and their sample had more than 400 large companies which included pharmaceutical ones [33]. Thus, RTA can be used to measure firms' technological competencies in the pharmaceutical industry. With respect to RPP, based on 21 mechanical engineering companies, Ernst utilized RPP to measure their leading degrees in several particular technological fields [9]. In addition, Ernst also applied RPP to investigate the leading degrees of the chemical companies in several particular technological fields [10]. Hence, RPP has been applied in the mechanical engineering industry and the chemical industry. Patents played an important role in protecting firms' innovation outputs in some industries, such as the chemical industry and the pharmaceutical industry [21–23]. Therefore, this study thought that RPP can also be used in the pharmaceutical industry. With respect to HHI of patents, Hall has defined this indicator very well and utilized it to describe the concentration of patents across patent classes and to measure the concentration level of a firm's technology capability, even though there is no research applying it in the pharmaceutical industry [34]. This study posited that HHI of patents can also be used in the pharmaceutical industry. With respect to patent citations, patent citations are usually used as a measure for patent value or importance [30,35,36]. Additionally, patent citations could indicate the value of innovations [6], and the importance of the knowledge [30]. Therefore, patent citations can also be used in the pharmaceutical industry.

Based on the mention above, this study asserted that the four patent indicators – RPP, RTA, HHI of patents, and patent citations – can be used in the pharmaceutical industry. Several well-known patent indicators, such as patent counts, can only measure the value of innovation from the quantitative aspect. It is important to explore the influence of patent "quality" upon firms' market value. There is no study exploring the influence of patent quality upon companies' market value from the four aspects of patent quality — leading position, technological capability, concentration of firms' patents, and innovative value. Therefore, this study used four indicators of patent quality – RPP, RTA, HHI of patents, and patent citations – to explore the relationship between patent quality and market value to fill this research gap.

2.3. The relationship between patents and corporate market value

Previous studies in the area of economics often employed Tobin's q model in which the value of companies reflects the market's perception of the flow of future profits and dividends which are partly driven by firms' tangible and partly by their intangible

assets, such as the stock of "innovative" knowledge and patents, to explore the influence of R&D activities upon firms' market values [37,38]. For example, Yang and Chen explored potential heterogeneity of patents that influenced the value of Tobin's *q* [39]. Moreover, Blundell et al. explored the issue of the market value equation including "innovation variables" which included patent activities, and found out that the innovation variables had a significantly positive impact on market value [40].

As the endogenous growth models suggested, the difference between low and high productivity of innovation translated directly into the difference of market value [41]. The market value of a company should be a forward looking indicator of corporate performance reflecting the discounted sum of future dividends, which should be closely related to the discounted sum of future profits including outcomes of patents [42]. Previous studies thought that innovative activity and patent performance impacted positively on market value [30]. However, Toivanen et al. found out that once the impact of R&D was taken into account in Tobin's *q* model, the ratio of patent counts to total assets had a negative impact upon market value [43].

Lin et al. found out that the diversity of a patent portfolio can measure two aspects: broad technology diversity and core field diversity, and mentioned that diversity of a firm's patent portfolio can create synergy and contribute to corporate market value [44]. In addition, Parchomovsky and Wagner thought that a patent portfolio can provide a firm with a strong market position in a particular field, thus encouraging innovators to combine their inventions with that of a portfolio holder, in result to enhance the ability to consolidate and coordinate related technological developments [45]. Previous researches demonstrated that the value of R&D is changing over time and depends on the ability to appropriate the surplus generated by R&D investment [38,46,47]. However, unlike R&D investment, another direction in the literature addressed the issue of the valuation of knowledge assets from a knowledge outputs such as patents. For Example, Hall et al. used patent citations as a proxy for the importance of the knowledge contained in a patent and found that the average number of citations per patent was positively related to corporate market value [30]. Previous researches also recognized the importance and commercial value of patents that were highly important for corporate market value [36]. In addition, Gilbert and Newbery argued that preemptive patenting attains the persistence of monopoly which can enhance corporate market value [48].

Previous literatures examined various aspects of the impact of innovation upon economic performance, and they included two main strands: one focusing upon the impact of R&D on productivity and the other on the market value [42,49,50]. The impact of patents and trademarks on market value was significant [43,51,52]. Therefore, the impact of patents is strongly associated with market value of firms. Previous studies thought that intangible assets have positive influence upon market value [53,54]. Moreover, previous studies showed that R&D is positively associated with earnings, and an increase in R&D is associated with a contemporaneous increase in market value [55,56]. Griliches measured the economic value of knowledge assets and innovation, and found out that firms' patents and R&D investment would impact their financial market valuation [57]. Nagaoka examined empirically how two patent indicators, forward citation and science linkage, affected the market value of firms, and found that they affected the market value of firms significantly [58]. Deng et al. applied several patent indicators, such as patent counts, patent citations, and science link index, to predict corporate performance and found that they were positively associated with the subsequent market-to-book value of companies [59]. Moreover, there were some studies which showed that the patent performance of a firm is significantly correlated with its market value [28,59,60].

2.4. Hypothesis development

2.4.1. The main effect of relative patent position (RPP)

Relative patent position (RPP) of a given company in its most important technological field means the patent counts owned by the company in its technological field where it has more patents than in others divided by the patent counts of the leader in the technological field [9,10]. This study defined the most important technological field of a firm as it had more patents in the field than in others, and technological fields of patents were discriminated according to UPC (US patent classification). In addition, this study defined the leader in a technological field as the company with most patents in the technological filed. RPP of a company in its most important technological field is used to measure the degree of leading in the technological field, and its maximum value is 1 [9,10]. If RPP of a company is high, it has a leading position in its most important technological field, and it is useful for its market value because of the first mover advantage. Therefore, the stronger the degree of leading in the technological field, the better is its market value. According to the mention above, this study proposed the first hypothesis in the following:

Hypothesis 1 (H_1). Relative patent position (RPP) of a firm in its most important technological field is positively related to its market value.

