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The Patent Asset Index – A new approach to benchmark patent portfolios

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ABSTRACT

Patent metrics are increasingly used to assess the competitive position of technology-oriented firms. Patent rankings and patent scoreboards are popular methods to benchmark patent portfolios of firms against each other. Existing rankings, however, have methodological limitations that significantly reduce the meaningfulness of these benchmarks for managers, investors and other stakeholders. In this paper, we develop a new benchmarking methodology that overcomes limitations of existing approaches and offers a more accurate assessment of a firm's patent portfolio vis-à-vis its competitors. Firms are ranked according to the Patent Asset Index, which is derived from a set of newly developed patent indicators. These indicators are empirically validated and reflect more accurately the value of patents. We apply the new benchmarking method in the global chemical industry and contrast our findings with those of other existing patent portfolio rankings.

1. Introduction

The majority of technological improvements that companies believe to be patentable and important are documented in patent applications [1–4]. Benchmarking patent portfolios therefore promises to objectively compare the technology strength of companies. Because proprietary technology is a cornerstone of market success and a valuable asset in many industries, patent benchmarks provide useful insights into the competitive position of a company [5–8]. As patents usually precede the actual use of technologies in commercial applications [9], these benchmarks can also offer an outlook into tomorrow's competitive landscape.

Patent rankings and patent scoreboards are therefore popular methods to benchmark patent portfolios of firms against each other. The Wall Street Journal, e.g., has been regularly publishing these patent benchmarks for multiple industries. These patent rankings receive increased attention from managers, investors and the general public. A number of firms, e.g., DuPont and Halliburton, use these benchmarks to signal their innovativeness and leading competitive position to investors [10–12].

Existing patent rankings or scorecards have methodological shortcomings regarding the quantitative and qualitative assessment of patent portfolios. The Wall Street Journal ranking, e.g., has a focus on US patents. This approach does not adequately reflect patenting activities by foreign firms and further neglects the importance of global patenting activities. The metrics used in these benchmarks to assess patent quality are dated because they do not incorporate recent advances in the development of more meaningful patent indicators that reflect the technological and commercial value of patent portfolios more accurately [13,14].

Assessing the value of patents is the most critical element of any patent portfolio benchmark since simple patent counts are an insufficient proxy of patent strength, innovation or competitive impact [7,8]. It is well-known that the majority of patents has little or no value [15–18]. According to a recent study by Gambardella et al., less than 20% of granted European patents are worth more than 3 million Euros [15]. Yet, these patents account for more than 90% of the total financial value of all granted European patents examined in this study [15].

In this paper, we develop a new benchmarking methodology that overcomes the limitations of existing approaches and offers a more accurate assessment of a firm's patent portfolio vis-à-vis its competitors. Firms are ranked according to the newly developed Patent Asset Index, which is derived from a set of new patent indicators. These indicators are empirically validated and reflect the value of patents more accurately. We apply the new benchmarking method in the global chemical industry and contrast our findings with those of other existing patent portfolio rankings.

2. Discussion of existing benchmarks

The assessment of smaller patent portfolios can be done by applying in-depth expert valuation techniques. In the case of larger patent portfolios, however, existing benchmarks have to rely on

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other indicators. For the reasons outlined above, merely comparing the quantity of patents is not sufficient to value the competitive impact of patent portfolios. Most patent benchmarks thus evaluate patent portfolios by calculating a patent quantity measure that is then multiplied by a measure of average patent quality. The quality dimension is typically derived from certain patent indicators such as citations. The existing benchmarks use US patent data only, both for calculating the quantity and quality measures. The methodologies differ, though, in the exact way patent value is estimated.

Some companies select and weight value indicators based purely on their statistical correlation to patent maintenance rates [19] or other correlates of patent value. This mathematical approach has the practical benefit of requiring no patent expertise to select value indicators. However, mere statistical correlation can be misleading when there is no solid theoretical and conceptual foundation [20].

Scientists and some consultancies use value indicators substantiated by validation studies [21–26]. We will discuss in more detail the patent benchmark published by The Wall Street Journal (see, e.g., [27]) as its foundations are documented in scientific publications from the 1980s [21] to 1990s [22,28].

