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Letter from the Editor

Be aware of Innovation Management

Innovation related topics, considered from both the academic as well as practical point of view, are constantly of highest interest in the present literature. Innovations belong to one the most important factors enhancing a firm's competitive advantage and subsequently its overall performance. Put differently, they provide sustainable growth opportunities. Therefore, fostering its own innovation activities represents the most appropriate way for a firm to generate long-life and superior growth. The necessity to be innovative, particularly for companies operating in developed markets, is getting more and more important due to the increasing competitive constraints arising from regions such as Asia or South America. Although many companies pay their highest attention on the development of innovative products, they additionally have to ensure that the underlying processes are managed efficiently and effectively, especially since decentralized R&D departments are dependent on their business units and the respective allocated research budget. Thus, the Journal of Business Chemistry, for example, aims to support you with some new academic as well as practical insights into the field of innovation management and, in so doing, particularly focuses on the chemical industry. In the present issue, we present you four articles related to the following topics: open innovation in small-sized R&D active companies, nanomedicine, morphological analysis of technologies, and IP strategies in business operations with China.

The relation of a firm's innovation strategy and its performance is addressed in our first research article of this section. In their article "Open innovation and firm performance in small-sized R&D active companies in the chemical industry: the case of Belgium", Peter Terlinck and Eline Poelmans classify companies according to the degree of openness to external knowledge. The different innovation strategies then are related to the firm's performance, in particular by means of evolution of employment and financial strengths.

Thomas S. Woodson delivers in the second article of this issue "Research Inequality in nanomedicine" some insight in the research portfolio of nanomedicine. Due to a bibliometric analysis, the author presents differences of nanomedical research in very high, high, medium and low income countries. Moreover, he presents and analyzes the most issued diseases in the field of nanomedicine.

In the third article of this issue "Morphological Analysis of Technologies using Multidimensional Scaling", Wukui Zheng, Jarno Kankaanranta and Arho Suominen review the method of Morphological Analysis as a technology analysis tool. The method as well as its applications is described. In addition, through a case study of portable fuel cell technology the paper exemplified its application and made several notions on practical limitations.

To answer the question, how to ensure that for new or existing business activities in China, all legal aspects relating to technology commercialization and knowledge transfer are taken into consideration, Andreas Bieberbach developed an IP strategy especially for China. The article "IP strategies in business operations with China" is part of the Practitioner's section in our current issue.

Now, please enjoy reading the first issue of the ninth volume of the Journal of Business Chemistry. We would like to thank all authors and reviewers who have contributed to this new issue. If you have any comments or suggestions, please do not hesitate to send us an email at: contact@businesschemistry.org.

Carsten Gelhard, Executive Editor
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Research Paper

Open innovation and firm performance in small-sized R&D active companies in the chemical industry: the case of Belgium

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This paper relates the practice of open innovation in small R&D active chemical companies to firm performance in terms of employment and financial position. This relationship is examined during a period of economic downturn and applied to the Belgian situation. The Belgian case is interesting since it is characterised by a high economic importance of the chemical industry and a strongly developed national (eco-) innovation system in the sector. According to their different evolution over the last decade, a distinction is made between basic chemicals and pharmaceuticals. In terms of open innovation strategy, a distinction is made between companies innovating completely internally (closed innovators), firms engaged in R&D outsourcing, firms engaged in research cooperation, and firms integrating outsourcing and cooperation in their knowledge sourcing strategy. After controlling for a broad range of R&D characteristics, we found that firms engaged in outsourcing or having an integrated open innovation approach performed better in terms of the evolution of employment during the period 2005-2010. Also, the analysis revealed firms having a formal R&D manager and a long-term research vision more often combine average to strong employment growth with a prosperous financial position.

Introduction

Innovation becomes increasingly complex and budgets and risks related to innovation force companies to carefully consider the use of external knowledge as a complement to in-house innovative activities. This challenges innovation management (Chesbrough, 2006) since innovation becomes increasingly 'distributed' over various partners (von Hippel, 1988; Coombs et al., 2003) and 'open' in a way that firms adapt their business model in favour of both outside-in and inside-out exchange of specialized knowledge (Chesbrough, 2003).

This paper addresses research cooperation and outsourcing of R&D in the chemical industry. More particularly it classifies the innovation strategy according to the degree of openness

to external knowledge and brings it into relation with firm performance. The focus is on small-sized firms in the chemical industry with Belgium as test case. The chemical industry in Belgium and Europe is characterized by declining market shares in the worldwide production and an increased importance of pharmaceutical business compared to basic chemicals.

Narula (2004) highlights a duality small firms are faced with when deciding to engage in external knowledge exchange in their innovation strategy. On the one hand, there is a challenge of lack of internal critical mass to deal with increasing budget requirements, complexity and risk. On the other hand, the engagement in external knowledge interaction might turn these firms into a vulnerable position in terms of knowledge leakage. This fits into the quest for equilibrium between research cooperation, R&D

outsourcing and internal R&D.

The central research question addressed is whether differences in the engagement in external knowledge interactions influence the firm's performance. The analysis is based on a representative sample of small firms in the chemical industry in Belgium. The period under consideration covers the years 2005-2010. The companies' research profile at the beginning of this period is brought into relation with firm performance during this period. Firm performance is accounted for by means of the evolution in terms of overall firm employment and in terms of the financial position at the end of the period. The specificities of small firms in the chemical industry in Belgium as well as the setting of a financial and economic crisis are accounted for.

The paper is organized as follows. Section 2 provides an overview of the actual insights and understandings related to the place of research cooperation and R&D outsourcing in the firm's innovation strategy and the particularities of small firms in the chemical industry in Belgium. Section 3 presents the database. The empirical analysis on the relation between innovation behaviour and firm performance forms the subject of Section 4. Reflections on implications for R&D management in small firms in the chemical sector conclude the work (section 5).

2 Open innovation in small firms in the chemical industry

2.1 Research collaboration and R&D outsourcing

The literature on 'distributed' (von Hippel, 1988) and 'open' innovation (Chesbrough, 2003; Chesbrough et al. 2006; Hunter and Stephens, 2010) emphasizes research cooperation and R&D outsourcing as important forms of external knowledge to complement the internal research base. Howells et al. (2003) relate this to a mounting competitive pressure for developing new products and processes combined with growing complexity and increased knowledge intensity (for a more recent overview see Huang and Rice, 2009).

Cohen and Levinthal (1990) define research cooperation as formal and informal ways of collaboration in which knowledge is generated that contributes to the internal knowledge base or in which the exchange of internally developed knowledge takes place (see also Veugelers and Cassiman, 1999; Coombs et al., 2003). The firm's

motives to engage in research cooperation mainly are threefold. Primarily, research collaboration enables the exploitation of economies of scale and scope in R&D, hereby reducing innovation costs and allowing to share risks (Röller et al. 1997). However, Cassiman et al. (2002) emphasize that in order to successfully co-operate, a sufficient degree of benefits of the properly or jointly generated knowledge (issue of knowledge appropriability and protection) is required to reduce free-rider possibilities by outsiders (see also Kesteloot and Veugelers, 1995 and Martin, 2002). Second, research cooperation is expected to improve the learning efficiency in absorbing external knowledge which fosters knowledge spillovers and the impact on innovative performance of incoming spillovers (Arrow, 1962; Romer, 1990). Finally, according to Hagedoorn (1993), research cooperation may facilitate access to knowledge which does not spill over and cannot easily be contracted through market transactions, i.e. intangible or tacit knowledge and know-how (see also Katsoulakos and Ulph, 1998).

R&D outsourcing refers to a broad range of activities involving procurement of routine services, technology acquisition, commissioned or joint research (Odagiri, 2003). During the past decades an upsurge in outsourcing R&D has taken place (Jones, 2000; Narula, 2004; Lai et al., 2009; Huang et al., 2009) and it is increasingly viewed as part of strategic decision making (Chesbrough et al., 2006; Howells et al., 2008). R&D outsourcing aims at capitalizing on external knowledge - that is internally not available or that can't be produced internally in a cost-effective way (Mol, 2005) - which can be licensed or bought (Gassmann, 2006). An important distinction in R&D outsourcing activities relates to core and non-core R&D activities. Non-core activities (mainly codified and relatively simple - Kogut and Zander, 1992) offer the opportunity to direct managerial attention and resource allocation to those tasks firms do best (Narula, 2001). Outsourcing core activities facilitates access to new knowledge and new technology complementary to internal capabilities. Similar to cooperation, following Teece (1986) and Chesbrough et al. (2006), outsourcing core activities occurs only in case sufficient appropriation of outsourced R&D is guaranteed. In this respect, outsourcing process-oriented tasks can help the firm in attaining more innovative R&D for any given level of investment (Friedman, 2010).

An important element in firm decision to engage in cooperation or R&D outsourcing is the distribution of (research and innovation) competences at firm level between research cooperation, R&D outsourcing, and in-house R&D. This involves balancing the use of external knowledge relations to explore new research areas with relatively less capital and lower risk involvement in case of failure with the risks of knowledge leakage and a deterioration of technological competitiveness. To minimize the latter risks, successful cooperation and outsourcing can be supposed conditional upon a sufficient internal R&D absorptive capacity (Cohen and Levinthal, 1990).

2.2 Small firms

In contrast with the ample attention paid to the study of open innovation in large (multinational) enterprises, relatively little is known about its implementation in small firms (Gassmann et al., 2010). Moreover, the benefits of open innovation in small firms are not straightforward. On the one hand, small sized firms present a higher R&D productivity because of their flexibility to exploit more efficiently knowledge generated outside the firm (see e.g. Audretsch and Vivarelli, 1996; Laursen and Salter, 2004). On the other hand, the absolute size limitations which may be enhanced by tendencies towards cross-border competition and multiple technological competences may be an important hampering factor for engaging in external knowledge interactions (Narula, 2004).

van de Vrande et al. (2009), using a sample of Dutch SMEs, put forward evidence that open innovation practices - among which external networking and R&D outsourcing - gained importance during the period 1999-2005. However, the implementation of open innovation practices is not without consequences. Compared to large firms, small firms are faced with balancing more limited resources to a wide range of aspects of the value chain in order to effectively market externally sourced and internally developed knowledge. Moreover, Narula (2004) clarifies that the potential loss of technological assets as a major issue particularly applies to research cooperation. This can be related to the necessity to guarantee and maintain outstanding internal competences in only a few or even a single technological area. Hence, R&D outsourcing and research

cooperation involve certain risks in terms of losing leadership in scientific innovation and diminishing firm abilities to influence the direction of the innovation the R&D will aim at (Friedman, 2010). Another hampering factor for completely relying on internal innovation in small firms relates to restricted possibilities to recruit specialized workers (Rothwell and Dodgson, 1991). This drives small sized firms to rely on networks to identify and to make advantage of missing innovation resources (Vossen, 1998).

Gassmann et al. (2010) highlight a trend toward more R&D outsourcing and research cooperation which is reflected in an increased labour division in innovation. Simultaneously, a shift is witnessed from cost reduction to enhancement of value creation by means of inter-organisational relationships (Enkel, 2010). Small firms are challenged to cope with the induced trend of professionalising the internal processes to manage open innovation more effectively and efficiently in combination with limited internal resources. Narula (2004) refers to a threshold level of internal capacity to absorb the externally acquired information, involving both the availability of R&D experts and (in particular with regard to tacit knowledge developed and exchanged in research cooperation) managerial resources.

2.3 Small firms in the chemical industry in Belgium

During the period under study, the years 2005 till 2010, the world manufacture of 'chemicals and chemical products (including pharmaceuticals)' is characterized by an on average moderate but unequal growth rate across the globe. In this period, the world's up-and-coming economies (more specifically Asia-Pacific) have been gradually overtaking the US and EU and hence have been impacting heavily on the increased average world production (Cefic, 2011a; Datamonitor, 2011a).

The spill-over effects of the global economic downturn of 2008-2009 have had a strong impact on the overall chemical market. Data about the European chemical industry's activity through 2009 indicate that some companies were experiencing a large pressure on their profit margins, which was particularly due to the lack in both customer demand and consumer spending (Cefic, 2011a). Except for Asia-Pacific, all regions had a negative growth rate in 2008

and 2009 in their production figures for the chemical industry as a whole (Cefic, 2011a). This negative trend, however, was not equal for all subsectors. In Europe, the economic crisis mainly affected the production of the subsectors inorganic base chemicals, petrochemicals and polymers, because these segments are much more dependent on business cycles than other chemical subsectors. In this respect, and in 2010, these subsectors experienced a stronger recovery than consumer and specialty chemicals (Cefic, 2011a). As in most other industrial sectors, the economic crisis caused many chemical companies as well as governmental institutions to diminish their activity and reconsider their R&D-projects related to the chemical industry. However, this approach always carries the risk of introducing too many short-term cost-containment measures that importantly compromise the stability and predictability necessary for the chemical industry (and especially pharmaceuticals industry) to work efficiently (Efpi, 2010).

According to size classes, the European chemical industry consists of one fourth of small sized firms (i.e. 10 to 50 employees). Together with micro-sized firms (less than 10 employees) these firms accounted for over eighty (respectively seventy) percent of all companies in basic chemicals (respectively pharmaceuticals), which means the total European chemical industry is characterized as an industry with many SMEs (Ecorys, 2009; Cefic, 2010). As SMEs typically lack the resources to conduct all steps in the 'production' of a good, from basic research through to marketing and distribution, they often specialize in innovation relating to a well-defined and narrow field. This also applies to the pharmaceuticals sector, where SMEs tend to focus on specific formulations of pharmaceutical products and often out-license or sell their innovations to larger companies that have the required resources, necessary for clinical trials and marketing (European Commission, 2009).

Belgium, one of the smallest European countries, is one of the largest world producers of chemicals and has been a home base for the chemical industry thanks to major innovations in the 19th and 20th century (Essenscia, 2011a). As a result, a diverse portfolio of chemistry-based industrial activities (including pharmaceutical activities) has developed in Belgium over the past two centuries (Essenscia, 2008). The basic chemicals segment was the largest segment in

terms of value both in 2005 and 2010, followed by the pharmaceuticals subsector that had gained largely in importance in this five year period. This trend had been going on for some time (Essencia, 2008, Datamonitor 2005 and 2011b). The Belgian chemical industry has one of the highest degrees of specialization in the world and is one of the most integrated chemical clusters (FPS Economy, 2012). Belgium only represents about 2.7% of the European GDP and 2.1% of the total EU-27 population. However, the total Belgian chemical industry (including pharmaceuticals) covered in 2008 about 6% of the total EU-27 turnover, 6% of total investments, and 14% of the EU-27 total extra-European exports of chemical products (Essencia, 2008). The comparatively very high level of Belgian chemical exports can be explained by the fact that many multinational firms use Belgium as an international transit centre, which implies that import-export trade in chemical products (especially pharmaceuticals) far outweighs the value of the domestic market (Ecorys, 2009). Furthermore, in 2009, Belgium was the number one country in the world producing chemical products (including pharmaceuticals) on a per capita basis and 11 of the world's top 15 chemical companies had invested in Belgium by establishing production sites (Essencia, 2011a). In 2010, the Belgian chemical industry (largely taken) accounted for a quarter of all the Belgian industrial activity, and employment in the sector remained stable in the past twenty years. The number of jobs in Belgian chemicals fell in 2009 - a year with difficult economic conditions - with 3.6%, to some 91,500 direct jobs. However, these job losses were lower than for the general manufacturing industry (-5.2%) (Essencia, 2011b).

Based on national account data for Belgium (Belfirst – accessed August 2012) small firms (i.e. firms with less than 50 employees) accounted for 70% of all firms in the industry in 2005. During the period 2005-2010 their share remained relatively stable (1% increase). In terms of employment, by the year 2010, the firms categorised as small firms in 2005 increased their employment with 15% compared to an overall decrease with 3% in the sector over this period. In terms of number of firms, the weight of basic chemicals compared to pharmaceuticals is about five to one. Small firms in basic chemicals account for 72% of the number of firms and during the period 2005-2010 their employment increased with 10% compared to

a sector reduction with 8%. Small firms in pharmaceuticals account for about three fifth of the enterprises and their employment increased with close to 60% compared to a sector average of 15%. As for the companies in the pharmaceuticals sector, Belgium had in 2010 more than 200 biotech and pharmaceutical firms, ranging from big pharmaceutical corporations to a large network of SMEs that specialize in all areas of biopharmaceutical fundamental and clinical research and manufacturing (FPS Economy, 2012). Because of these companies, Belgium was ranked in 2010 in the top 10 of most innovative (bio)pharmaceutical valleys in the world.

Six main reasons can be identified for Belgium being an attractive place for the chemical industry (Abrahamsen, 2011, Essenscia, 2011a and 2011b and FPS Economy, 2012): Belgium constitutes a unique logistical platform in the heart of Europe; it has a highly skilled labour force with world-class technical expertise for product and process technology and operational excellence; it provides attractive - including R&D - tax incentives for foreign investors; it developed a unique network to implement REACH (Registration, Evaluation and Authorisation of Chemicals) & CLP (Classification, Labelling and Packaging of substances and mixtures) which are both aimed at providing exchange of experience, knowledge and information between the chemical industry, the industry regulators and the service providers and at coordinating communication throughout the supply chain; it hosts and funds some of the major global and European research centres and a number of competence centres relating to the different segments of the chemical industry and there is a strong collaboration between the Belgian chemical industry and Belgian - and other countries' - universities and top scientists, and there are many academic spin-off companies; and finally, the relatively high R&D investments in the Belgian chemical industry prepare the Belgian chemical industry for top-end innovation and are directed towards sustainable innovation, which in turn makes it possible for the many SMEs in the Belgian chemical industry to grow and innovate thanks to collaborating with other firms, research institutions and universities. The latter reasons refer to the strong regional innovation (eco)system - and more specifically the interactions with private and public research organizations - available in the Belgian chemical industry (see also Teirlinck and Spithoven, 2008)

that is of crucial importance for the development of research and innovation (Cooke, 1992 and 2005) and for the enhancement of open innovation. As for knowledge sourcing and interaction, this 'regional dimension' is particularly important for the many SMEs within the chemical and pharmaceuticals industry because joint collaboration through all kinds of 'open innovation' initiatives carry substantially larger risks than is the case for larger companies (Incerti, 2008). The ample collaborations and synergies between the medical and academic worlds and the (bio) pharmaceutical research companies in Belgium generate a prosperous climate for the R&D of therapeutic innovations (Friedman, 2010), and the key contribution of this R&D in the pharmaceuticals sector is "*to turn fundamental research into innovative treatments that are widely available and - even more importantly - accessible to patients*" (Efpi, 2010, p. 5). Moreover, the 'in-house' research of SMEs is increasingly challenged because innovation often happens at the interface of several disciplines, with this scientific interdisciplinarity being extremely important for the innovative potential and hence future of the chemical industry (Essenscia, 2009).