2.4.2. The main effect of revealed technology advantage (RTA)

Soete and Wyatt defined the revealed technology advantage (RTA) as corporate advantage in one particular technological field compared to other firms [61]. RTA for a given firm in a given field is the firm's share of patenting in one particular technological field divided by the firm's share of total patenting in all fields [32]. Patel and Pavitt also used RTA to measure and to classify firms' technological competencies; moreover, they argued that the higher the RTA, the stronger is the relative strength of a firm in one particular technological field [33]. Based on previous studies, this study defined RTA for a given firm in its most important technological field as the firm's share of patenting in the technological field where it has more patents than in others divided by the firm's share of total patenting in all fields. If a firm's RTA in its most important technological field is higher, the firm is considered to have more specialization in this technological field; oppositely, if a firm's RTA in its most important technological field is lower, the firm is considered to have less specialization in this technological field [33]. On the other hand, RTA for a given country was used in

calculation as the country's share of US patenting in one sector divided by the country's share in all patenting sectors [32,61]. RTA is a wide-used measure for technological advantage, so it can describe the technological capability in the particular technological field for a given company. According the mention above, the higher the RTA of a firm, the stronger is its technological capability in the particular technological field. In addition, the stronger the technological capability of a firm in the particular technological field, the higher is its market value. Hence, this study proposed the following hypothesis:

Hypothesis 2 (H_2). Revealed technology advantage (RTA) of a firm in its most important technological field is positively related to its market value.

2.4.3. The main effect of Herfindahl–Hirschman Index of patents

Herfindahl–Hirschman Index of patents (HHI of patents) is used to measure the degree of technological concentration [62,63]. For example, when patents of enterprises are located at only one technological field, then their HHI of patents all equals to 1, and it means that the technological concentration of these enterprises is quite centralized. Originally, Herfindahl–Hirschman Index (HHI) was used to measure the degree of the industrial concentration [64]. When HHI is close to 1, a high degree of monopoly power exists in an industry. However, if HHI is close to zero, it is assumed that little monopoly power exists within an industry. Hall used HHI of patents to describe the concentration of patents across patent classes, and to measure the concentration level of a firm's technology capability [34]. If a company has all its patents in one patent class, HHI of patents equals to 1. On the other hand, if patents of a company are located in many patent classes, HHI of patents would be close to 0. Technological concentration and technological diversity were well-studied concepts in the field of industrial organization [65,66]. Technological diversity in corporations is a driving force behind four major features of contemporary businesses: corporate growth; increasing R&D investment; increasing external linkage for new technologies; and opportunities to engage in technology-related new businesses [32]. Moreover, technological diversity means that corporate technological competencies are dispersed over a wider range of R&D activities. If companies have broader technological competencies, they can take advantage of new technological opportunities more often, and thereby the risk of missing new technological opportunities is less. Furthermore, if companies have more diversity of technological capabilities, they can exploit the economy of scope in their broader technological competencies to coordinate the innovation with complementary support. Therefore, this study thought that the degree of a firm's technological diversity is positively associated with its market value. In addition, Hall used HHI of patents to describe the concentration of patents or cites across patent classes, and to measure the concentration level of a firm's technological capability [34]. Hence, this study proposed the following hypothesis:

Hypothesis 3 (H_3). Herfindahl–Hirschman Index of patents (HHI of patents) of a firm is negatively related to its market value.

2.4.4. The main effect of patent citations

Trajtenberg argued that patent citations could indicate the value of innovations and show out their potentials [6]. Besides, Park and Park used patent citations to measure the amount of technological knowledge [31]. In addition, Lee et al. [67] and Hu [68] applied patent citations to represent patent quality and knowledge flow of firms. Therefore, patent citations are usually used as a measure for patent value or importance [30,35,36]. Additionally, previous study showed that the patent performance of a firm is significantly correlated with its market value [28,58–60]. Hence, this study proposed the following hypothesis:

Hypothesis 4 (H_4). Patent citations of a firm are positively related to its market value.

The research framework of this study was shown in Fig. 1. As mentioned above, this study proposed four hypotheses to explore the influence of patent quality upon corporate market value from the four aspects of patent quality — leading position, technological capability, concentration of firms' patents, and innovative value.

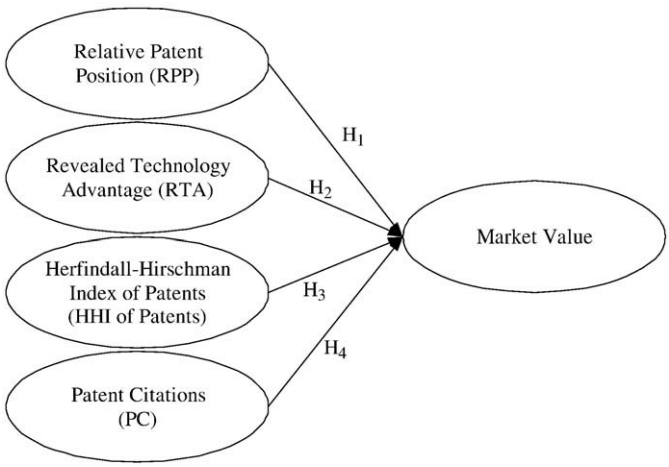

Fig. 1. Research framework.

3. Methodology and measurement

This study posited the methodology, sample and data collection in this section at first, and then pointed out the measurement of every variable.