The Wall Street Journal's patent benchmark is provided by the consultancy The Patent Board. It exclusively relies on US patent data. This is problematic for a comparison of international companies, because it may lead to a strong overestimation of the patent strength of US-based companies compared to companies from abroad [13,14]. Some large Japanese companies, e.g., only file US patent applications for less than 10% of their inventions [29]. The share of the patent portfolio that is visible in US patent data varies greatly among companies. Just 25% of all worldwide inventions are recorded in US patent data [29].

The Patent Board's analysis is restricted to US patent grants from the past 52 weeks. Taking into account both the geographic and temporal limitation, we found that only 0.5–10% of the actual patent portfolio of large multinational enterprises is therefore considered in this benchmark [29].

Only patent grants but not patent applications are taken into account. Patent grants are delayed by the substantial time needed for patent examination. Most patents granted by the United States Patent and Trademark Office (USPTO) in 2008 were filed at least 3 years earlier, 25% had even been first filed more than 5 years earlier [29]. Patent applications are a more up-to-date measure of inventive activity.

A company's position in the patent ranking by The Patent Board depends on the indicator "Technology Strength", which is the product of the number of patents granted by the USPTO to the company during the last 52 weeks, divided by four and multiplied by the patents' average value as measured by the indicator "industry impact". Industry impact is based on the number of citations which the company's US patents have received from other US patents over the last 12 months [28]. Patent citations are valid indicators of patent value [21–26]. Limiting the data to twelve months of US citations, however, means missing out on most of the information that is available worldwide to measure a patent's impact.

The Patent Board's patent benchmark ignores the validity of patents in world markets. Nowadays, most companies compete globally. The US only accounts for 25% of the world market in terms of Gross National Income [30]. Thus, the total value of a patented invention critically depends on whether patent rights in other important markets such as Europe or Asia have also been secured. None of the existing benchmarks considers the worldwide legal status of the patents. Further, they fail to assess the global market impact and relevance of a firm's patent portfolio.

In conclusion, the following limitations of the existing benchmark methodologies exist:

– US-centric approach neglecting global patent portfolio positions.
– Focus on granted patents neglecting recent changes of patent portfolio positions.
– Use of rudimentary indicators of patent value, esp. the current extent of patent protection in world markets – a critical determinant of patent value – is neglected.
– Incomplete.

3. Developing a new patent benchmarking method

The aforementioned limitations can be overcome. In order to correctly compare international firms, worldwide patent data should be used. The entire patent portfolio of all companies can be identified by retrieving patent data for all relevant countries worldwide from the respective databases. To analyse the extent of patent protection in global markets, international patents coherently protecting the same invention can be grouped into patent families and their respective legal status can be verified. In addition, recent inventive activity is evidenced in patent application data: patent applications are usually published 18 months after filing and often represent the first public disclosure of an invention [31]. Finally, disclosing how the metrics are calculated helps to create a transparent methodology that investors, managers and other stakeholders can understand and trust more easily.

We created a new benchmarking methodology along these general guidelines for improvement. In the following, we discuss our methodological approach in more detail: First, we elaborate on how patent 'portfolio size' can be measured to accurately reflect the entire and current worldwide patent portfolio of a firm. Second, we discuss new and better ways to assess the value of a firm's global patent portfolio. Here, we focus on two innovative indicators: 'market coverage' and 'technology relevance'. 'Market coverage' is a measure of the extent of patent protection in global markets. 'Technology relevance' is a new citation-based indicator to assess the technological impact of patents, which eliminates systematic distortions of existing citation-based patent indicators. Third, we combine 'portfolio size', 'market coverage' and 'technology relevance' to construct the 'Patent Asset Index' as our new key metric to assess the value of a firm's patent portfolio. Finally, we conduct an empirical analysis to cross-validate the new indicators used in the 'Patent Asset Index'.

3.1. Portfolio size

We define 'portfolio size' as the number of granted and valid (active) patents at a specific point of time when the ranking is done. We further add the number of patents under examination. Published pending patent applications are included because they offer some level of protection. Competitors know that the majority of all patent applications lead to a granted patent so they are discouraged to invest in the exploitation of the invention before the patent offices make their decisions [32]. In short, 'portfolio size' can be described as the number of active patent families a company owns (see below).