2.4 Research focus

The focus in this paper is on R&D active small companies in the chemical industry. The central research question is whether differences in the engagement in external knowledge interactions influence these firms' performances during a period of economic downturn. More specifically the R&D active small companies will be divided in closed innovators, innovators engaged in outsourcing, innovators engaged in cooperation, and integrated innovators (i.e. companies engaged both in R&D outsourcing and research cooperation).

Two aspects of economic performance will be taken into account. The main focus will be on the evolution of firm employment during the period under consideration. However, it is clear that the crisis also brought financial constraints, and this especially for risky and long-term oriented R&D activities in SMEs.

In Europe, most companies - large and small - reported large drops in demand since November 2008. However, most companies also had business areas that were less affected by this decrease in demand (European Parliament, 2009). The literature provides somewhat

opposite and conflicting views with regard to the economic performance of small firms in times of crisis, and some researchers argue that small enterprises are more affected by the crisis than large firms. Generally speaking, because larger companies often have more potential for diversification, the economic crisis-related decrease in demand may not hit them as hard as is the case for highly specialized companies serving volatile markets. Moreover, while many large companies were finding it difficult and expensive to obtain major credit lines, SMEs were having even greater difficulties in obtaining guarantees and credit letters for imports and exports. As a result of the above, the credit ratings for a number of chemical companies have been downgraded, which has in turn prompted the banks to re-evaluate the entire industry (KPMG International, 2010).

However, according to others, and contrary to the general view above, in the chemical industry, the SMEs were less affected by the crisis than large chemical firms. In the chemical industry - and mainly this industry not including pharmaceuticals - the majority of the SMEs was not focused on a specific downstream industry at the beginning of the economic crisis and some SMEs were operating in niche markets, less affected by the crisis, which made them more 'robust' to overcome adversities in times of crisis. Moreover, to get over the crisis, the small chemical SMEs took fewer risks and they even used the recent boom to improve their capital base. On average, the chemical SMEs were also better equipped to deal with the consequences of the crisis than larger companies, because they were less active in the production of basic chemicals, the production segment that was affected the most by the crisis. The larger chemical companies were more strongly affected by the crisis, as due to past acquisitions, buyouts and stock buybacks, the chemical sector was more leveraged than before and therefore badly positioned to deal with these adversities, resulting in bankruptcy for some, while others were forced to sell their assets to pay their debts. In other words, it seems that SMEs in the chemical industry were better prepared for the adverse economic environment resulting from the crisis than some of their larger counterparts (European Parliament, 2009). These findings were confirmed in section 2.3.

3 Survey

The starting point for the empirical analysis is firm-level data on R&D in small enterprises in the chemical industry in Belgium in the year 2005. Following the EU definition (as from January 2005), a small firm is defined as a firm having less than 50 employees; an annual turnover or balance sheet not exceeding 10 million euro; and being autonomous in the sense that it is completely independent or has one or more minority partnerships (each less than 25%) with other enterprises. For the latter it should be noted that a company may still be ranked as autonomous in case the 25% threshold is reached or exceeded by public or institutional investors.

The empirical section in this paper puts into relation the openness of these companies for research cooperation and R&D outsourcing on the one hand and firm performance on the other hand. Data regarding research behaviour is provided by the bi-annual OECD business R&D survey for Belgium. This internationally standardized postal survey collects data regarding R&D (employment, cooperation, outsourcing ...) and does so in a way to cover the population of permanent R&D active firms. Firms are classified into the chemical industry if (the bulk of) their R&D is performed in this business. The presented analysis is based on the R&D survey organized in the year 2006 and offering results for the period 2004-2005. The starting point is all permanent R&D active small firms in the chemical industry in Belgium in the year 2005. This information will help to create a profile of 'openness' to external knowledge for each company. The information is linked with information regarding firm performance from the annual account database (based on Belfirst) for the period 2005-2010. The aim is to identify differences in performance according to differences in research profile. In terms of performance, both the evolution in employment and the firm's financial situation will be accounted for.

The starting point of the analysis is the official population of small firms engaged on a (quasi-) permanent basis in R&D activities mainly related to the chemical industry in Belgium in the year 2005. Based on the official OECD bi-annual business R&D survey for Belgium a population can be derived consisting of 100 enterprises. For each of these enterprises the R&D budget and personnel is known or can be accurately estimated based on previous and

more recent information (for more details see: Commission Coopération Fédérale, 2001). These companies' performance is investigated during the period 2005-2010. In order to give an accurate picture, firms that were part of a merger or acquisition during this period are excluded (6 companies are involved). Eight companies (or one out of twelve) went bankrupt. Apparently, small firms in the basic chemicals sector have been severely hit by the economic crisis since all of these bankruptcies took place in the period July 2009-December 2010. This is in line with the earlier observation that since November 2008 the economic situation for 'manufacture of chemicals and chemical products (including pharmaceuticals)' has deteriorated dramatically for Europe as a whole as well as in the European countries separately. Since we have full information for these companies for the period 2005-2010 they remain in the analysis. This leads to a target population of 94 R&D active small firms in the chemical industry.

The focus of this work is on the link between the firm's openness to external knowledge interactions and economic performance. Information regarding these items is available for 67 companies. With respect to the 94 firms in the target population this is a 70% response rate. A comparison of the R&D personnel, R&D expenditures, overall employment and financial position (current ratio), and firm age revealed no significant differences between the cases included in the analysis and those excluded. Therefore, we can assume there is no response bias. We differentiate basic chemicals (41 companies) from pharmaceuticals (26 companies) because of their particularities both in terms of activities and evolution (see section 2.3).

Compared to the population of small companies in the chemical industry in Belgium in 2005 which consisted of 287 companies, the 100 R&D active enterprises represented 40.5% of the 6730 employees. During the years 2005-2007 the total labour force of SMEs in the sector increased with over 5%, stagnated in 2008 and reached in 2010 a level almost 7% lower than in 2005. The share in employment of the R&D active small firms rose in that period to 44.5%. It is explained by a longer growth period (+12% in the period 2005-2008) and a decrease afterwards to arrive at a level slightly (-1%) below the employment level in the year 2005 (based on national account data).

4 Empirics

4.1 Profile of small R&D active companies in the chemical industry

Figure 1 categorizes the companies according to four degrees of openness for external knowledge. A classification is made according to companies that perform research in collaboration with third parties, companies that outsource part of their R&D activities, companies that combine research collaboration and R&D outsourcing (referred to in this paper as companies with an integrated networking strategy), and closed innovators (neither engaging in research cooperation nor R&D outsourcing). Research cooperation involves both formal and informal knowledge development and knowledge exchange in research cooperation. R&D outsourcing relates to the outsourcing of parts of the R&D process since only companies are considered having an internal R&D base (i.e. having at least a certain level of absorptive capacity - Cohen and Levinthal (1989)).

For the chemical industry in its totality, close to two-fifth of the firms has an integrated innovation strategy. Over one fourth has a closed innovation strategy. However, differences can be noted between basic chemicals (only one in three companies has an integrated strategy) and pharmaceuticals (half of the companies has an integrated strategy). Differences in the share of firms with a closed strategy are more modest. With regard to overall firm characteristics the box plots on the right hand side of Figure 1 present the median (middle observation) and interquartile (50% of middle values) for firm age, average employment and the share of R&D employment in the overall firm employment. Differences in firm profile in terms of age and average firm employment in relation with degree of openness are modest. In terms of employment, the median both in basic chemicals and in pharmaceuticals and for each of the four different degrees of openness is around 20 employees. In terms of age, a notable difference is that SMEs in pharmaceuticals that cooperate tend to be relatively younger firms whereas cooperation in basic chemicals rather takes place in longer established small firms. The R&D intensity (share of R&D personnel in overall firm employment) is higher in pharmaceuticals and in firms engaged both in R&D outsourcing and research cooperation (integrated strategy). Also,

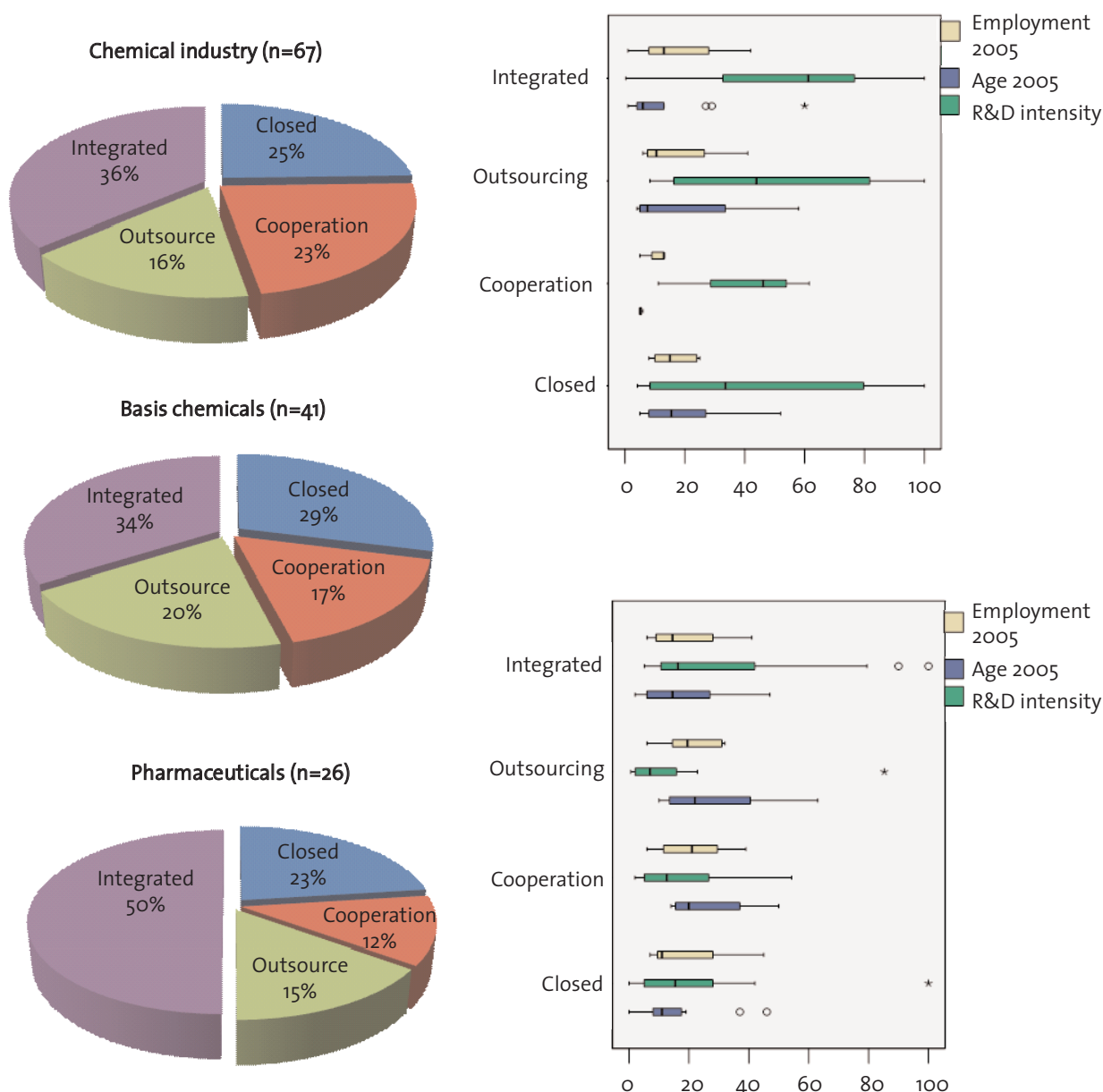
R&D outsourcing in the basic chemical industry tends to be related to small firms with a lower R&D intensity. The findings with regard to R&D intensity could point to outsourcing of more routine tasks and are a first indication for the necessity of absorptive capacity to valorise external knowledge, or can also refer to complex or more advanced research activities which

necessitate input from outside the company.

4.2 Company performance

In the literature review, the evolution of firm employment and the firm's financial position have been identified as important factors of firm survival. Figure 2 associates the different

Figure 1 Degree of openness of R&D activities in small firms in the chemical industry, 2005



forms of openness in innovation strategy in the year 2005 with firm performance in the period 2005-2010. The lagged values for research compared to firm performance indicators account for the fact that good firm performance could lead to a particular behaviour in the innovation strategy with regard to the use of external knowledge relations.

Firm employment is measured as the evolution of the overall firm employment between the year 2005 and 2010. The firm's financial situation is approximated by the current ratio (total current assets/total current liabilities) which is one of the best known measures of financial strength. The main question this ratio addresses is whether or not a firm has sufficient current assets to meet the payment schedule of its current debts with a margin of safety for possible losses in current assets, such as inventory shrinkage or collectable accounts. A generally acceptable current ratio amounts to 2 to 1. The optimum level can be sector depending but the minimum acceptable current ratio is obviously 1:1. In order to avoid strong fluctuations due to exceptional situations, the current ratio is calculated as the average ratio for the years 2009 and 2010. This ratio is of particular interest during a period of economic and financial downturn. Other financial indicators in terms of profitability and market share have been taken into consideration. However, based on the national account data for Belgium these indicators are lacking for close to half of the firms, and the indicators turned out to largely fluctuate from one year to another. This can be related to the fact that (unless some exceptions) small firms in Belgium have limited reporting duty in terms of annual accounts and balance sheet.

Figure 2 visualizes the evolution of the firms' performances. In terms of employment, a distinction is made between weak performance (negative growth – including the eight companies that went bankrupt), average growth (increase of employment between 0 and 33%), and strong growth (increase with over one third in the period 2005-2010). For the financial position, the companies are divided in a group of companies situated in a comfort zone (current ratio of two and more) and those below this threshold.

An important difference exists between companies with a closed and those with a more open innovation strategy. The majority of firms that were relying solely on the internal R&D

forces in the year 2005 experienced an average employment growth during the period 2005-2010. Firms with a more open innovation strategy tend to be characterized by a more extreme growth performance. This both in a negative (weak growth) and a positive (strong growth) sense. As such, firms that relied on a closed strategy were more stable in terms of employment during the period 2005-2010. In terms of financial position, firms with an integrated innovation strategy mainly are situated in the comfort zone (propensity of 2:1). Firms engaged in outsourcing or cooperation solely as well as closed firms have a more or less equal propensity to be in the danger zone compared to the comfort zone.

The right hand part of Figure 2 reveals companies in the pharmaceutical industry being more successful both in terms of employment and in terms of financial situation. This is in line with the general economic tendencies for these industries as presented in section 2.3. Companies with a closed R&D strategy perform relatively better in terms of the evolution of employment in the basic chemicals whereas outsourcing activities seem to be positively related both to performance and to a financial buffer in the pharmaceutical industry (as presented in Table 1). With regard to the financial buffer it should be seen whether R&D outsourcing helps to create an additional buffer due to cost-effective reasons or whether a financial buffer creates room for outsourcing. Despite the relatively low number of observations in each cell these results indicate that a strong engagement in external knowledge relations is not a guarantee for economic success at firm level and confirm Narula's (2004) findings with regard to protection of internal knowledge and preference for outsourcing activities rather than cooperation.

4.3 Broader set of R&D determinants for company performance

A main objective of this paper is to relate company performance to the degree of openness of the innovation strategy. A good company performance is related to a combination of a comfortable financial position and an average to strong growth in terms of evolution in employment. For the total of the chemical industry the upper left drawing in Figure 3 indicates the relation between different aspects of the company's (research) profile with

differences in openness in the innovation strategy. Account is taken of firm age, formal management (relates to the presence of an R&D manager), absorptive capacity (share in overall employment and the absolute number of R&D employment), and long-term orientation (share of research - versus development - in the R&D expenditures).