3.1. Sample and data collection

This research was conducted in the firms of the pharmaceutical industry in US. The financial data of this study were obtained from the COMPUSTAT database. The COMPUSTAT database contains financial data of publicly traded companies in US. The patent data of this study was gathered from the United States Patent and Trademark Office (USPTO). These patent data of this study had sufficient information about names of assignees, technical fields, and the issued dates and so on. There are 37 US pharmaceutical companies in the sample of this study. The panel data in this study containing patent data and financial data of the sample spanned the period of a decade from 1997 to 2006. Hence, the size of the panel data of the sample in this study was 370. This study listed the US pharmaceutical companies of the sample and their means and standard deviations of the variables from 1997 to 2006 in Appendix A. Panel data combining the characteristics of time series and cross sections may have firm-specific effects, period-specific effects, or both. In order to analyze the panel data, this study applied panel data models to verify the hypotheses in the research framework.

3.2. Measurement

3.2.1. Dependent variable: market value

The dependent variable of this study is 'market value'. 'Market value' is a term in both law and accounting to describe an appraisal based on the market's perception of the flow of future profits and dividends which are partly driven by firms' tangible and partly by their intangible assets [37,38]. Market value is generally estimated by the value which is the average stock price of a company in a given year multiplied by the number of its common stock shares outstanding. The data of market value in this study were acquired from COMPUSTAT.

3.2.2. Independent variables

3.2.2.1. Relative patent position (RPP). Relative patent position (RPP) of a company in its most important technological field means the patent counts owned by the company in its technological field where it has more patents than in others divided by the patent counts of the leader in the technological field [9,10]. This study defined the most important technological field of a firm as it had more patents in the field than in others, and technological fields of patents were discriminated according to UPC (US patent classification). In addition, this study defined the leader in a technological field as the company with most patents in the technological filed. Thus, the maximum value for RPP in each technological filed is 1. RPP of a company is used to measure the degree of leading of the company in the technological field. RPP of a given company in its most important technological field is calculated as follows [9,10]:

$$RPP = \frac{\text{the number of patents owned by the company in the technological field where it has more patents than in other technological fields}}{\text{the number of patents of the leader in the technological field}}.$$

3.2.2.2. Revealed technology advantage (RTA). Soete and Wyatt defined the revealed technology advantage (RTA) as corporate advantage in one particular technological field compared to other firms [61]. RTA for a given firm in a given field is the firm's share of patenting in one particular technological field divided by the firm's share of total patenting in all fields [32]. The higher the RTA, the stronger is the relative strength of a firm in one particular technological field [33]. This study defined RTA for a given firm in its most important technological field as the firm's share of patenting in the technological field where it has more patents than in others divided by the firm's share of total patenting in all fields. The RTA of a firm in its most important technological field is defined as follows:

$$RTA = \frac{P_{kg} \Big/ \sum_i P_{ig}}{\sum_j P_{kj} \Big/ \sum_i \sum_j P_{ij}}.$$

P_{kg} means the patent counts of the focal company g in its most important technological field k. $\sum_i P_{ig}$ means the patent counts of the focal company g in all technological fields. $\sum_j P_{kj}$ means the patent counts of all companies j in the technological field k. $\sum_i \sum_j P_{ij}$ means the patent counts of all companies j in all technological fields.

3.2.2.3. Herfindahl–Hirschman Index of Patents (HHI of patents). Hall used HHI of patents to describe the concentration of patents across patent classes, and to measure the concentration level of a firm's technological capability, although Herfindahl–Hirschman Index (HHI) was used to measure the degree of the industrial concentration originally [34]. For example, when patents of enterprises are located at only one technological field, then their HHI of patents all equals to 1, and it means the technological concentration of these enterprises is quite centralized. For a set of N patents falling into I classes with N_i patents in each class ($N_i \geq 0$, $i = 1,...,I$), HHI of patents across the classes is defined by the following expression:

$$HHI\ of\ patents = \sum_{i=1}^{I} \left(\frac{N_i}{N}\right)^2,\ 0 \leq HHI\ of\ patents \leq 1.$$

3.2.2.4. Patent citations (PC). Hall et al. used patent citations as a proxy for the importance of the knowledge contained in a patent and found that patent citations of a firm were positively related to its market value [30]. The more times a company's patents are cited by others, the better is the innovative value of the company's patents. Therefore, this study used patent citations (the sum of self-citations and other-citations of patents) to assess the innovative value of companies' patents.

3.2.3. Control variable

The control variable of this study was "growth of firms". The rate of sales growth is widely used to measure the growth of firms [69,70]. Therefore, this study used "the rate of sales growth" of firms as the proxy variable of "growth of firms". "The rate of sales growth" is defined as annual percentage change in sales. Additionally, firm size is measured by the logarithm of sales in this study. Firm size can demonstrate the economies and diseconomies of scale. This study acquired "the rate of sales growth" and "sales" of US pharmaceutical companies from COMPUSTAT.