To consider the entire patent portfolio of companies, patent publication data from all (or most) worldwide patent offices from at least the last 20 years – the maximum regular lifetime of a patent – has to be integrated. Using this dataset creates a variety of new challenges, including the identification of international patents covering the same invention and tracking patent ownership over time. As 'portfolio size' reflects the number of active patents and published pending applications, the legal status of all patents applied for during the last 20 years must also be tracked in order to exclude, e.g., all lapsed patents and rejected applications from the analysis.

Patent applicants often seek protection in more than one country so that more than one patent publication per invention exists. To accurately determine the number of patent-protected inventions in a portfolio, all international patent applications and patents for the same invention need to be identified and counted just once. A suitable approach known as the INPADOC patent family has been developed by the European Patent Office [33]. We adopt this well-established approach. A patent family comprises all patents and patent applications that describe the same invention and claim the same priority.

Tracking patent ownership over long periods of time is intricate: companies merge, change their names, create spin-offs, sell and acquire business units, sell and buy individual patents, etc. Identifying the current owner of all relevant patents requires substantial effort. Computer algorithms can – at most – harmonize some name spelling variations [34] and match some patent applicant names to company databases such as Amadeus [35]. However, we do not know of any computer-implemented approach that would acquire and process all required information. Specific expert research is required to accurately track patent ownership over time for each individual company. This step of the analysis is crucial since an accurate benchmark requires the correct assignment of patent families to their respective owners.

After the number of patent families owned by a certain company has been identified, the worldwide legal status of each of these patent families needs to be known in order to focus on those patent families only that contain valid patents or published pending applications. This information can be found in the patent gazettes and registers of the national patent offices. The evaluation of the worldwide legal patent status not only permits to calculate the current 'portfolio size', it also enables to compile a new metric of patent value: the extent to which the invention is protected in global markets.

3.2. Market coverage

Patents are territorial rights – an invention is only protected in those countries where the patent applicant owns an intellectual property right. In all other countries the published documents serve as blueprints for competitors that want to imitate the technology. If a company owns a patent only in the US, e.g., the invention can be used by competitors in other markets. The extent of worldwide patent protection thus strongly influences patent value.

This determinant of patent value has been ignored in existing benchmarking methodologies. Research, however, indicates that the number of countries in which patents are filed are related to patent value [8,14,36–42]. This indicator, however, has several drawbacks: it ignores whether or not the patent applications once filed internationally have led to granted patents or whether they have been rejected. It also neglects whether an eventually granted patent is still valid. Furthermore, all countries are treated as equally important while the size of the markets can actually be very different. For example, a Danish patent protects a market less than 3% of the size of the US market.

We thus propose a new metric called 'market coverage' that represents the actual market size covered by valid patents and published pending patent applications. The size of national markets will be different from industry to industry. In order to establish a standard method to calculate 'market coverage' across all industries, one could use the Gross Domestic Product (GDP) of each country as a proxy for the size of its market. The accuracy of this metric could further be improved, if industry-specific or product-specific market sizes are available.

In this paper, we define 'market coverage' as the sum of the GDP of all countries in which the invention is patent-protected, relative to the GDP of the USA. For example, the 'market coverage' of a patent family that consists of only one valid US patent is 1. While published pending patent applications also protect an invention to some degree (because competitors must fear that the patent will be granted), they are not as powerful as valid patents. We thus use the observed worldwide a priori probability that a patent application will be granted (70%) to discount for the contribution of pending patent applications to the indicator 'market coverage' [29]. It is close to the grant ratio of patent applications at the European Patent Office [43]. Alternatively, country- or firm-specific grants-to-applications-ratios can be used for this purpose. A further important issue is different levels of enforceability of patent rights in different countries. Ideally, that should be incorporated as well in the 'market coverage' indicator.

3.3. Technology relevance

The value of a patent strongly depends on its relevance for the development of subsequent technologies and products. Generally, a relevant patent will lead to further R&D (Research & Development), which will in turn be covered by patents. These later patents will cite the prior patent as 'prior art'. Furthermore, if a certain R&D topic attracts more interest in the industry (i.e., because it is more relevant for creating successful products), then the patents covering fundamental concepts in this technology field will be cited more often. Hence, the number of citations received by a patent is an indicator of its relevance for subsequent technological developments [21,22]. The number of citations received from later patents has been found to be an indicator of patent value [14,23–26,36,37]. The study by Hall et al. showed that the total number of citations received is more informative for the market value of the patent portfolio than the total number of patents [23].