Firms with an integrated R&D strategy score high on all factors, except company age (these firms are on average younger companies). Also closed innovators on average are younger than

firms engaged in cooperation or - in particular - outsourcing. Companies engaged in cooperation turn out to be more long term oriented. However, this picture is somewhat different for companies in basic chemicals compared to pharmaceuticals. First, important differences can be noticed in terms of cooperation. Companies in the basic chemicals engaged in cooperation are relatively more engaged in formal R&D management, are older and perform better compared to pharmaceutical companies engaged in cooperation. Also closed

Figure 2 Degree of openness of R&D activities and firm performance

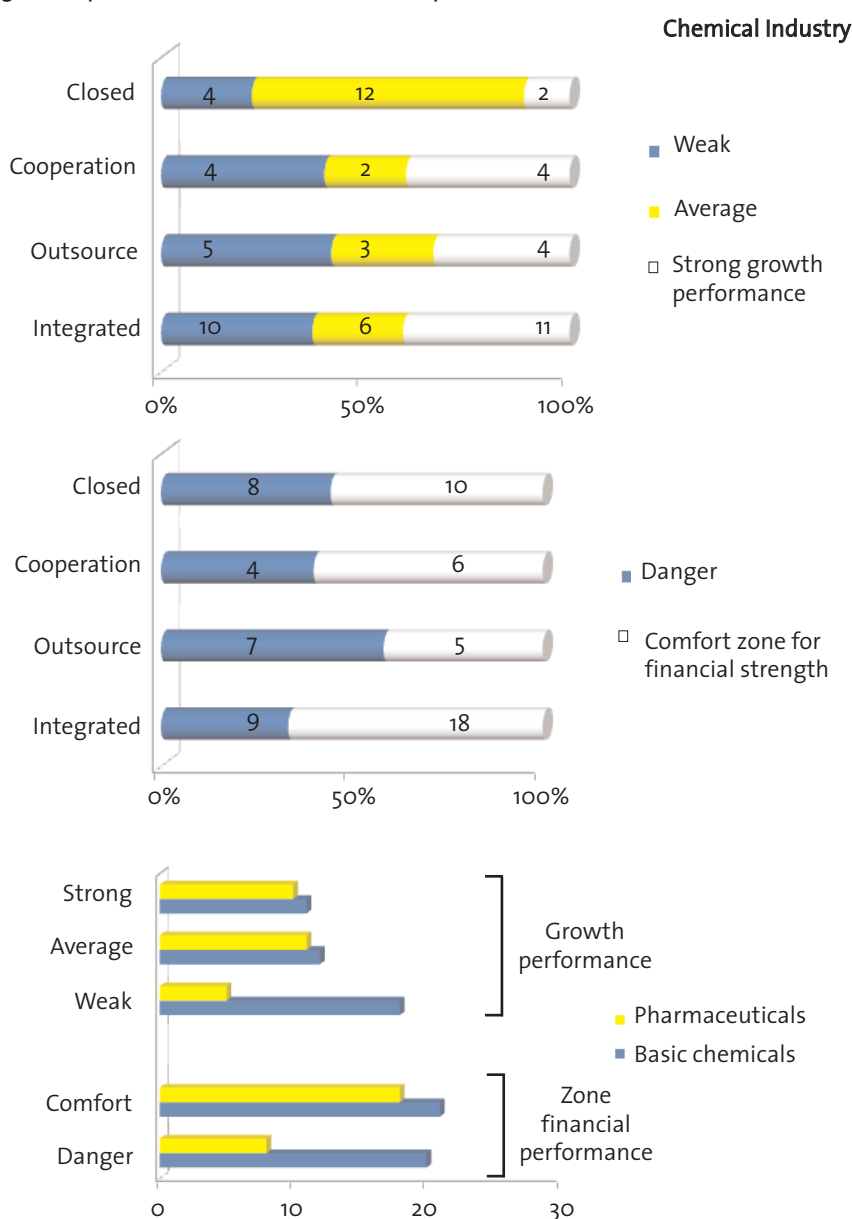
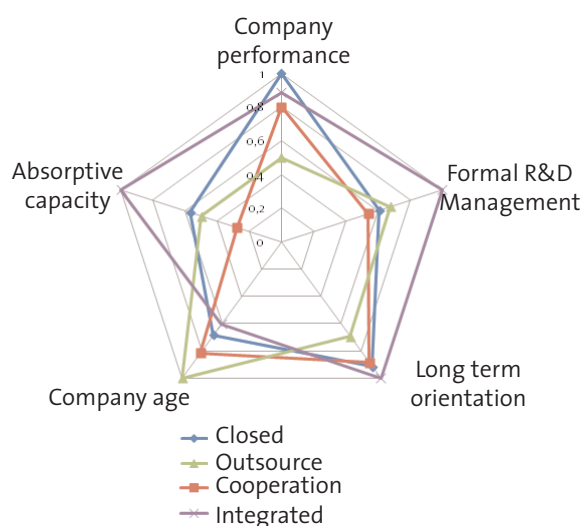


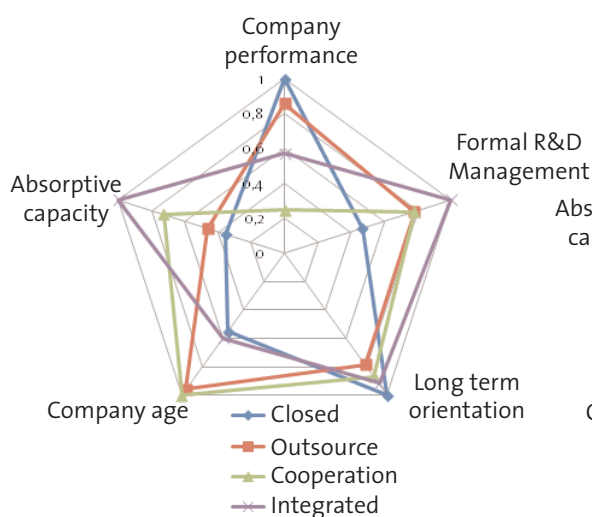
Figure 3 Characteristics by degree of openness and determinants of company performance

Chemical Industry

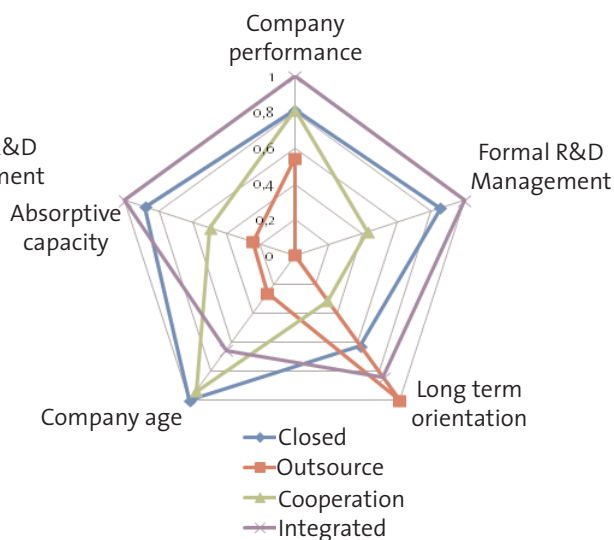


| | Probability Performance [°] | Regression Employment ^{°°} |
|-----------------------|--------------------------------------|-------------------------------------|
| Cooperation | 0.21 | 0.30 |
| Outsourcing | 0.46 | 0.59* |
| Integrated | 0.27 | 0.63* |
| Absorptive capacity | 0.02 | 0.01 |
| Formal R&D management | 1.06* | -0.08 |
| R&D experts | -2.32*** | -0.84** |
| Long term oriented | -0.04* | 0.01* |
| Company age | -0.03 | -0.01 |
| Pharmaceuticals | 0.02** | 0.46 |
| Constant | | -0.02 |
| Wald Chi2/F | 19.43** | 3.71** |
| PseudoR2/R-squared | 0.31 | 0.40 |

Basic chemicals



Pharmaceuticals



[°]Probit analysis overall good performance; ^{°°} Regression analysis for explaining the evolution of employment in the period 2005-2010; *, **, *** Significant respectively at 10%, 5% and 1%

innovators in basic chemicals perform better and are more long term oriented in their R&D. By consequence, in the pharmaceutical industry cooperating firms are relatively younger, have less absorptive capacity and perform relatively worse. Also, firms in the pharmaceutical industry that are engaged in outsourcing rely relatively less on formal R&D management and firms with an integrated strategy perform relatively better. As could be seen from Table 1 the latter mainly is related to a good position in employment growth. On the right hand side of Figure 3, a probit regression analysis presents in a more analytical way the relationship between these variables and the firm's performance. As explained before, a good company performance (binary variable: yes-no) is related to a combination of a comfortable financial position and an average to strong growth in terms of employment. The probit analysis is complemented with a regression analysis explaining the evolution of firm employment over the period 2005-2010.

The probit analysis reveals openness of the innovation strategy to exert no significant influence on firm performance (combined employment growth and financial position). Turning to the R&D related variable, the presence of formal R&D management and longer term oriented research positively influence the firm's performance. By contrast, company age and especially the share of experts in the internal R&D personnel negatively influence firm performance. The latter is surprising but could be linked to the economic and financial crisis. The overall measurement of absorptive capacity (a combined measurement of critical mass of R&D employment and the intensity of R&D employment in overall firm employment) has no significant influence on firm performance. Of course, this should be seen in light of the fact that only (quasi-) permanent R&D active companies are part of the target population.

A refinement of the results in the regression analysis explaining employment growth provides a different picture. The analysis reveals both R&D outsourcing and an integrated innovation strategy at the beginning of the period to positively influence the evolution of overall firm employment during the period 2005-2010. R&D outsourcing positively affects firm employment. These findings are in line with earlier findings by Teirlinck et al. (2010) concluding that R&D outsourcing does not negatively influence internal R&D employment.

Also a longer term oriented research focus positively influences overall firm employment. By contrast the share of highly qualified experts in total R&D employment negatively influences employment evolution. This could be related to missing opportunities to valorise research findings within the company or to highly specialized or niche market activities in small firms heavily relying on this type of employee profile for R&D. Further qualitative research in this field is advisable. Finally, a similar regression model to explain the financial position of the company did reveal no significant influences of the variables under consideration. This does not necessarily mean that the influence is absent since the measurement of a good financial position remains a difficult endeavour. Both a below average and above average current ratio may point to a weakness. The former since there clearly is a lack of short term financial means. The latter could point to management incapability to make appropriate use of financial slack (Cyert and March, 1963).

5 Reflections on implications for R&D management in small firms in the chemical industry

This paper examined the relation between the use of external knowledge interactions and performance in small firms in the chemical industry. In a sector increasingly characterised by internationalisation of knowledge and research, small firms are disadvantaged due to their absolute size limitations which may be enhanced by tendencies towards multiple technological competences and cross-border competition (Narula, 2004). Moreover, high risk and uncertainty involved in research is hard to bear on the shoulders of small firms. Therefore, adapting an open innovation model with engagement in research cooperation and R&D outsourcing may - partly - compensate limited internal resources.

In an empirical analysis of a representative sample of R&D active small firms in the chemical industry in Belgium, the relationship between the extent of engagement in open innovation practices and firm performance has been examined.

The Belgian chemical sector is characterised by a strong economic importance, a high export orientation and the presence of a broad range of big multinational companies and research centres and a well developed (eco) innovation

system. Like most of the other developed economies the sector is confronted with increasing international competition and decreasing market shares in the world production. The period under consideration covers the years 2005-2010, a period initially characterized by economic prosperity turning into a financial and economic crisis since the year 2008. The openness of research activities in the year 2005 is brought into relation with the firm's economic performance in terms of employment growth as well as its financial position.

Differentiating according to the degree of open innovation, one fourth of the firms follows a closed R&D approach, compared to two-fifth combining both outsourcing and collaboration in research. About one sixth of the firms engages in outsourcing solely and almost one fourth does so in research cooperation. Firms active in basic chemicals tend to be less (one third) engaged in a combined cooperation-outsourcing approach compared to firms in the pharmaceutical industry (one out of two firms).

In line with the dominant tendency in Europe of a more positive evolution of pharmaceuticals compared to basic chemicals in the period 2005-2010, firms active in basic chemicals turned out to perform weaker in terms of employment growth and more often face a danger zone in terms of ability to pay short term debts. In terms of openness of the innovation strategy, closed firms tend to perform at a more constant and average growth rate whereas firms more open for external knowledge interactions tend to perform further away from the average (very well or rather badly).

Taking into account a broad range of additional factors, openness of the innovation process is found to exert a positive influence on the evolution of firm employment; however only in case R&D outsourcing is involved. Firms solely engaged in research cooperation do not outperform firms following a closed R&D strategy. In terms of a combined successful employment evolution and a healthy financial position, no significant influence is noted by the degree of openness of the firm's R&D strategy. Elements that do matter are the presence of formal R&D management and a long-term vision in research activities. Also, compared to more established firms, younger firms face more difficulties to perform well during a period of economic downturn. Taking the empirical findings presented in this paper

into account, the answer to the central research question is not straightforward: the engagement of SMEs in open innovation practices in the chemical industry is not a priori a reason for later successful performance. It seems that companies that formally manage, have a long term orientation in R&D, and that outsource (non-core) R&D activities outperformed their counterparts not having these characteristics. These results should be seen in light of the particularities of the Belgian context and a period of economic downturn.

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Research Paper

Research Inequality in Nanomedicine

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The 10-90 gap is an idea in the healthcare literature that less than 10% of all research funding goes to solving health problems that are 90% of the global disease burden. This paper examines whether there is inequality in nanotechnology healthcare research (nanomedicine). To understand the inequality in nanomedicine, I conducted a bibliometric review of Web of Science and PubMed databases. Overall there is not large inequality in nanomedicine research. The bibliometric analysis shows that most nanomedicine research is done in high income countries, but their research portfolios extend beyond rich world diseases like Alzheimer's disease and diabetes to include research on malaria, tuberculosis and HIV/AIDS. Of the nanomedicine articles that are directed towards specific diseases (about 20% in Web of Science and PubMed), the majority of the research (86%) will help both the rich and the poor, while only 7% of the research focuses solely on rich world diseases and 7% focus solely on diseases of poverty. The most researched nanomedicine topic is cancer. It accounts for 16% of nanomedicine literature. Overall less than 20% of nanomedicine research goes to solving health problems that are 50% of the global disease burden. Given nanotechnology is so linked to chemistry and the chemicals industry, the inequality within nanomedicine will impact how those industries supply materials, supplies and information to the various stakeholders involved in nanotechnology and healthcare.

1 Background/Literature Review

Access to health care is a basic human right and over the past twenty years healthcare has become a focus of development and aid organizations. One major initiative to improve global health is the United Nations' (UN) Millennium Development Goals (MDGs) that were adopted in 2000. The MDG's outline eight different poverty arenas that the world community wants to alleviate by 2015 (United Nations, 2010a). Three of the goals, child health, maternal health, and HIV/AIDS, deal directly with healthcare. With regards to child health, the UN wants to reduce under five-child mortality rate by two-thirds by focusing on decreasing pneumonia, diarrhea and measles. For maternal health, the MDG is to reduce the maternal mortality ratio by three-quarters and ensure that every woman has access to pre-and postnatal care. Finally the world community has committed to halting and reversing the spread

of HIV/AIDS. It's estimated that HIV/AIDS is the 6th most deadly disease and that the disease kills 2 million people each year (World Health Organization, 2008).

Despite efforts to improve the health of the indigent, the poor live a greater proportion of their lives sick compared to the rich and they have significantly lower life expectancy than the rich (World Health Organization, 2008). A potential cause of the health disparity is that there is not much research on diseases that affect the poor. The Global Forum for Health Research came up with the term the 10/90 gap to describe the inequalities in health research funding (Global Forum for Health Research, 2004). The 10/90 gap refers to the phenomenon that less than 10% of research funding goes to studying diseases that are 90% of the disease burden. Since 1990, the Global Forum for Health Research has brought awareness to the 10/90 gap by producing reports that track research disparity and engaging with the public and

media about the problem. A report by the Médecins Sans Frontières found that health research expenditures are still heavily imbalanced. Four major diseases in developing countries tuberculosis, leishmaniasis, malaria, and trypanosomiasis are 5% of the global disease burden, but research expenditures for this disease are 0.1% of global health R&D (Global Forum for Health Research, 2004; Médecins Sans Frontières, 2001). Other studies have discussed the 10/90 gap in other healthcare arenas like medicines (Reich, 2000), female healthcare research (Doyal, 2004), cardiovascular diseases research (Martini et al., 2003) and healthcare publications (Mari et al., 2010; Pastrana et al., 2010). In general these studies reach similar conclusions as the Global Health Forum and Médecins Sans Frontières; medicine and health R&D is unequal and that society needs major reforms to fix the problem.

Compared to income and education inequality, health inequality is particular dangerous because unlike other problem facing society, diseases can easily jump borders and spread around the world. Bacteria and infections are not biased; they can infect the rich and poor, global north and global south. In the past century rich countries undertook vast campaigns to eradicate several diseases like malaria and mumps. However if the diseases are not treated in other parts of the world, they could reemerge in healthier nations. Recently The National Institute of Allergy and Infectious Disease in the USA identified five reemerging diseases including the mumps virus, streptococcus (strep throat), staphylococcus aureus (staph infection) (NIH, 2010).

However the legitimacy of the 10/90 gap has been challenged (Stevens, 2007). The opponents of the 10/90 gap argue that the poor's higher mortality rates have little to do with research portfolios, but rather other societal conditions that prevent the poor from getting the necessary treatment. The opponents cite that most individuals in developing countries do not die from obscure diseases, but rather from more common illnesses like lower respiratory infections and heart disease. These diseases afflict both the rich and the poor (World Health Organization, 2008) and hence it is an exaggeration to say that 90% of all research funding goes to solving problems of the rich. Moreover critics note that other major killers of the poor, like malaria and diarrheal diseases, have been thoroughly studied and many

medicines exist to treat these ailments. Individuals die from these diseases because of other societal factors that prevent treatment, not from a lack of research. Finally the opponents of the 10/90 problem state that many organizations, like the Infectious Disease Research Institute, study diseases of poverty and hence there is not a dearth of research on neglected diseases (Stevens, 2007).

This paper investigates the 10/90 gap in relation to nanotechnology. Many believe that nanotechnology is the next big research trend. One scholar, Mohamed Hassan (2005), says that "nanotechnology could prove to be a 'transformative technology comparable in its impact to the steam engine in the 18th century, electricity in the 20th century, and the Internet in contemporary society'" (Hassan, 2005). As a result many countries, especially poorer countries, are heavily investing in the technology. A study conducted by Salamanca-Buentello et al. (2005) outlines ten different nanotechnologies that will help the world's poor. Three of the ten technologies, disease diagnosis, drug delivery, and health monitoring, deal with healthcare issues (Salamanca-Buentello, 2005).

There is often confusion in defining nanotechnology (Balogh, 2010). This paper uses the National Nanotechnology Initiative definition of nanotechnology which "is the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale" (PCAST, 2010). At the nanoscale, matter has different properties, like conductivity and reactivity, which make it possible to do novel research and create new products. Central to nanotechnology is chemistry. Chemistry specializes in manipulating atoms and molecules to create new substances (Whitesides, 2005). Without chemistry, nanotechnology and hence nanomedicine, could not exist as an emerging technology.

It is estimated that in 2005 there were 38 nano-enabled medical products with sales of about \$6.8 billion, over 150 companies working in nanomedicine. This market was expected to double by 2012 (Wagner, Dullaart, Bock, & Zweck, 2006). In addition to these products, the field of nanotechnology will have a variety of economic impacts like increasing the

productivity of manufacturing, create a bigger market for scientists familiar with nanotechnology, and increase competition between sectors (Zawislak, Marques, Esteves, & Rublescki, 2010). Chemistry and chemical companies are also expected to benefit from the increased emphasis on nanomedicine. Chemical companies supply many of the materials and equipment to conduct nanomedicine research. Moreover chemists are often used in nanotechnology labs to do research. (Zawislak et al., 2010). Hence it is important for chemists and chemical businesses to understand nanomedicine in order to participate in this new emerging field and market.