4. Results

The descriptive statistics of this study were showed in Table 1. This study explored the influence of firms' patent quality upon their market value from the four aspects of patent quality — leading position, technological capability, concentration of firms' patents, and innovative value. The dependent variable of this study was market value, and the independent variables were RPP, RTA, HHI of patents, and patent citations, while the control variables were the rate of sales growth and firm size. The panel data of this study containing patent data and financial data span the period of a decade from 1997 to 2006. In order to analyze the panel data, this study applied panel data models to verify the hypotheses in the research framework. Panel data combining the characteristics of time series and cross sections may have firm-specific effects, period-specific effects, or both. There are three types of panel data models: pooled regression model, fixed effect model, and random effect model [71]. Solutions to problems of heterogeneity and autocorrelation are of interest among these three types of panel data models. Both intercepts and slopes of the pooled regression model have constant coefficients. In the pooled regression model that has neither a significant firm-specific effect nor a period-specific effect, we could pool all of the data and run an OLS regression model [72]. Although there are often either firm-specific effects or period-specific effects, there are some occasions when both firm-specific effects and period-specific effects are not statistically significant. The fixed effect model assumes that there are differences in intercepts across firms or periods, whereas the random effect model explores differences in error variances. The fixed effect model, also known as least square dummy variable (LSDV), removes all between-firm variance and thus controls for any time invariant unobserved heterogeneity among firms. Hence, the fixed effect model constrains the coefficients to be within-firm effects [73]. The random effect model considers the firm-specific effects as random variables, and it assumes that firm-specific effects are normally distributed throughout the population [71].

There are three stages to determine which panel data models should be selected in this study. First, this study used Baltagi test (F test) to determine whether the pooled regression model or the fixed effect model should be selected as the empirical model [74]. The result showed that the fixed effect model was better than the pooled regression model. Second, this study applied Breusch–Pagan test (LM test) to determine whether the pooled regression model or the random effect model should be selected as the empirical model [71]. The result showed that the random effect model was better than the pooled regression model. Third, this study used Hausman test to determine whether the fixed effect model or the random effect model should be selected as the

Table 1
Descriptive statistics.

	Mean	Standard deviation	Min.	Max.
Relative patent position	0.31	0.37	0	1
Revealed technology advantage	809.73	4961.94	0	45,585
Herfindahl–Hirschman Index of patents	0.25	0.21	0	1
Patent citations	462.20	1280.44	0	6974
Sales (million dollars)	5333.02	10,460.84	4.42	53,194
The rate of sales growth	73.88	93.47	−207.11	556.01
Market value (million dollars)	26,475.75	49,446.17	8.97	290,215.78

Table 2
Empirical results of the panel data model.

Dependent variable: market value	Fixed effect model
Independent variable	
Intercept	−64,448.63** (0.000)
Relative patent position	26,722.00** (0.000)
Revealed technology advantage	−0.355 (0.351)
Herfindahl–Hirschman Index of patents	−18,793.26* (0.045)
Patent citations	6.116** (0.000)
Control variable	
Log sales	12,947.36** (0.000)
The rate of sales growth	3.790 (0.830)
F value	41.234**
p-value	0.000
Log likelihood	−4336.749
R^2	0.636
Adjusted R^2	0.621
N	370

Note: The numbers in parentheses are *p* values. $^{*}p<0.05$, $^{**}p<0.01$. The panel data spanned the period of a decade from 1997 to 2006. There are three stages to determine which panel data models should be selected in this study. (1) Baltagi test (*F* test): pooled regression model vs. fixed effect model. *F* value = 27.17 → reject H_0, and select fixed effect model. (2) Breusch–Pagan test (LM test): pooled regression model vs. random effect model. $\chi^2(1) = 630.83$ → reject H_0, and select random effect model. (3) Hausman test: fixed effect model vs. random effect model. $\chi^2(5) = 71.49$ → reject H_0, and select fixed effect model. Therefore, this study applied the fixed effect model to verify the hypotheses in the research framework.

empirical model [71]. The result showed that the fixed effect model was better than the random effect model in Table 2. Therefore, this study used the fixed effect model to verify the hypotheses in the research framework. This study showed the results of the fixed effect model in Table 2. The empirical results of the fixed effect model in Table 2 indicated that RPP of a company in its most important technological field was positively associated with its market value, whereas HHI of the company's patents was negatively associated with its market value. Additionally, patent citations of a company were positively associated with its market value. That meant that the higher the RPP of a company in its most important technological field, the more was its market value; the lower the HHI of patents of a firm, the more was its market value; and the higher the patent citations of a company, the more was its market value. Therefore, these three hypotheses, H_1, H_3 and H_4, were significantly supported in this study. However, Table 2 showed that the RTA of a company in its most important technological field was not positively associated with its market value. Hence, the hypothesis, H_2, was not significantly supported in this study.

RPP of a company in its most important technological field is used to measure the degree of leading in the technological field. Therefore, the implication of the positive relationship between RPP of a company in its most important technological field and its market value is that it should enhance its degree of leading in its most technological field, and thereby its market value would be better. Therefore, there is the first mover advantage in the pharmaceutical industry of US. HHI of patents is to describe the degree of the concentration of patents across patent classes and to measure the concentration level of a firm's technological capability. Therefore, the implication of the negative relationship between HHI of patents and a firm's market value is that it should diversify its patents or technological capabilities if it wants to enhance its market value. If pharmaceutical companies have broader technological competencies, they can take advantage of new technological opportunities more often, and thereby the risk of missing new technological opportunities is less. Furthermore, if pharmaceutical companies have more diversity of technological capabilities, they can exploit the economy of scope in their broader technological competencies to coordinate the innovation with complementary support. Therefore the degree of a firm's technological diversity is positively associated with its market value in the pharmaceutical industry. Patent citations are used to assess the innovative value of a company's patents. Therefore, the implication of the positive relationship between patent citations of a company and its market value means that it should enhance the innovative value of its patents to raise its patent citations to increase its market value.

However, RTA of a company in its most important technological field was not positively associated with its market value. Hence, the hypothesis, H_2, was not significantly supported in this study. R&D activities in the pharmaceutical industry have three characteristics: R&D investment is very expensive and intensive; horizons of R&D activities span very long; and risks of R&D activities are high. Therefore, if pharmaceutical companies have high value of RTA, their switching costs which can alleviate the positive impact of technological capabilities on corporate market value would be high. Hence, the hypothesis H_2 was not significant. Higher RTA does not guarantee to have better market value in the pharmaceutical industry in the United States.