As the majority of R&D is performed outside of the US and the majority of patent families are published outside the US, only a fraction of the relevance of patents is evidenced in US patent citation data. Furthermore, each patent office effectively processes just a fraction of all related prior patents. Figure 1 summarizes the origin and target of prior art citations in more than 8 million search reports and patent documents across multiple international patent offices [29]. The data shows that most patent examiners tend to cite only patents available in their native language or in English. This effect is particularly strong at the USPTO and the Japanese Patent Office (JPO) – patent examiners at these patent offices seem to almost ignore patents from other countries.

Citation-based relevance metrics can therefore be improved by using worldwide available patent citation data. Using this extended worldwide citation data creates some challenges: the amount of citations received is time-dependent – older patents are cited more often, on average, than younger patents. Some patent offices, for example the USPTO, have fundamentally different rules and practices concerning citations. This impacts the significance of patent citations published by different offices as an indicator of patent value. Finally, the different characteristics of technology fields have an impact on the frequency and significance of patent citations. In the following, we will discuss how these challenges can be addressed.

We define 'technology relevance' as the number of worldwide patent citations received by a patent family, corrected for patent age, patent office citation practices and citation differences between technology fields, as discussed below.

3.3.1. Time-dependence of citation counts

Patent citations appear gradually over many years while related R&D is performed. Patents are often cited for more than 20 years [29]. In any single publication year, less than 10% of the total number of citations that will be received by a patent is evidenced, on average [29]. The total number of patent citations received thus

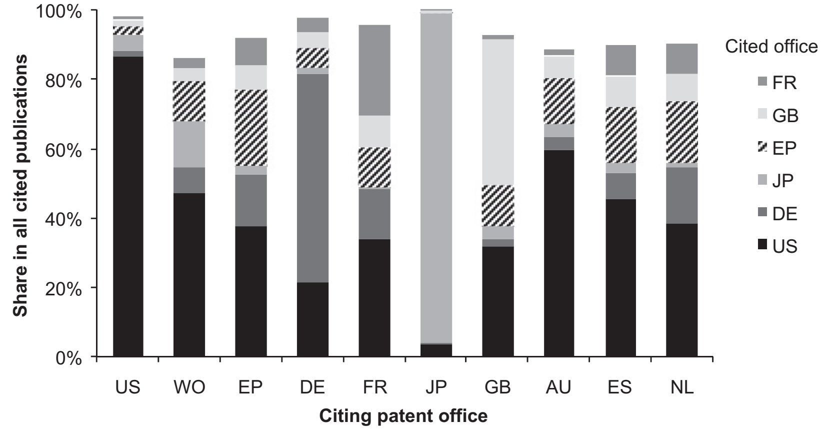

Fig. 1. Citation patterns across major patent offices. Source: Own calculations (*Note*: Cited EP documents can exist in multiple languages, including at least one of the EPO's official languages German, English and French).

not only depends on the relevance of the patented invention, but also on the time that has passed since the patent was published [6,14,23]. Patents only recently published tend to have received much less citations than older patents. Figure 2 shows that the average number of citations received is a function of time: compared to patents first published in 1998 those published a year later have received 15% less citations so far. Patents first published in 2003 have so far only received 42% as much citations as those published in 1998 [29].

There is a method to correct the time-dependency of citations that does not require limiting the data to a certain period of time: dividing the number of citations received by a patent by the average number of citations received by all patents published in the same year [6,14]. This method works well for worldwide citation data and we therefore adopt its use.

3.3.2. Patent office citation practices

The strength of the actual link between citing and cited patent varies greatly. Citations that reveal a closer link between citing and cited patent are more indicative of a patent's relevance than other citations. The average significance of patent citations varies across patent offices.