2 Research Problem

Though there is some agreement that nanotechnology can help the world's poor, is there poverty related nanotechnology research being conducted or is all the research geared to the problems of the rich and luxury goods? Is the 10/90 gap strong in nanomedicine or is the gap a different ratio? This study is a descriptive investigation of research intensity in nanomedicine and inequality in nanomedicine research.

There are three factors of nanomedicine inequality. First inequality in nanomedicine occurs between the different income levels of countries. Do very high income countries dominate the research or is the research occurring equally across the world? The global distribution of nanomedicine is affected by two competing trends. Scholars have observed that nanotechnology research is taking place in both rich and poor countries. Many poor countries view nanotechnology as the next technology revolution so they are investing in the field early so they will not be left behind (Hassan, 2005). As a result it is expected that nanomedicine research will be done in low income countries. However medical research is still dominated by rich countries (Médecins Sans Frontières, 2001) and therefore it is also likely that nanomedicine will follow the same trend as general medical research.

Hypothesis 1: Nanomedicine research is predominantly conducted in very high income countries

A second factor of inequality in nanomedicine is whether it focuses on diseases of very high

income or low income countries. The currently literature on the 10/90 gap supports the idea that medical research will focus on diseases of the rich. Moreover, much of the medical research is funded by governments. Since the very high income countries invest more in R&D than medium and low income countries, it is expected that most of the money will focus on problems that affect those countries.

Hypothesis 2: There is a disproportionate amount of nanotechnology research conducted on diseases of very high income countries as opposed to the diseases of other countries

A third factor of inequality is whether researchers are focusing on the most dangerous diseases or are their attentions drawn to diseases that cause relatively few deaths. The literature suggests that research is focused on diseases that cause relatively few deaths while neglecting diseases that cause a lot of deaths (Global Forum for Health Research, 2004).

H1.3 The majority of nanomedicine research will only address diseases that kill relatively few people.

This study fills a gap in the literature. Most other studies discuss the societal and ethical implications (SEI) of nanotechnology and describe potential problems that may arise because of it (ETC Group 2006; Meridian Institute, 2006; Roco & Bainbridge, 2005). But there are few articles that quantitatively analyze inequality in nanotechnology research. This paper, on the other hand, examines the actually trends in nanomedicine research to determine if scientists are studying nanotechnology for the poor. In addition, this study not only explores where the research is being conducted, but it analyzes the content of the publications to determine which diseases are receiving the most attention.

3 Methods

To analyze inequality in nanomedicine research, I conducted a bibliometric examination of Web of Science (WoS) and PubMed databases. Web of Science is one of the largest publication databases. It contains over 13,000 journals in 200 disciplines ranging from 1900 until today (Thomson Reuters, 2012). WoS is a prominent database used by bibliometricians (Leydesdorff,

2008) to study publication and collaboration patterns in diverse topics like including tropical medicine (Falagas, Karavasiou, & Bliziotis, 2006), nano/biosensors (Huang, Peng, Guo, & Porter, 2010) and emerging technologies (S. Cozzens et al., 2010). My analysis is based on a nanotechnology database created by a group of researchers at the Georgia Institute of Technology (Porter, Youtie, Shapira, & Schoeneck, 2007). The database contains a list of all the nanotechnology articles in WoS. The team created the database by using eight Boolean logical search phrases to find the nanotechnology articles and then they used a second list of keywords to remove extraneous articles from their search. The database contains articles ranging from 1990-2012, but this study limits its scope to nanotechnology publications from 2000-2010. From 2000-2010, there are about 617,000 nanotechnology articles.

The second database used in this study is

PubMed, a free online digital database of biomedical journal articles developed by the National Center for Biotechnology Information in the U.S. PubMed is a smaller database than WoS, but it is geared towards biomedical and health care related articles. The major component of PubMed is a database called Medline which has about 5,400 journals dating back to 1948 (National Center for Biotechnology Information, 2012). After accessing PubMed, I searched for nanotechnology articles in the database using a similar version of the Porter et al (2007) strategy. The PubMed search yielded 56,000 nanotechnology articles.

After the two nanotechnology databases were created, I developed a search strategy to find the health related articles by reading several nanomedicine review articles (ETC Group, 2006; OECD, 2005; Sahoo, Parveen, & Panda, 2007; Silva, 2004). These articles gave the keywords to formulate the health filter. See Table 1 for the

Table 1 Health search keywords

| | | | |
|--|--|--|---|
| - alzheimer alzheimer [a-z]* | - cardiovascular - cholesterol - clinical clinic[a-z]* | - hepatitis hepatitis[a-z]* | - pregnant pregnan[a-z]* |
| - biomedical biocomp[a-z]* biomedic[a-z]* | - dental dental[a-z]* ^peridonta[a-z]* | - humans male human[a-z]* female | - psychotic psychotic[a-z]* psycholo[a-z]* dopamine |
| - blood | - diabetes diabetes[a-z]* insulin | - liver ^liver\$ | - sick illness |
| - Bone dentin skull bones skeletal[a-z]* | - disease diseas[a-z]* | - malaria | - skin |
| - brain nervous syst[a-z]* brain[a-z]* neuron | - drug drug delivery vaccine antibiotic drug[a-z]* | - medical medic[a-z]* physio[a-z]* | - therapeutic therap[a-z]* |
| - cancer chemother[a-z]* mamap[a-z]* cancer breast mammogr[a-z]* tumor antitumor | - health health[a-z]* | - medicine nanomedi[a-z]* medicin[a-z]* | - tissue tissue engineering |
| | | - orthopedic orthoped[a-z]* prosthetic | - toxicity toxin[a-z]* toxic[a-z]* |
| | | - pediatric | - tuberculosis |
| | | - pharma pharma[a-z]* | |

list of keywords. Out of the 617,000 nanotechnology articles in WoS, 12% relate to nanomedicine; in PubMed, 48% of the 118,000 nanotechnology article relate to medicine.

Like all databases, WoS and PubMed have their limitations. These databases have a greater representation of journals from rich, western countries compared to developing countries and these databases bias towards journals that are in English (UNESCO, 2005). Moreover the databases do not have 100% coverage of all the journals and so some publications that are not indexed in Web of Science or PubMed will be

absent from the study.

The 10/90 gap refers to the observation in the 1990's that less than 10% of research funding went towards researching health problems that account for 90% of the global disease burden (Global Forum for Health Research, 2004). For this study, the global disease burden was based the mortality rates of the top diseases around the world. In 2008 the World Health Organization (WHO) updated a 2004 study that measured the top diseases based on their mortality rates. The WHO also classified the diseases based on a variety of factors including

Table 2 Leading cause of death worldwide in 2004 (World Health Organization, 2008)

| Rank | World | Deaths (millions) | % of Total Deaths |
|------|-------------------------------|----------------------|----------------------|
| 1 | Ischaemic heart disease | 7.2 | 12.2 |
| 2 | Cerebrovascular disease | 5.7 | 9.7 |
| 3 | Lower respiratory infections | 4.2 | 7.1 |
| 4 | COPD | 3.0 | 5.1 |
| 5 | Diarrhoeal diseases | 2.2 | 3.7 |
| 6 | HIV/AIDS | 2.0 | 3.5 |
| 7 | Tuberculosis | 1.5 | 2.5 |
| 8 | Trachea/bronchus/lung cancers | 1.3 | 2.3 |
| 9 | Road traffic accidents | 1.3 | 2.2 |
| 10 | Prematurity/ low birth weight | 1.2 | 2.0 |
| ... | ... | ... | ... |
| | Total Deaths Worldwide | 58.8 | 100 |

Table 3 Leading cause of death in high and low income countries in 2004 (World Health Organization, 2008)

| High-Income Countries | Deaths (millions) | Low and middle income countries | Deaths (millions) |
|-------------------------------|----------------------|------------------------------------|----------------------|
| Ischaemic heart disease | 1.3 | Ischaemic heart disease | 5.9 |
| Cerebrovascular disease | 0.8 | Cerebrovascular disease | 5.0 |
| Trachea/bronchus/lung cancers | 0.5 | Lower respiratory infections | 3.8 |
| Lower respiratory infections | 0.3 | COPD | 2.7 |
| COPD | 0.3 | Diarrhoeal diseases | 2.1 |
| Alzheimer/ other dementias | 0.3 | HIV/AIDS | 2.0 |
| Colon and rectum cancers | 0.3 | Tuberculosis | 1.4 |
| Diabetes Mellitus | 0.2 | Neonatal infections | 1.1 |
| Breast Cancer | 0.2 | Prematurity/ low birth weight | 1.1 |
| Stomach Cancer | 0.1 | Malaria | 0.9 |
| ... | ... | ... | ... |
| Total | 8.1 | Total | 50.7 |

the mortality rates of the diseases in high, middle and low income countries (World Health Organization, 2008). Table 2 shows that top ten causes of death worldwide and Table 3 shows the top diseases in high and low income countries. The leading causes of death in the rich world come from illnesses like Alzheimer's disease, lung, colon, breast and stomach cancers, and diabetes. In poor countries, a large percent of the population die from diarrheal diseases, HIV/AIDS, tuberculosis and malaria. There are four diseases, ischaemic heart diseases, cerebrovascular disease, lower respiratory infection and COPD, that are common in both high income and low income countries. The list of diseases from the World Health Organization's Burden of Disease report was used to develop a search filter to find diseases in the nanomedicine database and to classify the diseases as high income or low income country diseases (World Health Organization, 2008).

Finally this study classifies countries using the 2011 United Nations Human Development Index (UN-HDI). The UN-HDI groups countries

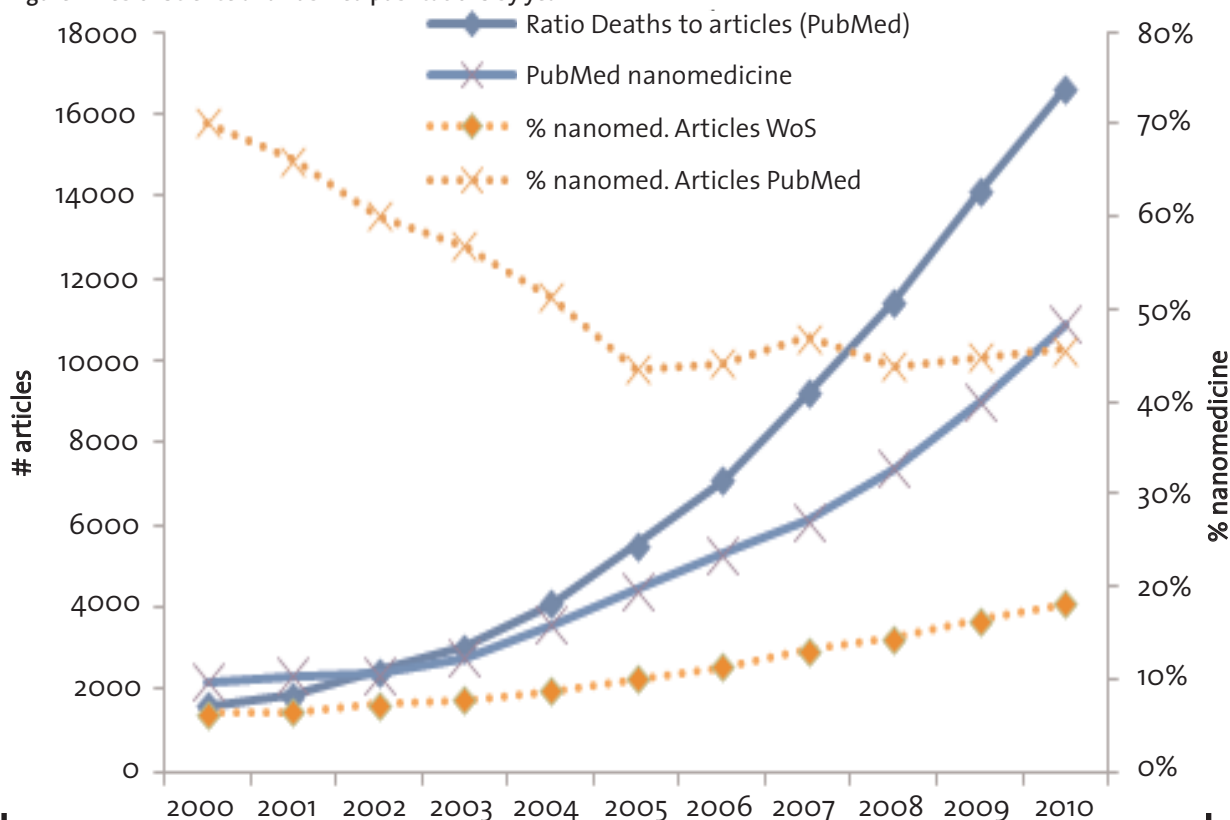
into four categories, very high development, high development, medium development and low development, by using three dimensions, health, education levels, and living standards to develop a composite measure of the countries and then ranks them (United Nations, 2010b).

4 Results

4.1 Data Description

Below is the summary data from the nanomedicine database. WoS contains 77,078 nanomedicine articles and PubMed contains 63,653 nanomedicine articles from 2000-2010. In those 11 years both PubMed and WoS had a steady increase in the number of nanomedicine articles. However the databases contain different relative amounts of nanomedicine publications (see right axis of Figure 1). In PubMed more than 50% of the nanotechnology articles relate to nanomedicine while in WoS between 10% and 20% of nanotechnology articles relate to nanomedicine. It's not surprising that PubMed has relatively more nanomedicine

Figure 1 Web of Science and PubMed publications by year



article compared to WoS because the database focuses on biomedical journals. The percent of nanomedicine articles in WoS increase from 10% to 20% from 2000 to 2010. In 2000, 70% of nanotechnology articles in PubMed related to nanomedicine. However by 2005 the percent of nanomedicine articles in PubMed fell to 50%.

4.2 Country level inequality

Table 4 is a list of the top countries publishing nanomedicine articles. In general, very high income countries like the USA, Germany, UK, and Japan published the most nanomedicine articles. However there are several emerging economies that also publish a lot of nanomedicine research. Most notably, China and India rank within the top ten countries for nanomedicine publications.

In both the PubMed and Web of Science, China has the second most nanomedicine publications. China's prominence in nanomedicine research is not unexpected. It is estimated that China spent over \$250 million on nanotechnology in 2008 (Liu et al., 2009) and that it has over 30 institutions conducting nanotechnology research (Niosi & Reid, 2007). Moreover, other studies have also confirmed that China is a world leader in nanotechnology (Guan & Ma, 2007; Liu et al., 2009). India ranks tenth in nanomedicine publications in WoS and seventh in PubMed. Since 2001, India has formally invested in nanotechnology. In 2007 India started the NanoMission and they committed US \$230 million to nanotechnology (Ramani, Chowdhury, Roger, & Reid, 2010). Other emerging economies like Brazil, Russia, Turkey and Iran rank within

Table 4 Nanomedicine publications by country

| Rank | Country | WoS | PubMed |
|------|----------|-------|--------|
| 1 | USA | 24400 | 17200 |
| 2 | China | 12500 | 7900 |
| 3 | Germany | 6000 | 3500 |
| 4 | Japan | 5200 | 3700 |
| 5 | UK | 4600 | 3700 |
| 6 | France | 3900 | 1900 |
| 7 | S. Korea | 3600 | 1400 |
| 8 | Italy | 3000 | 2400 |
| 9 | India | 2900 | 2000 |
| 10 | Canada | 2400 | 1600 |
| ... | ... | ... | ... |
| 16 | Brazil | 1300 | 1200 |
| ... | ... | ... | ... |
| 19 | Russia | 1000 | 200 |

Table 5 Nanomedicine publications by country classification

| Country Classification | % Nanomedicine | | % Nanomedicine | |
|------------------------|----------------|-------|----------------|--------|
| | WoS | WoS | PubMed | PubMed |
| Very High Development | 71500 | 76.6% | 46900 | 77.3% |
| High Development | 5500 | 5.9% | 3200 | 5.3% |
| Medium Development | 16300 | 17.5% | 10500 | 17.3% |
| Low Development | 100 | 0.1% | 100 | 0.2% |

* Note: articles co-authored by scientists in different country classifications are double-counted. Therefore if someone from a very high development country works with someone from a low development country, the article is counted in both categories.

Table 6 Most researched diseases using nanomedicine in WoS and PubMed

| Disease | Deaths in 2004 (1000's) | Nano-medicine Publications (WoS) | Nano-medicine Publications (PubMed) | High Income Disease | Low Income Disease | High and Low Income Disease |
|------------------------------|-------------------------|----------------------------------|-------------------------------------|---------------------|--------------------|-----------------------------|
| heart disease | 8923 | 420 | 1000 | | | X |
| cerebrovascular dis. | 5712 | 100 | 230 | | | X |
| lower respiratory dis. | 4177 | 170 | 620 | | | X |
| prematurity/neonatal infect. | 3180 | 80 | 630 | | X | |
| COPD | 3025 | 60 | 130 | | | X |
| diarrhea | 2163 | 60 | 110 | | X | |
| HIV/AIDS | 2040 | 420 | 300 | | X | |
| tuberculosis | 1464 | 270 | 180 | | X | |
| lung cancer | 1323 | 480 | 290 | X | | |
| traffic accidents | 1275 | 0 | 0 | | | X |
| diabetes | 1141 | 290 | 940 | X | | |
| malaria | 890 | 170 | 150 | | X | |
| self inflicted wounds | 844 | 0 | 0 | | | |
| stomach cancer | 803 | 10 | 10 | X | | |
| psychological dis. * | 661 | 640 | 670 | | X | X |
| colon cancer | 639 | 220 | 210 | X | | |
| breast cancer | 519 | 1630 | 750 | X | | |
| Alzheimer | 492 | 820 | 430 | X | | |
| prostate cancer | 308 | 570 | 310 | X | | |
| hepatitis (B and C) | 159 | 530 | 320 | | X | |
| arthritis | 127 | 300 | 340 | | | X |
| Parkinson's | 110 | 300 | 210 | X | | |
| skin cancer | 68 | 490 | 350 | X | | |
| ... | ... | ... | ... | | | |
| Total | 58,772 | 16,550 | 12,880 | | | |

* psychological diseases does not include Alzheimer's disease or Parkinson's disease

the top 25 nanomedicine publications in WoS or PubMed.