Table 3
The *t*-test for the difference of market value between companies with high patent counts and those with low patent counts.

	Companies with high patent counts (*a*)	Companies with low patent counts (*b*)	(a) − (b)
Market value (million dollars)	102,624.20 (65,433.06)	8393.67 (17,666.92)	94,230.53 **

Note: This study used the median of patent counts to distinguish companies with high patent counts and those with low patent counts. The value in the table is mean, and the standard deviation is in the parenthesis.
** $p<0.01$.

Table 4
The *t*-test for the differences of RPP, HHI of patents, and patent citations between companies with high patent counts and those with low patent counts.

	Companies with high patent counts (*a*)	Companies with low patent counts (*b*)	(*a*) − (*b*)
RPP	0.553 (0.339)	0.255 (0.353)	0.298**
HHI of patents	0.108 (0.049)	0.283 (0.217)	−0.175**
Patent citations	2277.94 (2108.74)	31.033 (116.437)	2246.91**

Note: This study used the median of patent counts to distinguish companies with high patent counts and those with low patent counts. The value in the table is mean, and the standard deviation is in parenthesis.
** $p<0.01$.

This study used the median of patent counts to divide the sample into two groups, companies with high patent counts and those with low patent counts. Then, this study compared market value, RPP, HHI of patents, and patent citations of companies with high patent counts to those with low patent counts. The results showed that market value of pharmaceutical companies with high patent counts was higher than that of companies with low patent counts in Table 3. Moreover, this study also found out that RPP and patent citations of pharmaceutical companies with high patent counts was higher than those of pharmaceutical companies with low patent counts in Table 4, while HHI of patents of pharmaceutical companies with high patent counts was lower than that of pharmaceutical companies with low patent counts. As mentioned in the literature review in this study, previous studies posited that innovation varies enormously in its technological and economic importance or value, and the distribution of such value is extremely skewed, so patent counts are inherently limited because they can't remove such heterogeneity of the distribution of the patent value, and the number of patent counts is an imperfect indicator to capture and to measure the true economic value of inventive activities very well [6,30–33]. In addition, this study compared the assets and sales of companies with high patent counts to those with low patent counts in Table 5. This study found out that the firm sizes of high patenting pharmaceutical companies were larger than those of low ones in this industry, so this study posited that high patenting firms may perhaps be larger companies.

As mentioned in H_1, RPP of a company in its most important technological field was positively associated with its market value. Pharmaceutical companies with low patent counts can increase their RPP in their most technological fields to enhance the degree of leading in the fields, and further enhance their market value. Additionally, since HHI of patents was negatively associated with corporate market value in H_3, pharmaceutical companies with low patent counts should decrease the HHI of their patents to cultivate more diversity of technological capabilities, and further enhance their market value. Besides, patent citations were positively associated with corporate market value in H_4, so pharmaceutical companies with low patent counts can increase the innovative value of their patents to raise their patent citations to increase their market value.

5. Conclusions and implications

5.1. Conclusions

This study proposed four hypotheses to explore the relationship between firms' patent quality and their market value in the US pharmaceutical industry. Although some previous researches discussed the influence of patent indicators upon market value, this study found that these patent indicators mainly represented the quantitative aspect of patents, such as patent counts. There is no study exploring the influence of patent quality upon companies' market value from the four aspects of patent quality — leading position, technological capability, concentration of patents, and innovative value of patents. Therefore, this study used four patent qualitative indicators – RPP, RTA, HHI of patents, and patent citations – to explore their influences upon corporate market value to fill this research gap. The results of this study indicated that RPP of a company in its most important technological field was positively associated with its market value. HHI of patents was negatively associated with its market value. Additionally, patent citations were positively associated with its market value. However, RTA of a company in its most important technological field was not positively associated with its market value. Therefore, hypotheses, H_1, H_3 and H_4, were significantly supported in this study, but hypothesis H_2 was not.

Based on the positive relationship between RPP of companies and their market value, they should enhance their degrees of leading in their most technological fields, and thereby their market value would be better. Hence, there was the first mover

Table 5
The *t*-test for the differences of assets and sales of patents between companies with high patent counts and those with low patent counts.

	Companies with high patent counts (*a*)	Companies with low patent counts (*b*)	(*a*) − (*b*)
Assets (million dollars)	30,869.49 (25,995.45)	2726.02 (5779.48)	28,143.47**
Sales (million dollars)	21,701.51 (14,182.72)	1446.19 (3042.71)	20,255.32**

Note: This study used the median of patent counts to distinguish the companies with high patent counts and those with low patent counts. The value in the table is mean, and the standard deviation is in parenthesis.
** $p<0.01$.