In most jurisdictions, patent citations are generated only by patent examiners. At the USPTO, however, a patent applicant and his attorney have a duty to disclose all information known to the individual to be of relevance for patentability. However, to ensure compliance with this duty and to avoid highlighting the most relevant references, the applicant and his attorney may be motivated

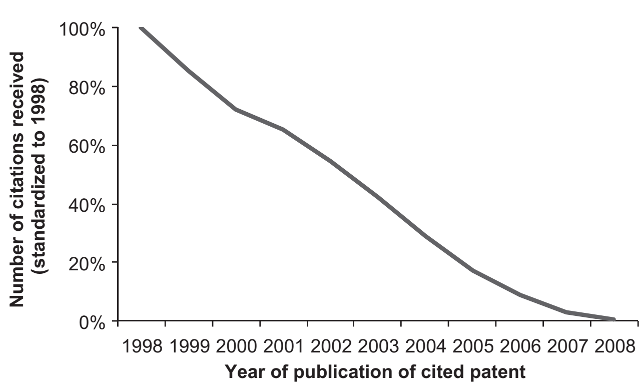

Fig. 2. Patent citations as a function of publication year. *Source*: Own calculations.

to disclose to the USPTO a longer list of prior art that goes beyond which is actually relevant [14,44].

These issues are evidenced in patent data. We analysed the citations made by all patents that have been applied for both at the USPTO and at another patent office. Our analysis shows that the USPTO cited approx. 3–4 times more prior art for a given invention than the other patent offices [29]. Similar results have been found by Michel and Bettels [45].

When worldwide patent citation data is used, the different background of the citations from different origins has to be taken into account. A simple solution to this problem is to use a discount factor for citations published by the USPTO. However, we observed that there are also some differences between the other patent offices and that citation practices are time-dependent. We thus adopt a more comprehensive approach to correct the differences in the practices of worldwide patent offices. We created a time-variant estimate for the average weight of citations from each patent office by calculating the reciprocal of the average number of patent citations made by that office per patent, in a given year. For example, citations from a patent office that generates, on average, twice as many patent citations as others are weighted with a discount of 50%.

As worldwide patent citation data is used, the same invention might be cited by multiple patents protecting the same subsequent invention. These multiple citations indicate that there is one related subsequent invention. They should thus not be confused with multiple citations received from patents covering different inventions, which show that there are several related subsequent inventions. To calculate the strength of the citation link between patented inventions, we use the maximum of the weights of all equivalent international citations between the respective patent families.

3.3.3. Citation differences between technology field

The average number of citations received by a patent strongly depends on the respective technology field the patent belongs to [46]. In some areas, technologies are intertwined, progress is incremental, or many patents are applied for each year. This leads to a large average number of citations made for these technologies, and consequently to a higher average number of citations received. In other technology fields, technologies are more discrete, technical progress occurs in larger steps, or fewer patents are applied for each year. This leads to a lower average number of citations made and consequently to a lower average number of citations.

For illustration, Fig. 3 contrasts the average number of citations received by patents in different technology fields [29]. The metric

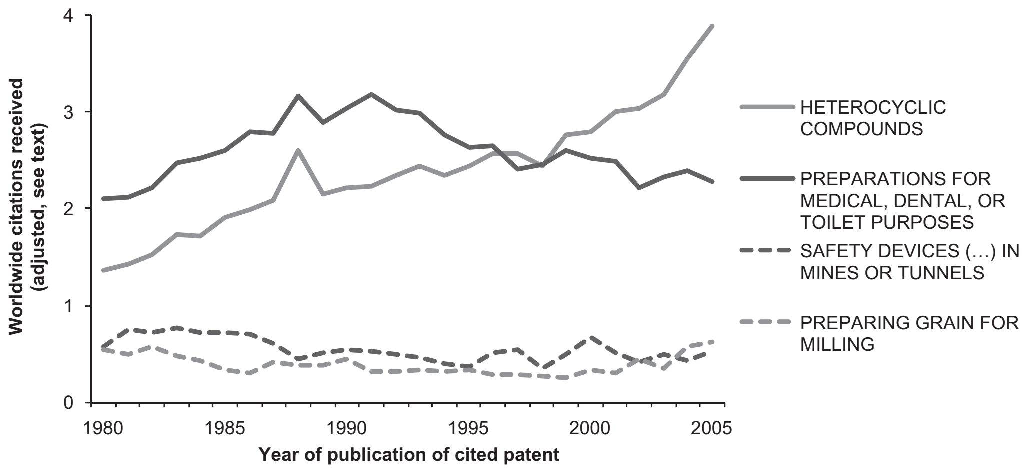

Fig. 3. Patent citation rates in four different technology fields. *Source*: Own calculations.

shown is the number of citations received per invention (patent family) published in a certain year, corrected for the age of the patents and patent office citation practices. The citation rate differs among technology fields and it is time-variant.