Table 5 classifies the countries based on the 2011 United Nations Human Development Index. There is a clear research gap between the different country classifications. The majority of nanomedicine research is conducted in very high income countries (about 77%) while the high, medium and low income countries lag behind. Medium development countries have the second highest nanomedicine publication count followed by high and low development

countries. The productivity of medium countries is led by China and India which are classified as medium developed countries.

4.3 Disease research inequality

Nanomedicine, like other scientific fields, contains both basic and applied research. Much of the current literature in nanomedicine is basic research and does not apply to a specific disease. Using the top diseases found in the World Health Organizations Burden of Disease report as a

guide for prominent world diseases, this study finds that about 20% of nanomedicine publications were directed towards a particular illness. The rest of the nanomedicine research was not directed towards fixing a specific disease. Table 6 lists the top researched diseases in nanomedicine. High income country diseases are illnesses like Alzheimer's and diabetes while low income country diseases are diarrheal diseases, HIV/AIDS, tuberculosis, malaria and neonatal infections/deaths from prematurity. Common to both groups are cancer, heart disease, cerebrovascular disease, respiratory infection and chronic obstructive pulmonary disease (COPD).

The disease with the most research publications in both WoS and PubMed is cancer. In both databases cancer accounts for 16% of all nanomedicine publications and about 75% of the directed nanomedicine research. Cancer is major cause of death, but the strong emphasis on cancer over exaggerates its burden of disease. It is estimated that cancer causes 12% of deaths worldwide (World Health Organization, 2008). For men the most deadly type of cancer is lung and trachea cancer while breast cancer is the deadliest type of cancer for women. Over the past decade governments and foundations invested a lot of money in cancer research. For example, in 2009, the National Cancer Institute (NCI) disbursed \$5 billion dollars for cancer research; 12% of the funds went to breast cancer, 6% to prostate cancer and 5% to lung cancer ("National Cancer Institute", 2011). The large investment in cancer research likely drives the emphasis on cancer in nanomedicine. Table 7 lists the most researched cancers in nanomedicine. The publication profile closely resembles that funding patterns of the NCI. The

cancers with the most publications, like breast cancer, also have the most funding by the NCI.

Another reason cancer features prominently in nanomedicine is that scientists are investigating whether nanoparticles cause cancer. Some scientists worry that nanoscale fibers like carbon nanotubes may increase the risk of some types of cancer, like lung cancer, if the particles are inhaled (Stern & McNeil, 2008). Environmental, health and safety (EHS) research of nanotechnology has grown in prominence and funding over the past 10 years (National Science and Technology Council, 2011) and the increasing emphasis on the EHS aspects of nanotechnology may increase the nanomedicine research on cancer.

Two main uses of nanomedicine for cancer treatment are drug delivery systems and cancer detection systems (Nie, Xing, Kim, & Simons, 2007). Scientists are inventing better drug delivery systems in order to target cancerous cells more directly. If the scientists can improve drug delivery systems, they can increase the effectiveness of the drugs and decrease the side effects of cancer treatment. For cancer detection, scientists hope that nanotechnology will enable early detection of the cancerous cells so that the disease can be treated earlier in its development which will reduce the mortality rate of cancers (Ferrari, 2005).

Alzheimer's, the second most researched topic in WoS, is the 6th most common cause of death for developed countries. Like cancer there is significant funding and advocacy to support Alzheimer's research (Alzheimer's Association, 2012). But unlike cancer Alzheimer's is not one of the top ten causes of death. Rather, Alzheimer's disease is only a leading cause of death in very high income countries. The other

Table 7 Cancer Research in Web of Science (WoS) and PubMed

| Type of Cancer | WoS | PubMed | (\$ millions) |
|-----------------|-------|--------|---------------|
| breast cancer | 1630 | 749 | 600 |
| prostate cancer | 567 | 307 | 294 |
| skin cancer | 494 | 354 | 104 |
| lung cancer | 484 | 291 | 247 |
| colon cancer | 217 | 205 | 264 |
| bladder cancer | 69 | 54 | 26 |
| ... | ... | ... | ... |
| Total cancer | 12350 | 10083 | 5000 |

“high income” diseases that receive a lot of attention from nanomedicine are diabetes, colon cancer and stomach cancer.

In contrast to very high income diseases, the most researched diseases for low income are diarrheal disease, HIV/AIDS, neonatal infections, tuberculosis and malaria. Hepatitis, another major nanomedicine research area, is not one of the top killers in low income countries but the disease disproportionately affects the poor (see Table 6).

The nanomedicine publication patterns from low income countries are distinct from very high income countries. While very high income countries conduct research on all the diseases, nanomedicine research from low income countries is focused on diseases of poverty like malaria and tuberculosis; 78% of the nanomedicine in WoS from low income countries are about diseases of poverty. In comparison only 16% of nanomedicine articles from very high income countries deal with diseases of poverty. Therefore even though low income countries produce far fewer nanomedicine publications than very high income countries, their research profiles are geared towards diseases that affect their population.

Another trend among low income countries is that they collaborate more than high income countries; 78% of the nanomedicine articles from low income countries in WoS were “north-south” collaborations. On the other hand a small percentage of collaborations in very high income countries were with the global south. The data suggests that low income countries rely on collaboration with rich countries in order to produce researched indexed in WoS or PubMed.

Overall in WoS (Figure 2) about 86% of the nanomedicine research impacts both rich and middle/low income countries; 7% of the research is directed towards problems of the rich and 7% is directed towards problem of middle/low income countries. A significant amount of the research that will help both rich and poor relates to cancer; 88% of the “pro-poor” research is cancer research. Even when cancer is removed from the dataset, the data still shows that nanomedicine research is balanced between country income groups (Figure 3)¹. Finally, when the publication profile is examined based on population, there is not any inequality in nanomedicine research. About 5.7 billion or 82% of the world’s population live in middle/low

income countries and 93% of nanomedicine research will benefit this population. Most of that benefits the poor is about cancer, however there is significant research on malaria, tuberculosis and HIV/AIDS.

4.4 Inequality in Disease Burden

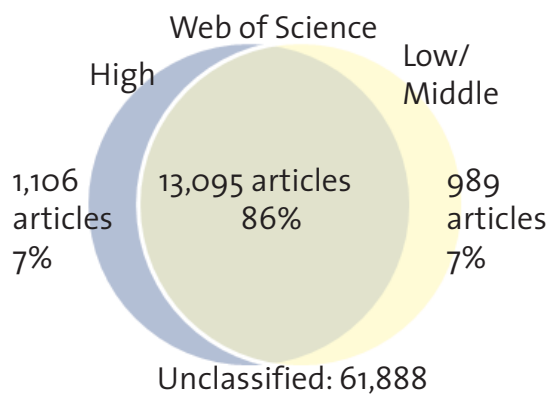
The top ten leading causes of death accounted for 30 million deaths or 50% in 2004. The total amount of directed nanomedicine research on these deadly diseases is 10% in WoS and 19% in PubMed. Hence diseases that account for half the world’s death receive between 10% and 19% of research. This suggests that is a 20/50 gap: Less than 20% of nanomedicine research goes to solving problems that account for 50% of the global disease burden. Though this statistic shows that there is inequality in nanomedicine research, it is not as bad as a 10/90 gap.

Some diseases kill relatively few people each year but they receive a lot of attention from researchers; these diseases are over researched. On the other hand some diseases are under researched; these diseases have high mortality rates yet are not heavily researched. Figure 4 shows the disease research to death ratio of several diseases. If the disease to death ratio is less than 1, then scientists are spending less time researching the disease relative to its mortality rate. On the other hand, if the disease to death ratio is greater than 1, then researchers are spending more time studying a disease compared to its mortality rate. Six diseases, diarrhea, COPD, lower respiratory disease, cerebrovascular disease, heart disease, and prematurity/low birth weight in infants receive significantly less research than they deserve². On the other hand, cancer, hepatitis, Alzheimer’s, Parkinson’s disease and arthritis receive more attention than is warranted. Hepatitis publications are about 3% of all directed nanomedicine research, but it only kills about 0.3% of the world’s population. The disease ratio to research ratio for the three major diseases of poverty, tuberculosis, HIV/AIDS, and malaria are not heavily skewed. The research to death ratio for these diseases range from 0.65% to 0.9%. This shows that scientists are devoting sufficient amount of attention to these diseases and that overall there isn’t research inequality for these diseases.

1) Note: WoS and PubMed have similar results so only graphics are shown

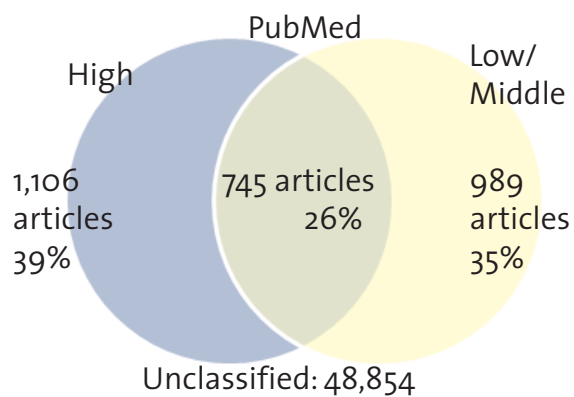
2) Stomach cancer, which appears to have a low disease to death ratio was excluded from the list of understudied diseases. Even though stomach cancer causes a lot of deaths and is not discussed in the literature, there is a lot of research on cancer in general

Figure 2 Research inequality in Web of Science



High Income
Diseases
Pop.=0.97 billion

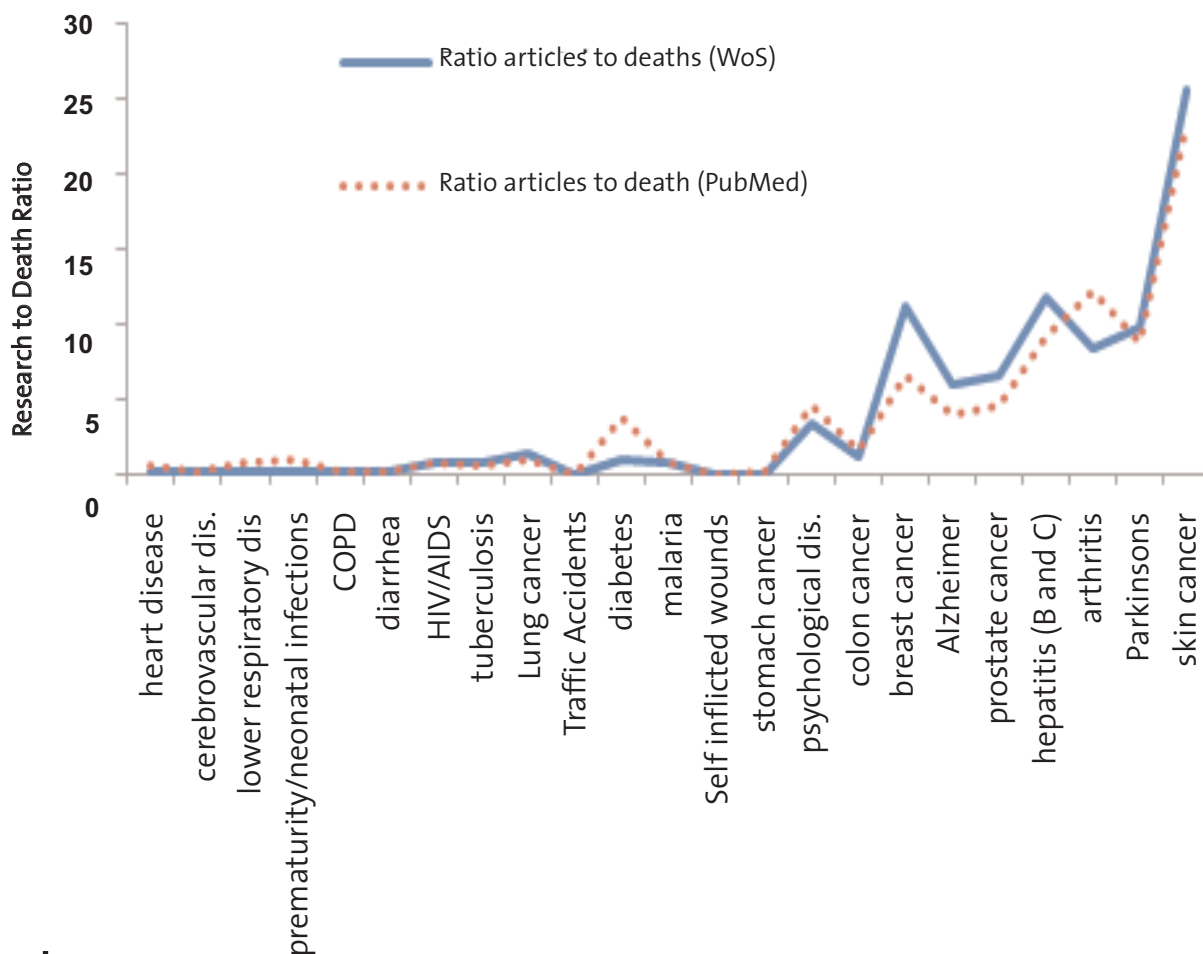
Low and Middle
Income Diseases
Pop.= 5.54 billion

Figure 3 Research inequality in Web of Science,
without cancer research

High Income
Diseases
Pop.=0.97 billion

Low and Middle
Income Diseases
Pop.= 5.54 billion

Figure 4 Normalized ratio of the number of research articles to the number of people killed by that disease



5 Discussion

This paper gives a descriptive analysis of nanomedicine research and classifies whether there is inequality in the research. Overall twenty percent of all nanotechnology articles are related to nanomedicine and in WoS the percent of nanomedicine articles has grown over the past 10 years. Nanomedicine is growing in importance and scientists are developing new medicines to address many of the world's diseases.

This study has three hypotheses. The first hypothesis is that nanomedicine is predominantly conducted in very high income countries. The data supports this hypothesis. About 77% of nanotechnology research is conducted in very high income countries but these countries only contain 15% of the world's population. However over the next few decades, it is possible that the trend will change. Medium income countries like China and India are becoming world leaders in nanotechnology and they are rivaling countries with very high incomes in nanomedicine research.

The second hypothesis is that there is a disproportionate amount of nanotechnology research conducted on diseases of very high income countries. There is no evidence to support this hypothesis. Scientists are doing nanomedicine research on a variety of diseases that affect both the rich and the poor. Although diseases of the rich like Alzheimer's and breast cancer receive the most attention, diseases like tuberculosis, malaria and HIV/AIDS also receive some attention from nanomedicine scientists. The disease with the most nanomedicine publications is cancer. Cancer is a leader killer in high income countries, but currently cancer is not a top disease in middle and poor countries. However as people in poor countries get richer and have longer life expectancies, cancer will become a more serious problem.

The third hypothesis is that the majority of nanomedicine research only addresses diseases that kill relatively few people. This hypothesis is partially confirmed. Several diseases like skin cancer, hepatitis, breast cancer, Parkinson's and arthritis are over researched. These diseases cause relative few deaths yet they receive a lot of attention from scientists. Nevertheless there are several diseases like diarrhea disease, COPD and infant death due to prematurity and low birth weight do not receive enough attention

from scientists. However there are many diseases of poverty, like malaria, HIV/AIDS, and tuberculosis that do receive enough attention in relation to the number of people the diseases kill. Moreover there is a 20/50 gap in nanomedicine: less than 20% of nanomedicine research goes to solving diseases that account for 50% of deaths.

There are several limitations to this study. First the study uses Web of Science and PubMed to quantify inequality in nanomedicine. Though these databases are often used in bibliometric studies they have small biases. These databases tend to have a higher representation of English journals and they tend to have more journals from high income countries (UNESCO, 2005). As a result, research from developing countries may be under represented in the dataset. Also this study cannot determine whether the articles were discussing how nanotechnology can cure diseases, cause more diseases or provide patients with more access to nanomedicine. This is especially significant when analyzing cancer. Scientists study both how nanotechnology can fight cancer (Ferrari, 2005) and how it could potential cause cancer (Stern & McNeil, 2008). As a result some of the nanomedicine papers may focus on toxicology as opposed to fighting cancer. Finally many of the top "diseases" do not have much overlap with nanomedicine. For example, traffic accidents is the ninth leading cause of death, and self-inflicted injuries is the sixteenth leading cause of death. It is doubtful that nanomedicine will impact those areas.

From this study it is hard to conclude why nanomedicine does not have large research inequalities like those reported in other medical fields. One potential cause is that research profile is heavily influenced by funding agencies that sponsor disease specific nanomedicine. 15% of the WoS articles in the nanomedicine dataset attribute a funding sponsor. Most of the sponsored research is attributed to large government research funding organizations like the USA National Institutes of Health (NIH). Since cancer is a major focus area for the NIH, scientists may be drawn to cancer research in order to get research money. Other factors that affect scientist motivations may like organization structure and reward system (Fox, 1983).

This study is a first step in understanding inequality in nanomedicine and adds to the discussion on the 10-90 gap. It shows that scientists are studying how emerging technologies, like nanotechnology, can benefit

the poor and that many of the inequality trends that existed in research and technology are changing. In the future scholars can add information about whether nanomedicine effects health inequality based on disability adjusted life years (DALY). DALY's is an alternative measure of the burden of disease that captures the disease burden based on the years of life lost resulting from premature death and the loss resulting from losing full quality of health (World Health Organization, 2008). By studying inequality with DALY we can understand the effects of nanomedicine on non-fatal diseases. Moreover, scholars need to understand why nanomedicine is not following the pattern of other medical research. Is there a reason that nanomedicine is not following the same 10-90 gap that is apparent in other medical fields?

Moral philosophies and belief systems view inequality as bad for society (S. E. Cozzens, 2007). Science and technology can play a crucial role in diminishing inequality however science and technology does not automatically reduce inequality (Woodhouse & Sarewitz, 2007). If the technology is not introduced correctly it can lead to greater inequalities as seen in other areas of medical technologies. The chemicals industry plays a crucial role in nanomedicine. Although it may not be directly involved in choosing the research portfolio for researchers, the chemical industry plays a big part of providing supplies, equipment and expertise for the technology. The research in nanomedicine will influence where companies should operate and what type of nanotechnology products it should offer to consumers. By understanding the research in nanomedicine, the field will be able better respond to customer demand.