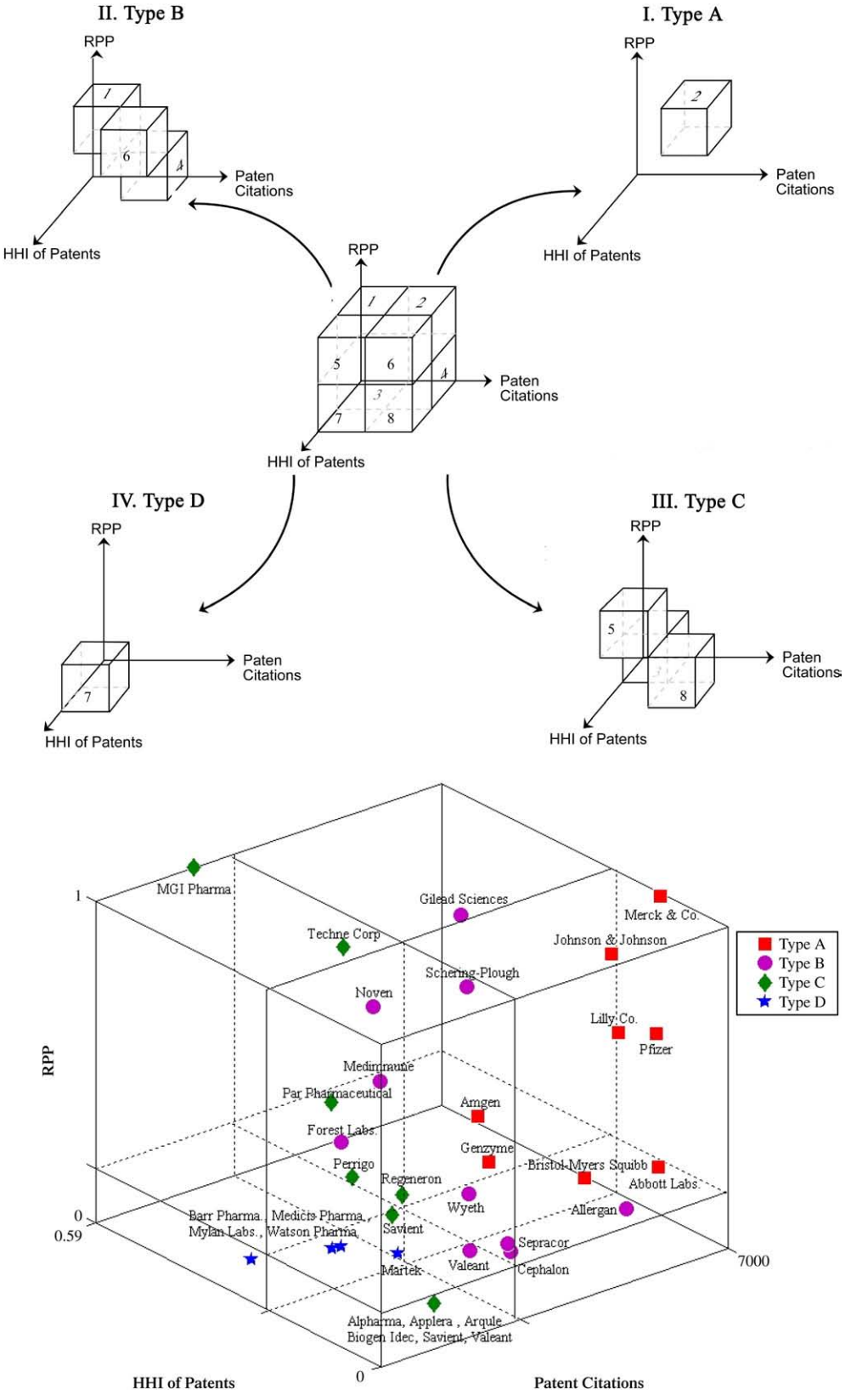

Fig. 2. The classification for the pharmaceutical firms.

advantage in the pharmaceutical industry of US. According to the negative relationship between HHI of patents and firms' market value, they should diversify their patents or technological capabilities if they want to enhance its market value. If firms have wider technological competencies, they have more chances to take advantage of new technological opportunities, and thus the risk of missing new technological opportunities is less. Moreover, if companies have broader technological diversity, they can utilize the economy of scope in their wider technological competencies to coordinate the innovation with complementary support. On the basis of the positive relationship between patent citations of companies and their market value, they should enhance the innovative value of their patents to increase their patent citations such that their market value would be better. Besides, RTA of a company in its most important technological field was not positively related with its market value in this study because of three characteristics in the pharmaceutical industry: R&D expenditures are very costly and intensive; horizons of R&D activities span very long; and risks of R&D investment are high. Thus, if pharmaceutical companies have high RTA, their switching costs would be very high such that the positive influence of technological capabilities upon corporate market value is not significant. Thus, possessing higher RTA doesn't guarantee to have better market value in this industry.

This study found out that pharmaceutical companies with high patent counts had higher market value than those with low patent counts. However, previous studies posited that innovation varies enormously in its technological and economic importance or value, and the distribution of such value is extremely skewed, so the number of patent counts is an imperfect indicator to capture and to measure the true economic value of inventive activities very well [6,28–31]. This study found out that the firm sizes of high patenting pharmaceutical companies were larger than those of low ones in this industry, so this study thought that high patenting firms may probably be larger companies. Moreover, this study indicated that pharmaceutical companies with low patent counts had lower RPP than those with high patent counts. Because H_1 was supported in this study, RPP of a company in its most important technological field was positively associated with its market value. Pharmaceutical companies with low patent counts should improve their RPP in their most technological fields to raise the degree of leading in the fields, and further increase their market value. In addition, this study also demonstrated that pharmaceutical companies with low patent counts had higher HHI of patents than those with high patent counts. Since H_3 was supported in this study, HHI of patents was negatively related to corporate market values. Pharmaceutical companies with low patent counts should decrease HHI of patents to diversify their technological capabilities in the pharmaceutical industry to raise their market value. Besides, this study pointed out that pharmaceutical companies with low patent counts had lower patent citations than those with high patent counts. Since H_4 was supported in this study, patent citations were positively associated with corporate market value. Pharmaceutical companies with low patent counts should improve the innovative value of their patents to increase their patent citations to further enhance their market value.

5.2. Managerial implications

Finding out that RPP and patent citations were positively associated with corporate market value and HHI of patents was negatively associated with it in the pharmaceutical industry of US, this study developed a classification for pharmaceutical companies based on three dimensions, RPP, patent citations, and HHI of patents in Fig. 2.