The differences in the average number of citations across technology fields can be taken into account by using a similar approach as for patent age: calculating the relative citation count compared to other patents concerning the same technology. The preliminary technology relevance metric, which is the number of citations corrected for patent age and patent office citation practices, is divided by it's time-variant technology-specific average value. To assign patents to technology field, one can, e.g., use the International Patent Classification (IPC) of the World Intellectual Property Organization (WIPO). IPC classification data is available for all worldwide patents, while other classification systems such as for example the US classification or the Japanese F-terms are specific to the publications of particular patent offices. Other approaches to classify patents into fields or sectors (see, e.g., [47]), could be used in the same way to determine citation indicators as described above.

3.4. Competitive impact

The metric 'competitive impact' measures the usefulness of the patent to create sustainable competitive advantage. Thus, both the potential to create competitive advantage through important technologies (the relevance of the patents as measured by 'technology relevance') and the potential to exploit that competitive advantage in large markets (the effectiveness of the patents to avoid imitation as measured by 'market coverage') must be considered simultaneously. High 'technology relevance' combined with a large 'market coverage' creates high value for the firm. A technology, however, is worth much less without a large market to exploit it. Likewise, broad international patent rights protecting a weak technology are of lower value too. The level of a patent's 'competitive impact' should therefore be determined based on the combination of 'technology relevance' and 'market coverage'. Combining the two quality determinants on the aggregate portfolio level would lead to inaccurate results. We therefore define 'competitive impact' as the product of a patent's 'technology relevance' and its 'market coverage'.

3.5. Patent Asset Index

The 'Patent Asset Index' measures the overall strength of a company's patent portfolio. Each patent contributes to portfolio strength according to its 'competitive impact'. Thus, the 'Patent Asset Index' for a firm is calculated as the sum of the 'competitive impact' of all active patents in the firm's patent portfolio.

The 'Patent Asset Index' indicates a firm's level of important intellectual assets that create competitive advantage and hence economic returns. It helps managers, investors and other stakeholders to better understand a fundamental source of a firm's competitive advantage that is otherwise not visible in a firm's balance sheet.

3.6. Validation

In order to validate our measures, we conducted an empirical validation study. We compared a group of patents (A) with significant competitive impact to another group of patents (B) without competitive impact. Patents that survived oppositions from competitors were found to have a higher impact on the competition [48] and to be of a significantly higher value [16]. Using data from the European Patent Office's INPADOC database, we identified those patents published between January 1985 and December 2003 for which oppositions had been filed, or re-examination or revocation had been requested and which fully survived these procedures. In total, we identified 37.366 patent families that pertain to group A.

Group B consisted of granted patent families that were abandoned by their respective owners within 6 years after priority filing. If the owner looses interest in the granted patent that fast, it is very likely that it had no or little value to them [17,18]. We identified approx. 70,000 patent families published between 1985 and 2003 that pertained to group B in the first step. To ensure the correctness of our statistical test, group B was then limited to exactly the same size as group A by drawing a random sample. In the end, group B also contained 37.366 patent families.

We calculated 'technology relevance', 'market coverage' and 'competitive impact' for all patent families. As 'market coverage' changes over time and as the current 'market coverage' of all patent families in group B is zero, we used the maximum 'market coverage' achieved at any point in time between first filing and abandonment of the patent right for this validation study.