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Research Paper

Morphological Analysis of Technologies using Multidimensional Scaling

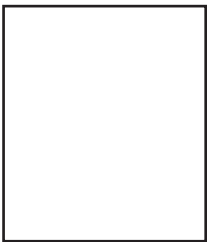


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This study focuses on the application of Morphological Analysis to making technology analyses. In this study, Morphological Analysis is used as a framework for applying expert opinion, bibliometrics, text mining and multidimensional scaling to problem-structuring. We describe the method used as well as its application and apply it to a case of portable fuel cell technology. The results demonstrate the practicality of using Morphological Analysis in structuring complex problems and offer an example of its application in assessing the status of a technology.

1 Introduction

Different quantitative, semi-quantitative and qualitative methods have been used to analyze socio-technical change through current state analysis and foresight. An abundance of methods, such as Morphological Analysis (MA), Trend extrapolations, Key technologies analysis and SWOT, have often been used to elaborate on technological development and to give tools for strategic management decisions. Despite having been suggested early on as a tool for technological analysis (Zwicky, 1969), MA has only been used by a small number of scholars (Popper, 2008).

MA, as explained by Zwicky (1947) and Ayres (1969), has significant value in structuring highly complex problems. As our technological world is becoming more complex, our need for methods that enable us to structure these problems has increased (Van Wyk, 1988). However, as MA has often been used as a purely expert opinion approach, adding an evidence-based component to MA could be valuable, thus broadening the knowledge sources used in the foresight effort (refer to Popper, 2008 for a theoretical framework of foresight knowledge sources). Additionally, although Zwicky elaborated on the method through several studies (1947; 1948a; 1948b; Zwicky and Wilson, 1967) and a few scholars have used the method (Wissemma, 1976; Ritchey, 1998; Ritchey, 2006; Ritchey, 2004; Ritchey, 2006;

Yoon and Park, 2004), studies validating the applicability of the method are needed (Yoon and Park, 2005).

To address the challenges mentioned above, we have focused on demonstrating the use of evidence-based methods as a part of MA, simultaneously demonstrating a practical application of MA to technology analysis. In this study, we have applied bibliometrics, text mining and Multidimensional Scaling (MDS) to MA, striving for structure and a more evidence-based approach. Thus, we have significantly broadened the knowledge base compared to a study applying only expert opinion. Using a case study on Fuel Cell (FC) technology, we extended the expert opinion based MA with evidence-based data and statistical analysis. This case study strives to demonstrate the application of MA to a practical problem.

Using the case study, the work elaborates on the methodological possibilities and limitations of MA. Using bibliometric data and expert opinion, we created a valuable dataset for the analysis. MA was used as a methodological approach for data gathering and analysis. The method was able to cross-validate expert opinion findings and bibliometric results, which made the expected result clear to the stakeholders. However, complexities in structuring different complex morphological structures are argued to require computer-aided tools that would be able to better integrate evidence based data

and expert opinion. This might partly explain the limited use of the method.

Our study is structured as follows: Section 2 will present the theoretical background for Morphological Analysis and its historical applications. Section 3 will elaborate on the case study at hand, followed by the application of the method to the case study. Section 4 will discuss the benefits and challenges of the approach, while the final section will conclude the study.

2 Theoretical background

The conceptual background for this study is based on a MA performed for the study. In the MA, expert opinion, bibliometrics, text mining, a co-occurrence matrix and Multidimensional Scaling (MDS) were applied to the structuring of a case study problem. This MA thus forms the theoretical framework for the study.

2.1 Morphological analysis

The background of MA can be traced back to the term morphology, which comes from a classic Greek term referring to the study of shape and form. An extensive discussion of the historical background of the morphologies used in different disciplines exceeds the scope of this study (for a review, refer to Ritchey, 2006). In Zwicky's work, however, Morphological Analysis was used to study "interrelations among

phenomena, concepts, and ideas, whatever their character might be." (Zwicky, 1969) Zwicky described the approach in a number of papers ranging from case study work on astrophysics (1948a) and rocket propulsion (1947), to more conceptual studies (1948b, 1967) laying the foundation for a wider adoption of MA. In 1969, Ayres described the use of MA in a technological forecasting. According to his work, MA is "A technique for identifying, indexing, counting, and parameterising the collecting of all possible devices to achieve a specified functional capability. The method can be used for identifying and counting all possible means to a given end at any level of abstraction or aggregation." Elaborating the definition further, Ayres sees Morphological Analysis as a tool to structure and map the space of feasible solutions to a given problem at any abstraction level, weeding out the unfeasible to focus the work on more practical solutions.

Since the 1960's Morphological Analysis has been tested as a methodological approach in several fields, such as economic and knowledge management (Shurig, 1984; Shurig, 1986; Edwards et al., 2009; Champon and Wilson, 2010; Levin and Barnard, 2008), technological analysis (Foray and Grubler, 1990; Ritchey, 2002; Ritchey, 2006), the last mile problem (Levin, 2011), corporate strategy (Higgins, 1996), product creation in a service (Kim et al., 2008) and in bibliometrics (Yoon and Park, 2004; Yoon and Park, 2005; Yoon and Park, 2007). However, the

Table 1 Morphological analysis process (Zwicky 1969)

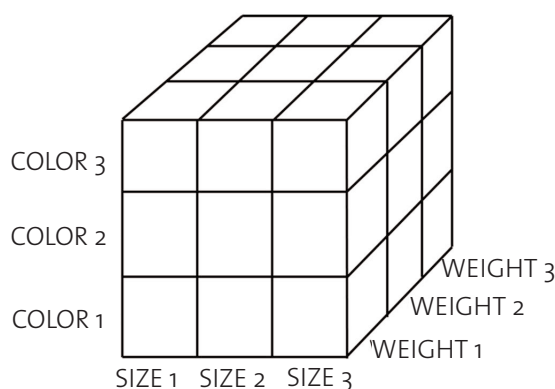
| | | |
|-----|---------------------------------------|--|
| 1.) | Define | The problem to be solved must be very concisely formulated. |
| 2.) | Identifying characteristic parameters | All of the parameters that could be important for the solution of the given problem must be identified and analyzed. |
| 3.) | Transforming parameters to "states" | The morphological box or multidimensional matrix, which contains all of the potential solutions of the given problem, is constructed. |
| 4.) | Evaluate solutions | All the solutions contained in the morphological box are closely scrutinized and evaluated with respect to the purposes that are to be achieved. This includes identification of the "known area" or current knowledge and logically impossible solutions. |
| 5.) | Find optimal solution | The optimally suitable solutions are selected and applied, provided the necessary means are available. This reduction to practice requires in general a supplemental morphological study. |

practical use of MA remains scarcely demonstrated. (Yoon and Park 2005; Popper 2008)

In a more practical approach, Zwicky (1969) summarizes the five steps of the MA process as seen in Table 1. Ayres (1969) and Ritchy (1998) have, based on Zwicky's work, further elaborated on the process.

Morphological Analysis can be seen as beginning from clearly defining the problem and creating parameters for the characteristics of the problem (Zwicky, 1969; Ayres, 1969; Ritchy, 1998). These parameters are then assigned a range of relevant conditions or values called states, which are transformed to a morphological box of all possible combinations of states. This can be exemplified using a problem with three parameters: size, weight, and color, which all have three states. This creates 27 possible solutions to the given problem, seen in Figure 1 as a morphological box. This can easily be understood as the elements of a set, which we

Figure 1 Morphological Box



can define as Set A, containing 27 members.

The Morphological box thus presents all of the 27 possible configurations, or potential solutions to the problem. Returning to Zwicky's original idea that "...nothing can be discarded a priori as being unimportant" (Zwicky 1969) the box shows all of the options not taking to account their feasibility.

Within the created box, or Morphological space, each parameter is defined by pk^j , where k is parameter and j is state, and the space has as many dimensions as there are variables. For the morphological space, Ayres (1969) has described several metrics, seen in Table 2, to further define the problem.

Using the earlier concrete example of a morphological box, we suppose that two configurations are actually developed, these being (p_1^1, p_2^1, p_3^1) and (p_1^2, p_2^1, p_3^1) . We can define these as Set B. These developed configurations are described by Ayres (1969) as the "known or occupied" space, arguing that the probability of a technological breakthrough, let's assume that would be (p_1^3, p_2^2, p_3^1) , is a decreasing function of its morphological distance. In the given example, the distance would be two from a maximum of three. Using the example, we can also define the surface of the morphological neighborhood of the known space. We can define these as Set C. Seen in Table 3, Ayres argues that most of the advancements will occur on the surface, or active perimeter, as it is defined.

The surface, in addition to the two known states, forms a perimeter of 10 possible configurations, which forms the "area" defined in Table 2. Although a different sized surface might be feasible by using the weighted area, taking into account the all of the distances and weighing them with a selected coefficient, this possibility has been excluded from this study due to difficulties in defining a suitable coefficient. After this we are left, in the practical example, with an additional 15 variations as unknown or "Terra incognita". Using the Set analogy we then define $B \subset A$, $C \subset A$. This defines Set D (Terra incognita) as $A \setminus (B \cup C)$.

In addition to the aforementioned definitions, Ritchey (1998) states that unfeasible solutions may be included in the group of untested solutions. He argues that there are three types of unfeasible solutions: 1) purely logical contradictions, 2) normative contradictions and 3) empirical constraints. Ritchey (1998) states that logical contradictions are those based purely on the nature of the concepts being evaluated. Normative contradictions, on the other hand, are based on outside influence such as politics or ethics. Empirical constraints are those that are, with current knowledge, seen as improbable or implausible.

A process of cross-consistency assessment is achieved through a screening process, which was also used by Ritchey. All of the parameter values are compared with each other as a cross-impact matrix. Analyzing each pair of conditions, a judgment has to be made on whether a pair can coexist. The technique of using pair-wise consistency relationships between conditions, in order to weed out internally contradictory

Table 2 Morphological metrics

| | |
|---|---|
| Morphological distance | The distance between two points in the space is defined as the number of parameters wherein the two configurations are different. |
| Morphological neighborhood | A subset of points that are morphologically close to each other |
| Surface (of a morphological neighborhood) | A set of configurations differing in at most a single parameter in the neighborhood |
| Area (of the surface) | The count of configurations in the surface set |
| Weighted area (of the surface) | The sum of configurations differing by one, two, three, etc. parameters, multiplied by a decreasing coefficient. |

Table 3 Surface (of a morphological neighborhood)

| Known Area members $b \in B$ | Surface members $c \in C$ |
|--|--|
| (p_1^1, p_2^1, p_3^1) | $(p_1^2, p_2^1, p_3^1), (p_1^1, p_2^2, p_3^1), (p_1^1, p_2^1, p_3^2), (p_1^3, p_2^1, p_3^1), (p_1^1, p_2^3, p_3^1), (p_1^1, p_2^1, p_3^3)$ |
| (p_1^2, p_2^1, p_3^1) | $(p_1^1, p_2^1, p_3^1), (p_1^2, p_2^2, p_3^1), (p_1^2, p_2^1, p_3^2), (p_1^3, p_2^1, p_3^1), (p_1^2, p_2^3, p_3^1), (p_1^1, p_2^1, p_3^3)$ |
| (p_1^1, p_2^1, p_3^1) (p_1^1, p_2^1, p_3^1) | $(p_1^1, p_2^2, p_3^1), (p_1^1, p_2^1, p_3^2), (p_1^3, p_2^1, p_3^1), (p_1^1, p_2^3, p_3^1), (p_1^1, p_2^1, p_3^3), (p_1^2, p_2^2, p_3^1), (p_1^2, p_2^1, p_3^2), (p_1^2, p_2^3, p_3^1)$ |

configurations, is made possible by a principle of dimensionality inherent in the morphological approach.

In our simple example we defined a constraint restricting certain weight - size combinations, marked in the Table 4 with "X", making combinations (p_1^1, p_2^1, p_3^3) and (p_1^2, p_2^1, p_3^3) impossible. For this, F is $F \subset A$. Considering these constraints, Set F is formed by 6 members.

The conceptualization of "progressive exhaustion of possibilities for invention in a field" (Ayres, 1969) seen in Figure 2 exemplifies the practicality of approaching a problem using MA. MA, with a systematic and practical approach, enables a researcher to analyze a technology by categorizing what is known, how that could lead to different incremental advancements (surface), and where we can expect to find radical solutions (Terra Incognita).

Ayres claims that "...it is possible to construct

a morphological space for any well-defined technology..." and further argues that the process is relatively straightforward up to the point of creating the known area. However, the process becomes more challenging when the known area and perimeter remain small. In this study, we have created the known area utilizing expert opinion and then evaluated the results using bibliometric data analyzed through text mining and MDS.

2.2 Methodological approach

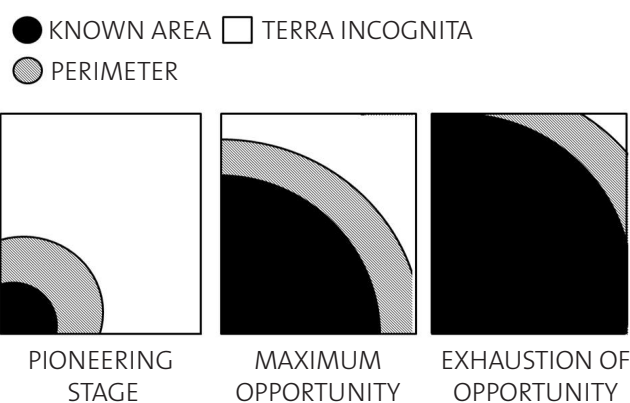
2.2.1 Expert opinion

Expert opinion was used to define the problem area in the case study. With expert opinion we aimed to define the problem to be structured with MA. In addition, we used it to identify characteristic parameters and to

Table 4 Cross-tabulation of constraints

| | Color | | | Weight | | | Size | | |
|--------|-------|----|----|--------|----|----|------|----|----|
| | C1 | C2 | C3 | W1 | W2 | W3 | S1 | S2 | S3 |
| Color | C1 | NA | NA | NA | | | | | |
| | C2 | NA | NA | NA | | | | | |
| | C3 | NA | NA | NA | | | | | |
| Weight | W1 | | | | NA | NA | NA | | |
| | W2 | | | | NA | NA | NA | | |
| | W3 | | | | NA | NA | NA | | |
| Size | S1 | | | | | | X | NA | NA |
| | S2 | | | | | | X | NA | NA |
| | S3 | | | | | | | NA | NA |

Figure 2 “Progressive exhaustion of possibilities for invention in a field” (Ayres, 1969, adopted)



transform parameters to “states”. We used expert opinion as a guideline to define the parameters that were of interest regarding the problem and then listed each of the states of the parameters. The result was a table of words with their interconnections, which suggested possible synonyms or abbreviations.

2.3 Bibliometric data and text mining

Bibliometrics is defined as a method of analyzing textual databases with quantitative methods (Borgman and Furner, 2002). We used the aforementioned vocabulary created using expert opinion to perform a bibliometric quantification of case data. We downloaded data from published journal and conference articles from the ISI Web of Science by using a search algorithm of “fuel cell” or “fuel cells” being mentioned in the title or topic. This

resulted in a dataset of 47,837 articles, from which the bibliographical data was downloaded.

We used the SPSS Modeler software for text mining to further study the dataset. We analyzed the abstract field of the dataset by first searching for any reoccurring words. We compared the expert opinion vocabulary and the text mining results to identify possible synonyms of words missing from the expert opinion vocabulary. Thereafter we used the corrected expert opinion vocabulary as the library for the text mining. This resulted in a co-occurrence matrix, which was further analyzed with MDS.

2.4 Multidimensional Scaling (MDS)

The analysis of co-occurrence data is a part of author co-citation analysis (ACA). McCain (1990) describes author co-citation analysis as a set of data gathering, analytical and graphic

presentation techniques that can be used to create results like empirical maps about noticeable authors in different disciplines. Statistical analysis of co-occurrence data is widely studied in academia. For example, White and Griffith (1980) studied the use of different multivariate methods, MDS and factor analysis for analyzing author co-citation data. MDS is a mathematical tool that presents similarities of data spatially in a map (Schiffman, Reynolds et al., 1981).

Leydesdorff and Vaughan (2006) suggested the use of the symmetric co-citation matrix as a proximity matrix directly for MDS. This is based on Kruskal and Wish (1981), who argued that proximity is only a number which indicates how similar or dissimilar two objects are. Cox and Cox (2001) argued that proximity matrices could be either similarity or dissimilarity matrices. However, Borg and Groenen (2005) have a more specific definition for the direct application of the co-citation matrix.

Borg and Groenen (2005) explained that the direct use of co-occurrence data as proximities depends on the definition of 'direct'. In many cases, this definition of direct is mainly related to the researcher interpretation. They suggested that the direct use of co-occurrence data is usually not acceptable. Instead, it is better to norm co-occurrence data before the analysis. Several academics like McCain (1990), Peters and van Raan (1993), Waltman and van Eck (2007; 2007) share this opinion and they explain that the direct use of co-occurrence data as a proximity matrix is not acceptable.

Instead, they argue that a similarity measure for this kind of data should be calculated, suggesting that the data must be normalized before the analysis with MDS.

There are many possible methods for normalizing co-occurrence data. These are Pearson's correlation coefficient, Salton's Cosine, Jaccard index or its extension, Tanimoto index (for nonbinary situations), inclusion index, proximity index or the association strength. (White and Griffith, 1980; McCain, 1990; Peters and van Raan, 1993; Ahlgren et al., 2003; Leydesdorff, 2008; van Eck and Waltman, 2008; van Eck & Waltman, 2009) As several scholars have written about the different methods for normalizing co-occurrence data, there has been a lot of debate concerning which method is the best and which method should be used. Ahlgren et al. (2003) as well as van Eck and Waltman (2008) have argued that the use of the Pearson

correlation as a measure of similarity might be problematic. Ahlgren et al. (2003) agreed that the use of Salton's cosine instead of the Pearson correlation as a measure of similarity should be considered. Van Eck and Waltman (2009) and van Eck et al. (2010) have argued that the use of Salton's cosine and the Jaccard index have been very popular among academics. Our work follows van Eck et al. (2010), as they argued that the most appropriate measure for normalizing co-occurrence frequencies is the association strength:

$$AS_{ij} = \frac{c_{ij}}{c_i c_j} \quad \text{for } i \neq j$$

where c_{ij} indicates the number of items in which scholar i and j both occur and c_i represents the number of items in which scholar i occurs (van Eck and Waltman, 2007a).