- The *X*-axis of the classification in this study is the number of patent citations. Patent citations can measure the innovative value of the firms' patents. Because H_4 was supported in this study, patent citations were positively related to market value. This study used the median of patent citations to distinguish the pharmaceutical companies with high patent citations from those with low patent citations. The median of patent citations in this study was 462.20.
- The *Y*-axis of the classification in this study is the number of HHI of patents. HHI of patents can measure the concentration level of a firm's technological capability. Because H_3 was supported in this study, HHI of patents was negatively related to market value. This study used the median of HHI of patents to distinguish the pharmaceutical companies with high HHI of patents from those with low HHI of patents. The median of HHI of patents of patents in this study was 0.2492.
- The *Z*-axis of the classification in this study is the number of RPP of a company in its most important technological field. It can measure the degree of leading of a given company in its most important technological field. Because H_1 was supported in this study, a firm's RPP in its most important technological field was positively related to its market value. This study used the median of RPP to distinguish the pharmaceutical companies with high RPP from those with low RPP. The median of RPP in this study was 0.3118.

Based on the classification above, this study divided the space into 8 cells in Fig. 2, and categorized the pharmaceutical companies into four types: “Type A companies”, “Type B companies”, “Type C companies”, and “Type D companies”. The characteristics of Type A companies which are located in Cell 2 include: high patent citations, low HHI of patents, and high RPP. Type A companies are the ideal target of the companies of other types, because they don't need to improve their RPP, patent citations, and HHI of patents. There are three subtypes of Type B companies: Type B1 companies, Type B2 companies, and Type B3 companies. The characteristics of Type B1 companies which are located in Cell 1 include: low patent citations, low HHI of patents, and high RPP; the characteristics of Type B2 companies which are located in Cell 6 include: high patent citations, high HHI of patents, and high RPP; and the characteristics of Type B3 companies which are located in Cell 4 include: low RPP, low HHI of patents, and high patent citations. Type B companies need to improve only one indicator of patent quality. For example, Type B1 companies need to enhance their patent citations; Type B2 companies need to decrease their HHI of patents; and Type B3 companies need to raise their RPP.

In addition, there are three subtypes of Type C companies: Type C1 companies, Type C2 companies, and Type C3 companies. The characteristics of Type C1 companies which are located in Cell 5 include: high RPP, high HHI of patents, and low patent citations;

the characteristics of Type C2 companies which are located in Cell 3 include: low RPP, low HHI of patents, and low patent citations; and the characteristics of Type C3 companies which are located in Cell 8 include: low RPP, high HHI of patents, and high patent citations. Type C companies need to improve two indicators of patent quality. For example, Type C1 companies need to enhance their patent citations and to decrease their HHI of patents; Type C2 companies need to raise their RPP and patent citations; and Type C3 companies need to increase their RPP and to decrease their HHI of patents. Finally, the characteristics of Type D companies which are located in Cell 7 include: low RPP, high HHI of patents, and low patent citations. Type D companies are the worst ones among the four types, because they need to improve all three indicators of patent quality — RPP, patent citations, and HHI of patents.

One limitation of this study was that not all patentable inventions were patented. In some cases, firms protect their innovations with other alternatives such as trade secrets, because the race of R&D in the pharmaceutical industry is so fierce and it is very difficult to assure their appropriability regimes [75]. When technologies are very difficult to copy, patenting is not always worthwhile and adopting trade secrets is a good alternative. Future studies can focus on this issue, and fill this research gap. This research was conducted in the pharmaceutical industry in US. Future studies can focus on other industries or countries to explore the relevant topics, and compare to this study. Moreover, this study explored the influence of patent quality upon corporate market value from the four aspects of patent quality – leading position, technological capability, concentration of patents, and innovative value of patents – by using the four patent quality indicators — RPP, RTA, HHI of patents, and patent citations. Future studies can focus on other novel patent qualitative indicators to explore the relevant topics, and compare to this study. In addition, future studies can link this research to the issue of technological forecasting by using these four patent indicators. Finally, we hope that the results of this study are beneficial to managers, researchers, or governments, and contribute to relevant studies and future researches as reference.

Appendix A. The US pharmaceutical companies in the sample list and their statistics of the variables in the period 1997–2006.