'Competitive impact' should reflect the value and importance of the patent as perceived by its owner and competitors. Consequently, we expected a significantly higher 'competitive impact' for patents in group A than in group B. Table 1 shows the arithmetic mean and the standard deviation in the two groups. The 'competitive impact' for patents that had been opposed by competitors was 7.8, on average for patents in group A. The average 'competitive impact' of patents in group B was 0.7. A t-test showed that

Table 1
Results for patent groups A and B.

	n	Competitive impact		Technology relevance		Market coverage	
		Mean	SD	Mean	SD	Mean	SD
Group A – attacked by competitors	37,366	7.8*	14.3	4.0*	5.6	1.6*	0.8
Group B – owner lost interest	37,366	0.7*	1.1	1.1*	1.3	0.5*	0.4

* Level of significance < 1%.

the mean differences between both groups of patents were highly significant. The Mann–Whitney *U*-test, a more robust test that does not require normal distribution of data, yielded exactly the same result.

The 'competitive impact' metric can be used to predict which of the two groups a patent in the sample pertains to. For example, a threshold for 'competitive impact' of 1.5 can be set and all patents that score higher can be classified into group A and all patents that score lower can be classified into group B. Using this simple process, 80% of all patents are correctly classified.

Harhoff et al. [16] surveyed the value of German patents renewed to full term as perceived by their owners. They found that the patents that survived an opposition were 11.2 times more valuable, on average. Despite using a much more diverse dataset and applying our competitive impact measure rather than a value measure based on a survey, our results confirmed these findings: the ratio between the 'competitive impact' of patents that survived an attack by the competition (group A) and other patents (group B) is approximately 11.

4. Applying the Patent Asset Index in the global chemical industry

4.1. Sample

We analysed the 10 most R&D intensive companies from the global chemical industry in order to illustrate the newly developed patent benchmarking method. Those include AkzoNobel, BASF, Bayer, Dow Chemical, DSM, DuPont, Mitsubishi Chemical, Solvay, Sumitomo Chemical and Syngenta [49]. We benchmarked the complete patent portfolio of the companies. In the case of Bayer AG this means that its portfolio includes a substantial share of patents that relate to pharmaceuticals rather than to chemical products. About half of Bayer's sales are in pharmaceuticals, the chemical business comprises Bayer CropScience and Bayer MaterialScience.

We consolidated patent publication data from more than 50 countries that represent more than 90% of the World's GDP. We also included the publications of multinational offices such as the World Intellectual Property Organization and the European Patent Office. In addition, we implemented a computer system that evaluates the legal status of the patent rights in most countries around the world. For some countries, legal status information is not always available for all patent applications in an electronically readable form. Where electronic legal status information was missing for a certain national patent right, we used the legal status of other patent rights on the same invention or the average lifetime of patents from that country to estimate the legal status of the patent right.

Furthermore, we collected patent citation data from 10 major patent offices. In order to correctly assign inventions to their current owners, we consolidated patent applicant names to reflect merger and acquisition activity, subsidiaries, joint-ventures, spinoffs, etc. We also tracked patent ownership using the legal status data. We were thereby able to identify the actual current portfolio of the companies. Comparing our results for the current patent portfolios of the companies with those of commercial patent databases that also harmonize applicant names, we found that our process led to significantly improved results.

After that, we calculated the metrics 'portfolio size', 'technology relevance', 'market coverage', 'competitive impact' and the 'Patent Asset Index' as discussed in the previous sections.

4.2. Results

Table 2 illustrates the overall results of the benchmark analysis. The ranking reflects the portfolios of active patents as of December 31, 2008.

BASF has the highest 'Patent Asset Index' – the company owns the strongest patent portfolio in the chemical industry. BASF owned 11,780 patent families at the end of 2008. Its patents had an average 'competitive impact' of 3.8. On average, their patents were twice as relevant as the average of all patents in the same technology fields. The company's patents typically have a 'market coverage' of 1.8 times the size of the US market. The lead of BASF in the 'Patent Asset Index' corresponds with their R&D investments: from 1999 to 2008, the company invested 13.9 billion Euro in R&D in the field of chemicals – more than any other company [50].

Bayer's portfolio, including pharmaceuticals, has the second highest 'Patent Asset Index'. This might be surprising at first sight as Bayer reported R&D expenditures of 23.5 billion Euro from 1999 to 2008 [50] – much more than BASF. But pharmaceutical R&D is much more expensive, per patent, than R&D in chemicals. It is thus not surprising that Bayer has to invest more, overall, per unit patent strength. In 2008, only 35% of Bayer's R&D investment was for chemicals [50]. Considering only inventions related to chemical products, Bayer would probably score fourth, behind DuPont and Dow Chemical.