Typically co-citation or more generally co-occurrence type of data is analyzed using MDS (Leydesdorff and Vaughan, 2006). MDS is based on the work of Torgerson (1952; 1962). MDS is a set of mathematical methods that could be used for finding uncovered structures of data (Kruskal and Wish, 1981). MDS analyzes similarities or dissimilarities between objects in datasets. This kind of similarity data might consist of, for example, similarities between political candidates. MDS tries to model this kind of data as distances between points in geometric space. The distance between the points in this space corresponds to the original similarities or dissimilarities (Borg and Groenen, 2005).

There are two versions of MDS, metric MDS and non-metric MDS. Metric MDS analyzes objects with dissimilarities σ_{rs} and tries to find a set of points in a space where one point represents one object. The distances (d_{rs}) between points could be defined according to the following equation (Cox and Cox, 2001):

$$d_{rs} \approx f(\sigma_{rs})$$

According to Cox and Cox (2001) the function in the previous equation is a continuous parametric monotonic function. It is possible for the function to be a transformation function or a special transformation function that transforms dissimilarities into distances. For metric MDS, it is assumed that proximities are ratio scaled values. In many cases, for example in social sciences, rank order of proximities is assumed. In these cases where proximities are

rank order data, non-metric or ordinal MDS is a suitable method for data analysis (Borg and Groenen, 2005).

3 Morphological analysis of portable FC system designs

3.1 Define

Due to their versatility, portable FCs have been seen as a future energy source for smaller devices (Cropper et al., 2004). Analysed in several studies (Agnolucci, 2007; Broussely and Archdale, 2004; Dyer, 2002; Hellman, 2007; Suominen and Tuominen, 2010) scholars have tried to form a view on the future development of portable scale fuel cells. Studies have pointed out social and technical aspects inhibiting development. However, what is noteworthy with regard to fuel cells is the abundance of technological options available in designing a portable FC. In this study, we focus on portable fuel cells in the power range of 1-50 W.

3.2 Identifying characteristic parameters

The parametric possibilities, based on a literature review, were classified according to seven characteristics, seen in Table 5. These were the overall type of the fuel cell, system type, control electronics system used, stack structure, fuel phase, operation modes, and operational purpose.

In regard to the type of fuel cell used, there are around 6 different types of FCs overall, and more than 20 sub-types. (Rayment and Sherwin, 2003) Not taking into account the sub-categories, these are Polymer Electrolyte Membrane (PEM) FCs, Alkaline FCs, Phosphoric Acid FCs, Molten Carbon FCs, Solid oxide fuel cells (SOFC) and Microbial FCs.

These systems operate with different systems types, divided into an active and a passive system. In the passive system, without additional power-consuming active sensors and actuators for operation, the mass/heat transport is done by the natural capillary forces of diffusion; convection and evaporation are the driving forces behind all processes. The compactness, reliability, and relatively low cost are suitable for portable applications. A passive system is usually operated at a low current density, because it is dependent on the operational conditions. Furthermore, a passive system requires more catalyst than active system. (Liu et al., 2006).

In an active system, the auxiliary system (heater, pump or fan), is used to help the mass and heat transport. It can offer a better operational environment for the device and thus produce more energy (Qian et al., 2006). An active system is more complex than a passive system, however it is better suited for solutions characterized by large power consumption. A passive system, with a simpler device structure, can offer a good solution for low energy requirement systems.

In addition to the requirement for auxiliary systems or control electronics, portable FCs might require a secondary power source in order to operate on a practical level. Systems are therefore divided into hybrid, independent or half-independent designs. In a half-independent system, the FC system requires an auxiliary energy source to start the cell. In addition to these, a system can be designed as an autonomous system, where the ignition is given by, for example, a mechanical system. These are later referred to as independent.

In addition to the system design, there are several FC structures, referred to as stack structures. An FC stack, the basic unit cell, can be configured as a unit single cell, a unit bi-cell, or as a bi-polar structure. These structures, similarly to active or passive systems, vary in their power output.

In relation to the fuel used in FCs, a liquid, gaseous, or solid fuel can be used. The term 'fuel state' does not refer to the fuel's state during storage but rather to the form in which the fuel is used. Usually the fuel supplied to a FC is a gas or a liquid fuel. However, high temperature FCs, such as the SOFC and MCFC, use gaseous fuel.

In addition to the above-mentioned characteristics, FCs are defined by the system's ability to start and stop the chemical process during operation. In addition, the mode of use - one-time or cyclical - can be seen as design characteristics.

3.3 Transforming parameters into "states"

When transforming the parametric possibilities into the morphological box noted as ($p^1_j, p^2_j, p^3_j, p^4_j, p^5_j, p^6_j, p^7_j$), there are 864 distinguishable configurations of the parametric possibilities. The number of configurations is the result of multiplying $6 \cdot 2 \cdot 3 \cdot 2 \cdot 3 \cdot 2 \cdot 2$. This means there are 864 distinguishable configurations of the above

Table 5 Parametric possibilities of portable FCs

| | Parameter | States |
|----------------|----------------------|---------------------------------------|
| p_1^{123456} | FC type | PEMFC, AFC, PAFC, MCFC, SOFC, MFC |
| p_2^{12} | FC system | Passive, active |
| p_3^{123} | FC electronic system | Hybrid, independent, half-independent |
| p_4^{12} | Stack structure | Bipolar, monopolar |
| p_5^{123} | Fuel phase | Gas, liquid, solid |
| p_6^{12} | Operation | Continuous, intermittent |
| p_7^{12} | Purpose | One time use, cyclical |

parameters, which define the total set of configuration. This is further noted as set A.

3.4 Evaluate solutions

Currently, to the author's knowledge, there are a variety of - mostly prototype based - portable FCs available. Demonstrational projects for several companies have shown promise, and this study focuses on the different published results as the "known" area. Products from, among others, Horizon, PowerTrekk, MTI Micro, and Toshiba have applied different morphologies in designing their products. As an example the MiniPAK device from Horizon is "a palm-size universal portable power charger and power extender for any electronic device requiring up to 2W of power" (Horizon, 2007). It is a passive air breathing H₂ PEMFC charger, using a metal hydride storage unit due to the challenges in gas storage. It can be used to charge 1-2 smart phones. PowerTrekk FC charger is similar as the MiniPAK, but it has a Li-ion battery as a secondary energy source and buffer. Toshiba's Dynairo FC charger is a passive air breathing DMFC charger with multiple cells. With a 14 ml fuel tank, the charger can charge two cell phones. The size of the Dynairo charger is similar to the MiniPAK, and both of them are using an USB port to charge the cell phones. Similarly to

PowerTrekk, Dynairo uses a Li-based battery as a buffer zone and to supply the energy to start the DMFC. MTI Micro is producing a passive DMFC charger with 25 ml cartridge. It can be used for charging 10 phones. The difference between this one and the Dynairo is that the fuel (methanol) tank is a cartridge and filling the fuel can be done by changing the tank.

The following portable FC characteristic were collected from the literature review, which was based on professional literature and patent databases. Although we admit that this is not an exhaustive list of all possibilities, it is seen as capturing different prototyped systems, while keeping the exercise in a practical length to be demonstrated in a single study. The states of different systems can be seen in Table 6.

This creates Set B, which is defined by the 12 members of Set A. By using the definition in Table 2 the surface, or Set C, can be defined. In this case Set C, or the perimeter as defined by Ayres, is defined by the 118 permutation of the known area. Arguing that within Set C lays the most significant near future discovery. This table has been excluded to conserve space.

However, as noted by Ritchy (2002), Set A might contain members that are constrained from existing together. While being cautious of removing members that seem implausible

Table 6 Morphological analysis summary of FC products

| | | | | | | | |
|--------------------------------|--------|---------|----|---|--------|--------------|----------|
| Medis 24/7 | AFC | passive | I | M | liquid | continuous | one time |
| Angstrom Micros FC torch | PEM-FC | passive | I | | gas | intermittend | cyclical |
| Samsung's laptop power | PEM-FC | active | H | | liquid | intermittend | cyclical |
| EFOY 600 | PEM-FC | active | HI | | liquid | intermittend | cyclical |
| UC25/XX25 | PEM-FC | active | H | | gas | intermittend | cyclical |
| Horizon's racing car | PEM-FC | active | I | | gas | intermittend | cyclical |
| Dynairo | PEM-FC | passive | H | M | liquid | intermittend | cyclical |
| MTI Micro charger ¹ | PEM-FC | passive | I | | liquid | intermittend | cyclical |
| MiniPAK ² | PEM-FC | passive | I | | gas | intermittend | cyclical |
| PowerTrek FC charger | PEM-FC | passive | H | | gas | intermittend | cyclical |
| G2 source charger | PEM-FC | passive | I | | gas | intermittend | cyclical |
| Lilliputian Systems | SOFC | active | H | | gas | intermittend | cyclical |

1. According to the information the company has provided third generation Mobion® Chip based on 100% methanol fuel, passive, direct methanol fuel cell technology. We assumed this product is running without accessorial power sources inside.

2. Since Horizon's products are mostly independent, we assumed this product also works independently.

M = Monopolar, I = Independent, H = Hybrid, HI = Half-Independent

but potentially practical in the future, several physically impractical solutions were excluded. These are designated as a Set F, to clearly state that these are noted as unfeasible with regard to the currently available knowledge, as seen in Table 7. Since portable FCs are a relatively new technology, their development and research is merely in its infancy, and what is empirically impossible now may be possible in the future. We should be wary of weeding out the possible solutions when analyzing the empirical constraints.

By definition, this leaves the "Terra incognita", or Set D.

3.5 Statistical evaluation

Firstly, the gathered co-occurrence data was transformed into proximities. This

transformation was carried out using the previously mentioned approach from van Eck et al. (2010) by using the measure of association strength. This transformed data could be used as proximities in MDS. Choosing the proper type of MDS might be challenging, because researchers of bibliometric data do not usually state which MDS method they have used. Ratio MDS is not a suitable method when proximities are similarities. In this kind of a situation, where researchers use MDS to create bibliometric maps, they usually apply ordinal MDS or interval MDS (van Eck et al., 2010). On the other hand van Eck et al. (2010) argue that when proximities are calculated using association strength, the use of MDS is not completely satisfactory. Instead, they propose the use of the visualization of similarities (VOS) method as proposed by van Eck and Waltman

Table 7 A cross-tabulation of the constraints of portable fuel cells

| | | FC System | | FC electro-nic System | | | Stack structure | | Fuel phase | | | Operation | | Purpose | |
|-----------------------|-------|-----------|---|-----------------------|---|----|-----------------|---|------------|---|---|-----------|----|---------|----|
| | | P | A | H | I | HI | B | M | G | L | S | Co | It | OTU | Cy |
| Fuel cell type | PEMFC | | | | | | | | | | N | | | | |
| | AFC | | | | | | | | | | N | | | | |
| | PAFC | E | | | E | | | | | | N | | | | |
| | MCFC | E | | | E | | | | | N | N | | | | |
| | SOFC | E | | | E | | | | | N | N | | | | |
| | MFC | E | | | E | | | | | | N | | | | |
| FC System | P | - | - | | | L | | | | | | | | | |
| | A | - | - | | L | | | | | | | | | | |
| FC electro-nic System | H | | | - | - | | | | | | | | | | |
| | I | | | - | - | | | | | | | | | | |
| | HI | | | | | - | - | - | | | | | | | |
| Stack structure | B | | | | | - | - | - | | | | | | | |
| | M | | | | | - | - | - | | | | | | | |
| Fuel phase | G | | | | | | | | - | - | - | | | | |
| | L | | | | | | | | - | - | - | | | | |
| | S | | | | | | | | - | - | - | | | | |
| Operation | Co | | | | | | | | | | | - | - | | |
| | It | | | | | | | | | | | - | - | | |
| Purpose | OTU | | | | | | | | | | | | | - | - |
| | Cy | | | | | | | | | | | | | - | - |

P = Passive, A = Active, H = Hybrid, I = Independent, HI = Half-Independent, B = Bipolar, M = Monopolar, G = Gas, L = Liquid, S = Solid, Co = Continuous, It = Intermittend, OTU = One time use, Cy = Cyclical

L = Purely logical contradictions, N = Normative contradictions, E = Empirical constraints.

(2007b). However, we have chosen the traditional way of mapping similarities with MDS. According to van Eck et al. (2010) similarities that are calculated based on association strength could be treated as measurements on a ratio scale. Based on the previously presented facts about the proper type of MDS we have chosen interval MDS as our analysis method.

Figure 3 shows the scree plot with “elbow” between dimensions 2 and 3. According to (Borg and Groenen, 2005) that “elbow” corresponds to the number of dimensions included in the final solution. The interpretation is that two dimensions are enough for the final solution. Now we have recalculated using 2 as the maximum and 1 as the minimum amount of dimensions. The fit

Figure 3 Stress plot for determining the required amount of dimensions in final solution

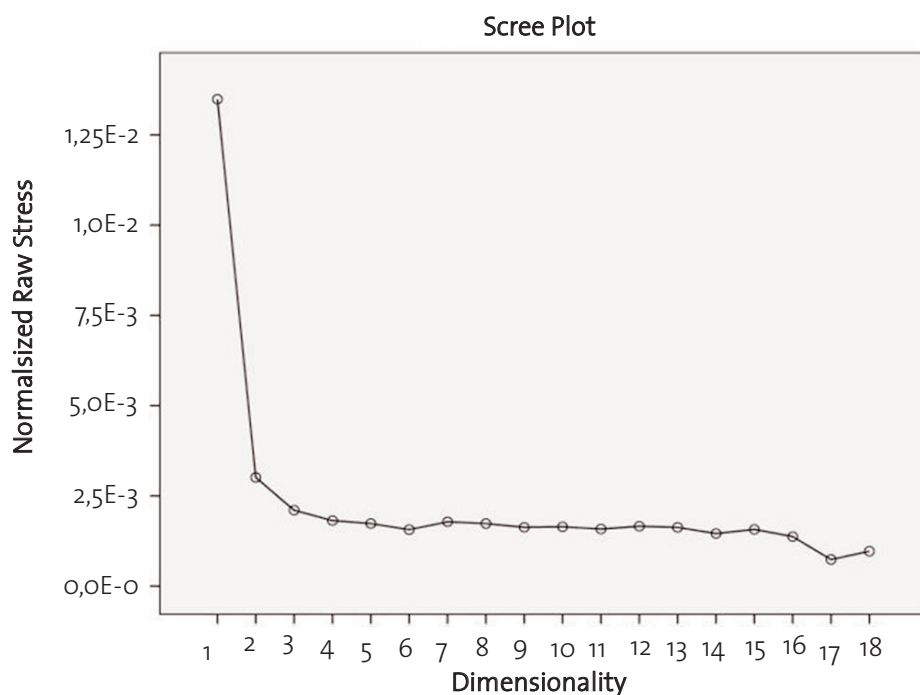
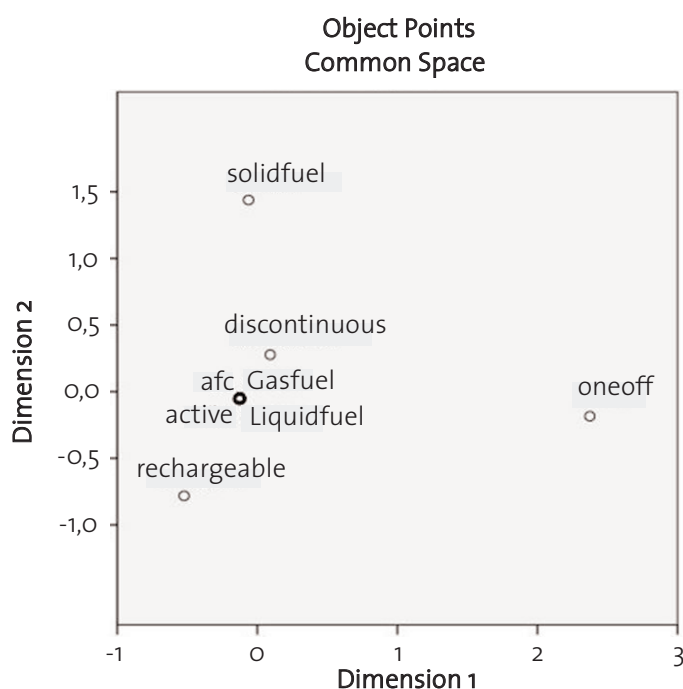


Figure 4 Common space plot for final analysis of co-occurrence data



of the MDS model could be analyzed using Stress criterion. This criterion defines the best fit between distances in original input matrix and the estimated distances in low

dimensional solution. Low stress values are required and usually values smaller than 0.2 are acceptable (McCain, 1990). The stress in our model is 0.02113 which is smaller than the

required value.

The final analysis solution for our co-occurrence data can be easily visualized using a common space plot (Figure 4).

The common space plot (Figure 4) of the solution of our co-occurrence data in two-dimensional space. Points that are near each other in a space can be interpreted as similar and points that are far from each other can be considered dissimilar. Based on this, there is a group of points in the space plot, close to each other, which means that these points are similar. There are also points that are separate from this group as well as each other. These variables are more dissimilar than anything else in our data.

The visualization produced by the MDS analysis should visualize the known area and we would expect that the solutions identified with the use of expert opinion should form a close group. In addition, new solutions should be either individual points in the visualization or non-existing. However, the visualization has only created one clear group with several dissimilar points. The closely formed group in Figure 4 clearly defines several of the existing prototypes described in Section 3.4.

4 Discussion

As Ayres claimed, "...it is possible to construct a morphological space for any well-defined technology..." (Ayres 1969) Enabling the structuring of complex problems, the morphological approach has made it possible to make the different permutations of a problem at hand explicit. The value of the approach as a technology analysis tool is three-fold. As a current state analysis tool, Morphological Analysis structures the existing solutions within a technology in a practical way. The future aspect of the approach enables the discovery of the perimeter, which shows the near field of discovery and finally approximates the unknown.