	RPP		RTA		HHI of patents		Patent citations		Log sales		The rate of sales growth		Market value (million dollars)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Abbott Laboratories	0.25	0.02	0.64	0.02	0.06	0.00	1908.1	373.45	9.71	0.24	32.66	14.13	68,565	10,901
Allergan Inc.	0.09	0.01	1.23	0.03	0.11	0.01	1517.9	445.41	7.45	0.29	34.40	24.88	9689	4758
Alpharma Inc.	0.13	0.17	282.81	306.64	0.15	0.17	0.00	0.00	6.72	0.37	23.63	65.39	806.7	290.3
Amgen Inc.	0.41	0.03	13.12	6.43	0.21	0.02	60.10	45.41	8.62	0.66	51.32	27.61	62,710	25,453
Applera Corp.	0.17	0.22	9.12	8.21	0.23	0.21	5.10	9.21	7.35	0.15	23.98	14.23	5414	3091
Arqule Inc	0.00	0.00	0.33	0.14	0.11	0.06	3.00	2.62	3.50	0.77	65.15	137.86	213.9	142.3
Barr Pharmaceuticals Inc.	0.00	0.00	2.62	1.31	0.52	0.29	0.00	0.00	6.52	0.59	89.22	55.79	2744	1679
Biogen Idec Inc.	0.05	0.10	35.85	59.49	0.11	0.19	0.00	0.00	5.96	1.48	156.63	56.82	9611	7102
Bradley Pharmaceutical Inc.	0.00	0.00	1.05	1.11	0.33	0.19	3.60	5.15	3.70	0.91	122.05	120.32	149.0	140.4
Bristol-Myers Squibb Corp.	0.23	0.08	1.18	0.07	0.11	0.01	390.80	258.76	9.84	0.06	13.26	20.15	84,439	39,907
Cephalon Inc.	0.02	0.01	1.80	0.25	0.18	0.03	96.90	68.99	5.43	1.72	125.13	119.98	2450	1435
Enzo Biochem Inc.	0.06	0.04	12.96	4.99	0.28	0.25	2.20	1.03	3.82	0.16	2.15	47.95	555.9	306.9
Forest Laboratories	0.27	0.19	165.01	63.65	0.37	0.00	9.00	0.00	7.33	0.75	99.85	67.28	12,961	7055
Genzyme Corp.	0.28	0.02	14.60	7.64	0.19	0.05	62.60	46.75	7.10	0.63	51.57	31.19	9675	5652
Gilead Sciences Inc.	1.00	0.00	220.85	42.65	0.25	0.05	64.30	35.79	5.88	1.56	185.13	70.95	10,257	9979
Johnson & Johnson Inc.	1.00	0.00	16.59	1.51	0.03	0.00	266.80	14.68	10.46	0.31	43.03	15.97	153,844	35,115
Lilly Corp.	0.59	0.05	1.27	0.06	0.12	0.01	4508.4	988.10	9.36	0.20	32.50	9.49	77,879	15,078
Martek Biosciences Corp.	0.03	0.01	14.02	4.60	0.24	0.01	7.30	5.70	3.52	1.62	143.25	102.46	600.0	484.6
Medicis Pharmaceutical Corp.	0.00	0.00	2.82	0.03	0.50	0.01	0.00	0.00	5.13	0.71	130.57	61.26	1403	545.0
Medimmune Inc.	0.24	0.22	149.05	73.29	0.30	0.08	4.20	6.99	6.34	0.90	109.24	77.97	6991	3075
Merck Corp.	1.00	0.00	1.33	0.02	0.13	0.01	6025.8	872.70	10.30	0.33	6.64	83.23	127,432	46,258
MGI Pharma Inc.	1.00	0.00	8451	9118	0.59	0.19	2.40	2.07	3.93	1.21	189.56	185.10	726.5	710.2
Millennium Pharmaceuticals Inc.	0.43	0.28	21.31	12.87	0.36	0.15	26.80	26.05	5.60	0.61	94.76	77.25	4358	3576
Mylan Laboratories	0.00	0.00	2.02	0.27	0.37	0.03	0.50	0.71	6.96	0.39	47.25	36.90	4309	1076
Noven Pharmaceuticals Inc.	0.62	0.22	207.72	70.42	0.40	0.02	39.20	18.56	3.60	0.50	66.42	70.59	380.2	214.7
Par Pharmaceutical Inc.	0.40	0.52	17,643	22,795	0.40	0.52	0.00	0.00	5.41	1.07	124.63	177.82	807.1	696.7
Perrigo Corp.	0.38	0.11	210.08	79.80	0.39	0.05	8.80	3.43	6.79	0.18	17.56	26.47	1015	346.7
Pfizer Inc.	0.61	0.09	1.36	0.06	0.14	0.01	1863.1	404.20	10.29	0.56	73.22	40.43	194,418	61,478
Regeneron Pharmaceutical Inc.	0.13	0.02	16.49	4.39	0.30	0.02	21.30	12.56	3.83	0.63	42.77	86.29	735.3	392.7
Savient Pharmaceuticals Inc.	0.00	0.00	1.03	1.83	0.23	0.42	0.00	0.00	4.43	0.29	24.96	66.51	395.5	202.1
Schering-Plough Pharmaceutical Inc.	0.95	0.14	80.93	12.48	0.11	0.03	8.70	7.53	9.10	0.13	20.85	34.98	47,911	21,230
Sepracor Inc.	0.03	0.01	1.44	0.32	0.15	0.04	66.30	36.75	4.92	1.59	210.54	163.21	3857	2197
Techne Corp.	1.00	0.00	2266	1519	0.27	0.29	2.00	0.00	4.77	0.40	66.22	20.27	1314	772.5
Valeant Pharmaceuticals Inc.	0.01	0.01	105.02	172.41	0.19	0.32	0.00	0.00	6.66	0.10	16.65	39.33	1972	517.1
Vertex Pharmaceuticals Inc.	0.04	0.02	1.63	0.06	0.18	0.01	28.40	15.69	4.46	0.73	65.25	76.00	1885	1497
Watson Pharmaceuticals Inc.	0.00	0.00	1.78	1.29	0.34	0.24	0.00	0.00	6.92	0.56	112.37	57.99	3836	1056
Wyeth Pharmaceuticals Inc.	0.12	0.04	1.48	0.10	0.26	0.02	97.70	0.95	9.64	0.15	19.36	20.69	63,293	12,761

Note: The panel data spanned the period of a decade from 1997 to 2006. 'Mean' is the average value of the variables from 1997 to 2006, and 'S.D.' is the standard deviation of the variables from 1997 to 2006.

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Dr. Chen is an associate professor in the Department of Business Administration in the National Yunlin University of Science and Technology in Taiwan. His research focused on management of technology, innovation management, and patent analysis.

Mr. Chang is a research assistant and Ph.D. candidate in the Department of Business Administration in the National Yunlin University of Science and Technology in Taiwan. His research focuses on artificial neural network (ANN), management of technology, and project management.