A look at the composition of the corporate patent portfolios in terms of quantity vs. quality yields some interesting insights: Dow Chemical's patents have the highest 'competitive impact', on average, of all the top 10 chemical companies. This is caused by the exceptionally high value for 'technology relevance'. By contrast, DuPont's patent portfolio benefits from its size rather than its quality: the average 'technology relevance' of DuPont's patents is 20% lower than Dow Chemical's and 10% lower than BASF's. Fur-

Table 2
Ranking of patent portfolio strength in the chemical industry as of December 31, 2008.

	Patent Asset Index	Portfolio size	Competitive impact	Technology relevance	Market coverage
BASF	44,187	11,780	3.8	2.0	1.8
Bayer[a]	31,665	8697	3.6	1.9	1.7
DuPont	27,863	9709	2.9	1.8	1.3
Dow Chemical	24,683	6403	3.9	2.2	1.5
Sumitomo Chemical	12,247	20,061	0.6	0.6	0.6
Mitsubishi Chemical	9867	14,801	0.7	0.7	0.5
DSM	6139	1807	3.4	1.8	1.8
Solvay	4615	1416	3.3	1.7	1.8
Syngenta	4538	1325	3.4	1.9	1.7
AkzoNobel	3909	1466	2.7	1.6	1.5

[a] Includes pharmaceuticals.

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Table 3
Ranking in the chemical industry according to different benchmarks.

	Patent Asset Index	The Patent Board
BASF	1	2
Bayer[a]	2	38
DuPont	3	1
Dow Chemical	4	3
Sumitomo Chemical	5	18
Mitsubishi Chemical	6	14
DSM	7	–
Solvay	8	–
Syngenta	9	–
AkzoNobel	10	–

'–' not ranked within top 50 companies.
[a] Includes pharmaceuticals.

thermore, DuPont tends to seek patent protection in fewer markets and thus scores lower for the indicator 'market coverage'.

The Japanese companies Sumitomo Chemical and Mitsubishi Chemical have by far the largest patent portfolios among the 10 chemical firms. The average 'competitive impact' of their inventions, however, is much lower. Japanese patent law tends to lead to patents describing less subject matter, per patent [51]. Several of such patents would be filed as a single patent at other patent offices. Typically, we observe that patent applications of Japanese origin that are filed outside of Japan claim three to five Japanese priority patents, i.e., multiple Japanese patents are the origin of one international patent [29].

4.3. Comparison to other benchmarks

Different benchmarking methodologies lead to different results. Table 3 compares the results of our analysis to the ranking done by The Patent Board and published by the Wall Street Journal [52]. Four of the 10 most R&D active chemical companies are not among the top 50 innovators in the chemical industry ranking of The Patent Board'. According to the 'Patent Asset Index', DSM, Solvay, Syngenta and Akzo Nobel take positions 7–10 in the global patent portfolio ranking. Bayer is ranked only at position 38 by The Patent Board. Based on the 'Patent Asset Index', Bayer is ranked as #2 in the global chemical industry. Beyond that, there are further notable differences between The Patent Board ranking and the ranking based on the new methodology using the 'Patent Asset Index'. This finding confirms that the choice of the benchmarking methodology has impact on the results.

5. Conclusion

Managers, shareholders, investors and other stakeholders have an increased interest to assess the competitive position of firms. In technology-oriented industries, a firm's capability to convert R&D expenditures into innovative products is a key driver of competitive advantage and hence financial performance. This critical capability is not reflected in balance sheets. Meaningful patent indicators can be an interesting proxy for assessing a firm's capability to innovate and to gain competitive advantage. Patent data have the great charm that they are publicly available and represent objective measures of a firm's most valuable technological assets. In this paper, we have developed, validated and tested a new methodology to assess and benchmark a firm's technological assets. The 'Patent Asset Index' offers a more accurate assessment of a firm's patent portfolio vis-à-vis its competitors than other similar methods. It could therefore become a standard method to assess the technological assets of firms as an indicator of innovativeness and sustainable competitive advantage in many industries.

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