MA is, however, limited. The identification of characteristic parameters is limited by the existing body of knowledge, which we are aware of, and as Ritchey (1998) has clearly stated "...the output of a morphological analysis is no better than the quality of its input". In the case study, the characteristics were extended to seven attainable characteristics, analyzing portable FCs at a high abstraction level. This was done partly to keep the length of the study

practical, but also to show that the characteristics could be extended almost indefinitely. At a lower abstraction level materials, components, and secondary batteries used would be a valid extension to the parameterization. It is clear that at an overly high level of abstraction the analysis appears trivial. A more in-depth parameterization of the problem area will enable a more valid assessment. This would, however, increase the amount of data significantly. This would require computer-aided analysis of permutations, as suggested by Ritchey (2006).

By using bibliometrics, text mining and MDS the research strove towards a more structured method of performing MA, which would make the method more applicable. The statistical analysis was used as a validating tool for the expert opinion analysis. We discovered that the statistical results were able to identify the most visible group in the dataset. However, new research avenues were not identified.

As a management implication, the communicative elements within the MA should be noted (Wissema, 1976). The method enables a vision to be created of the current state of the technology, which is visible as a simple matrix of permutations. The method also makes explicit different permutations, some of which might not come up when using other methods. This frees the development group to not discuss which solutions are possible but to exclude those solutions that are impossible. This way a number of out-of-the-box ideas will remain, open for further analysis.

In conclusion, the method has received only mild interest since its "invention". Although the method's significant advantages in technology analysis were noted early on, (Wissema, 1976) and have been applied in different case studies (e.g. Ritchey, 2002; Yoon and Park, 2005; Lai, et al., 2005; Kim, et al., 2008) the method still requires more empirical studies in order to be validated. In addition, tools enabling the solutions of complex issues with a significant amount of parameters will require computerized tools and development of statistical analysis.

5 Conclusion

This study reviewed the MA method as a

technology analysis tool. Although the method was first suggested decades ago, it has not been used actively. Only more recently several scholars have adopted the method. Through a case study, the paper exemplified its application and made several notions on practical limitations. In conclusion, MA is well suited to the structuring of complex problems. However, the use of computerized methods, as the number of parameters increases, is seen as practical.

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Practitioner's Section

IP strategies in business operations with China

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This article deals with the question how to ensure that for new or existing business activities in China, all legal aspects relating to technology commercialization and knowledge transfer are taken into consideration.

For a valid IP strategy, an international company needs not only to analyze its own IP position, but has also to look on the current Chinese patent legislation, i.e. the way how Chinese companies act in this field and the specific regulations on technology transfer from and into China.

1 Introduction

“The competition of world’s future is the competition of IP.” (Li and Jiang, 2012)

This statement made by Prime Minister Wen Jiabao in 2010 indicates what China aims to represent: An innovative country and no longer just the “workbench of the world”. To make this happen, China issued a “National IP Strategy” on June 10, 2008 with the aim to “greatly promote China’s capacity in creation, utilization, protection, and administration of intellectual property (IP)” (State Council of the People’s Republic of China, 2008).

One important section within this National IP Strategy is chapter V, 4, “Improving IP Law Enforcement”, which is directed also towards Chinese companies to enforce their rights against third parties (State Council of the People’s Republic of China, 2008).

In addition to this and to improve the IP system further, China has issued a “National Patent Development Strategy (2011 – 2020)”. In view of China’s short history of establishing the modern patent system, the government took the position that some problems are remaining and “the patent system has not become fully integrated with the development of socialist market economy” (citation from this Strategy).

Hence, for an international company, it is not sufficient to develop an IP strategy for China solely from its own perspective, but it rather needs to take in consideration the ongoing changes in China’s IP landscape, which have an impact on a valid IP strategy.

The first aspect - as far as ongoing changes are concerned - refers to the amendments of laws, regulations, guidelines, and case law of the courts. This sets the legal framework for all business operations in China, i.e. R&D work, technology transfer into a joint venture, marketing new products, or any mergers & acquisitions.

The other aspect relevant for a valid IP strategy relates to the IP activities of Chinese companies.

Therefore, it is highly advisable to understand, first, the position of Chinese authorities and, in consequence, Chinese companies or other entities before developing the own IP strategy.

Concerning the first aspect (amendments of laws etc.), the third revision of the Chinese Patent Law, effective on Oct. 1, 2009, is one essential example. It clearly shows that since 1984, when the Chinese Patent Law has been established, this law is constantly adjusted to the actual needs and, in so doing, primarily of the Chinese companies.

As to the IP activities of Chinese companies, it is helpful to have a look on the Chinese patent statistics. Following the above mentioned “National IP Strategy”, Chinese companies are very active in filing all kinds of IP applications in China and abroad.

However, beyond of pure statistics, one can also see a change in the Chinese “mind-set”. One example is the statement by Nan Cunhui, Chairman of Chint Group, a Chinese electronic company, which sued Schneider, a French electronic company, over IP infringement:

"I don't mind how much Schneider pays us. What I care about is winning the case. It will help change the stereotype that it is Chinese companies that are always accused in IPR cases." (Lu 2008)

2 What can we learn from Chinese IP statistics?

The total number of patent applications with the Chinese Patent Office (SIPO) in 2011 was 1,633,347 (including 526,412 inventions, 521,468 designs and 585,467 utility models) (total number in 2010: 1,222,286). Only 21% of the 526,468 inventions in 2011 came from foreign companies (This term "inventions" corresponds to patent applications e.g. in Europe). The shares of foreign companies in the fields of Chinese design- and utility model-applications are even below 5% (according to SIPO statistics).

On the other hand, the numbers of patent application with the European Patent Office (EPO) submitted by Chinese companies soared from 6,490 in 2009 to 12,698 in 2011. For comparison: German companies filed 33,139 patent applications with EPO in 2011 (according to EPO statistics).

In other words, this means:

- Chinese companies are using their domestic IP system to a greater extend than foreign entities.
- Before entering the Chinese market, a company has to develop a freedom-to-operate opinion, meaning an analysis of possible IP rights in China which might block or at least hinder its market activity in China. The result of such an opinion has an increasing impact on any own product or project related IP strategy.
- Even in Europe, patents owned by Chinese companies might become relevant as a market barrier. However, in the fields of organic chemistry and pharmaceuticals, no Chinese company can be found so far in the list of the top 25 applicants with the EPO in 2011. For the time being, Chinese companies focus on digital communications and similar technical fields.
- In case a Chinese company will be the target for an acquisition by a non-Chinese company, the innovative potential, i.e. the IP position

of the Chinese company needs to be analyzed in detail.

To complete this picture, it is interesting to notice that between January and October 2011, IP rights civil cases received by the national courts numbered 52,708 (an increase of 42% over 2010). This means that IP law enforcement is getting more and more important. According to the Supreme Peoples Court of China, among the top ten IP cases for 2011 in the field of IP infringement, there are only two patent cases (related to an air conditioner and an antibiotic composition), but four trademark disputes, two copyright, and two unfair competition cases. This clearly shows that in the total field of IP right enforcement, patents (technical inventions) are not as much in focus. So, copying famous brands by Chinese companies is still the main concern of non-Chinese companies.

3 IP strategy for a product covered by a patent and designated for the Chinese market

3.1 Working on the specifics

"Chinese companies are extremely efficient at creating new versions of technologies and products, often simpler, cheaper and more effective, shortly after they are invented and marketed elsewhere in the world." (Comment in China IP Report, June 20, 2012).

Although this sometimes might be a wishful thinking, it nevertheless shows the approach Chinese companies in principle follow. One famous example is the above mentioned "fight" between the electronic companies Chint and Schneider over an infringement of Chint's utility model by Schneider, which resulted 2009 after a "court mediated decision" in a payment of 157.5 million RMB (20.1 million Euro) by Schneider (as a global settlement). Chint's utility model was only a small modification of the existing technology, but has been held valid by the courts.

For chemical and pharmaceutical companies, it is important to make sure that the above mentioned "new versions", which are usually small modifications of the original invention, must be covered by own patent applications or utility models. At least they should be published as a "defensive publication", e.g. via internet services, in order to make them prior art and to avoid that Chinese companies are able to file own IP rights on such modifications.

This means: Already during the internal

discussions with the inventor and before filing the priority application, e.g. with the EPO, the patent attorney has to think about possible implications, if a future product covered by such a priority application should be launched in China, maybe years later.

And it is not only about the small modifications which need to be included, it is also important from the very beginning to have a good “coverage” for the patent claims in such a priority application in terms of experiments and working examples. To meet the requirement of enablement (or “sufficiency of disclosure”) in China (and to some extent also in Japan), it is necessary that the original description already discloses enough experimental evidence and specific data to support the claims.

This is especially true for second medical use inventions. It is not sufficient to provide a mere written description of the use as claimed, but it requires convincing efficacy data for such a use in the initial application to prove that the claimed invention can solve the targeted problem. Clinical data, however, are not necessary.

So, as always, professional and detailed work in the very beginning sets the basis for a good strategy.

3.2 Considering amended Chinese IP regulations

As already said, the Chinese patent law has been revised in 2010. Although this patent law in general is in many aspects in line with, for instance, the European patent law, there are some amendments which might have an impact on a product related IP strategy.

Even if a company has filed a perfect patent application covering an important e.g. pharmaceutical product, one has to keep in mind that the patent law now includes a Bolar exemption (Art. 69, no patent infringement by using e.g. a patented medication for gathering data for administrative approval) without the usual compensation by a patent term extension (as it is the case in the US or Europe). And on top of this, the compulsory license system is rather favourable to generic companies: In case a company does not “sufficiently” exploit its patented product, a compulsory license might be granted (Art. 48). So far, no specific examples are known, but the “tool” exists anyway.

For biotech companies it is important to know that for inventions which depend on genetic resources the original and the direct source of

said genetic resources shall be indicated in the application. The applicant shall state reasons, if he is unable to indicate the original source (Art. 26).

So, before entering the Chinese market with a specific product, it needs to be analyzed whether or not there is a reasonable balance between the possible IP protection for this product and, on the other hand, the burden, e.g. costs, for such a market launch in China.

4 R & D activities in China

Another category of business operations is the establishment of a R&D center in China. There are a lot of reasons which make it meaningful to start an R&D center in China. Some of them should be mentioned:

a) Tax incentives for high tech companies: One essential point to achieve this high tech status is the number of inventions made in China (besides the number of employees in R&D and other topics).

b) The “Hai Gui program” intended for high-skilled returnees: In 2009, 63,300 young professionals went back to China from abroad, caused by the benefits of this program.

c) Biotechnology represents one of eight technology fields of main interest defined by state authorities. As a consequence, companies filed 12,081 inventions patents in this field in 2011 (40% more than 2010), 77.7% of them owned by Chinese companies.

d) In November 2008, China initiated the Mega New Drug Development Program, funded with more than 17 billion US-Dollars.

Irrespective of the importance of China as market, it might be very interesting for a foreign company to profit from this framework by establishing an R&D center in China, either as wholly owned Chinese affiliate or jointly with a Chinese partner.

If a Chinese partner is involved, either within a Joint Venture or as a co-operation partner, its IP position should be clarified in advance: Do the expected results stemming from such an R&D activity depend on already existing patents owned by the Chinese Partner? If so, it needs a respective licensing contract from the early beginning of such a co-operation as part of the

strategy.

Especially in the biotech field, there are several interesting Chinese partners within the Chinese Academy of Science for co-operations. Just to name one of them: Shanghai Institute for Biological Sciences (SIBS) has signed nine patent licensing deals in 2011 worth more than 300 million RMB (ca. \$46 million) according to China Daily.

In any case, part of the organizational set up for such an R&D activity and, consequently, of an appropriate strategy, are IP contracts which reflect the Chinese legal situation in a suitable way. Mainly, three regulations need to be taken into account in the first place:

1. Chinese universities as possible R&D partners usually do not have a business license and, therefore, are not allowed to sign a contract with a foreign company. In such a situation, the Chinese affiliate will be the right contractual partner instead of the foreign parent company.

2. All inventions "made in China" within such an R&D operation have to be filed with SIPO first (Art. 20 of the Chinese Patent Law).

3. All contracts covering regulations on the worldwide utilization of results stemming from such R&D operation in China fall under the Regulations of the People's Republic of China on Administration of the Import and Export of Technology, effective from January 1, 2002 ("TIER")

This shows that the necessary contractual framework is complex and, therefore, should be structured by an experienced attorney only.

5 Other important IP issues in China

In addition to the selected topics above, it is necessary to consider a lot of other IP issues for enterprises being active in China. Some of them are mentioned below.

5.1 Trademarks and designs

Part of the "IP package" for a product in China must be the right trademark and, if applicable, a design patent. The own trademark, especially in Chinese characters, is important, to make sure that Chinese competitors may not entry as copycats, not using the original trademark in latin letters alphabet, but using Chinese characters as a trademark which, pronounced

in Chinese, sounds like the known "western" trademark. One example is the "Rehau case", recently decided by the Shanghai No. 1 Intermediate Court. Rehau prevailed in a four years trademark litigation and stopped Chinese competitor Shanghai RUIHAO (!).

5.2 Enforcement of IP rights in China

It is a "common understanding" (maybe "misunderstanding") that western companies cannot enforce their IP rights in China because of the weak legal system in China. According to the "2012 China Business Climate Survey Report" published by the American Chamber of Commerce in China (AmCham China), 24% of the respondents in the survey mentioned IP rights infringement as a challenge (this seems rather moderate in comparison to other problems as management-level human resources constraints with 43% and inconsistent regulatory interpretation/unclear laws with 37%). Nevertheless, only 34% of the respondents found China's IP right enforcement has improved.

However, one has to distinguish between infringements of copyrights and designs, which are still a big problem, but do not effect the chemical industry so much as the consumer industry, and patents, which are more important in the field of chemistry and usually can be enforced more effectively.

To be successful in enforcing patents, it is essential to follow some "basic" rules:

- a) Set up the right team of internal and external experts and make sure that the communication within the team is more than just o.k.

- b) Select the right venue. To avoid local protectionism and have the case handled by an IP experienced court, the choice of the right court is important (Beijing or Shanghai are recommended).

- c) Select the right way of enforcement: In principle, there are two ways of enforcement: Administrative enforcement via the local Administration for Industry and Commerce (AIC), which is a Chinese speciality, and enforcement via the court system (as it is known from Europe). For complicated cases in the field of chemistry, the court system maybe the preferred way.

- d) Prepare the case very carefully and detailed. The evidence presented before the court from

the very beginning is decisive!

e) Do not focus on the payment of possible (but limited) damages, but try to stop competitors in the first place.

In general, the proceeding before the Chinese courts is all in all not longer than similar litigations before German courts (one to two years for one instance). In case, all evidence (which means all necessary documents) is presented to the court in the beginning of the litigation, a Chinese court may decide within 6 months.

5.3 Know How protection

From a Chinese point of view, the access to high tech know how is one crucial point in the process of making China an innovative country. For an international company two points need to be considered: Legal and illegal transfer of know how.

The legal “embodiment” is also known under “forced technology transfer”, which means the requirement of providing know how for market access.

According to the above mentioned survey by AmCham China, 67% of the respondents found that such practices have a negative impact on the assessment of the business environment in China. However, if a company decides that the Chinese market is important, it has to find a way to deal with it. In practice, this entails a detailed analysis of the situation, but there are no simple answers to this problem.

The other point is the illegal “transfer” of know how. There are a lot of measures to tackle the problem, including “simple” protection of the own premises or the own IT systems. Avoiding an unreasonable fluctuation of the personnel by an appropriate HR policy is another issue. One important point, however, is again the protection of the know how by effective and enforceable (see above) IP rights.

In addition to this, there is a completely different way for Chinese companies to get access to relevant know how: Acquiring a western company! One recent example is the acquisition of the Italian luxury-yacht manufacturer Ferretti by Shanghai Heavy Industry Group, a 350 million Euro deal. “We now own some hundreds of patents and rights to use eight brands of Ferretti, which is very helpful for improving our capacity in making general-

purpose motors.” said an official according to China IP Report of February 1, 2012 (Zhao, 2012).

If such an acquisition is a share deal (that means the whole company will be bought), the question of know how protection seems to be obsolete. However, the IP professionals within the targeted company should be very careful during the due diligence process: In case the deal fails (and nobody knows this in advance), it is important that only those parts of the know how are discovered during the due diligence which are inevitably necessary for an assessment of the value of the targeted company. In addition, the disclosed parts should be clearly documented.

If such a deal is an asset deal (that means only parts of the business are transferred), it is, in addition to the point made above, crucial that there is a clear distinction between transferred rights and rights which remain with the selling company. If there are rights which are used by both parties in the future, respective licensing deals are necessary, covering also know how.

5.4 Lobbying

Last but not least, it is very important for European companies to be present in the Chinese legal community. “Lobbying” in this context does not mean trying to directly influence, for instance, Chinese politicians, but working in detail together with Chinese authorities in order to improve the legal system. China’s IP laws are still very “young” in comparison to the western IP system and, therefore, are still in an ongoing process of improving and adopting the system to actual needs.

Although this procedure is sometimes a little bit frustrating, Chinese authorities are usually open to accept comments and proposals and discuss future amendments of the IP system with all participants. Therefore, it is necessary that western companies have established a system of representation (e.g. chambers of commerce in China, associations of multinationals in China as the Quality Brand Protection Committee, “QBPC”) which is able to communicate with Chinese authorities. Such a system, however, heavily depends on the commitment of all the companies active in China, including also the SME, not only the big ones!

6 Conclusion

In general, the development of an IP strategy, especially for China, has to follow a holistic approach.

In a changing environment, such as the Chinese IP system, it is not helpful to “rely” on a perpetual prejudice and to ignore opportunities, provided by such a changing system. During the last years, it becomes very clear that more and more Chinese companies use the Chinese patent system, not only by filing patent applications as can be seen from the statistics above, but also by starting IP litigations against other Chinese (and foreign!) companies. This will certainly lead to a further development of the Chinese IP system. So far the visible development is rather similar to what we know from the European IP system.

Therefore, it is crucial to keep two things in mind:

a) Setting up an internal IP structure and network appropriate to the needs of a company, which can serve as the basic for all IP work in China.

b) Developing a product- and/or project-specific IP strategy, which includes all aspects of possible IP protection.

Of course, this approach is not for free, but as always, sustainable operations need a permanent commitment.

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