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A study commissioned by Swiss Re Institute

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0 Executive Summary

Investments in R&D and related technological activities are an important factor to remain competitive in many markets. This has been shown in particular for the manufacturing industries, less so for the service industries and it has been hardly investigated for the insurance and reinsurance sector. With this study, we want to provide first empirical evidence on the patent activities of the 14 most important insurance and reinsurance companies worldwide over the period of 21 years (1992-2013). This does not only include the frequency of their patented technological activities, but also information about the technological basis of their R&D activities, the location of the invention activities, and their technological value. In essence, however, we want to investigate the relationship between the knowledge capital of a company - measured by number of patent families - and its performance. This is a non-trivial task and it requires appropriate econometric estimations in order to explore potentially causal relationships.

The descriptive information shows a clear expansion of patent activities since 1992. The observed 14 conglomerates filed – with the exception of 2007 – about 75 patent families or more annually between 2003 and 2013. Berkshire Hathaway, Swiss Re, China Investment, and Allianz are the main driver of this development.[1]

The technological fields (that can be found in patent documents) 'Electric Digital Data Processing' and 'Data Processing Systems of Methods' with its subgroup 'Insurance, e.g. Risk analysis or Pensions' seem to be the most important ones to the insurance business. Most of Swiss Re's patents can be assigned to one of these technological groups. Companies outside of the insurance business, however, dominate the technological activities in these fields. NEC Corporation, IBM, Fujitsu, Hitachi, and Toshiba are the main players.

In the insurance-related subgroup 'Insurance, e.g. Risk Analysis or Pensions', we see a dominance of insurance companies, however, most of them are not reinsurers. Swiss Re is the only re/insurance company that shows up in the top 15 applicants. Swiss Re predominately builds its technological activities upon patented technologies from companies outside the re/insurance business. Technological information in the patents filed by Panasonic Corporation, Toshiba, Canon, and Hitachi is of particular importance.

We also see that USA, Switzerland, and China are the main inventor countries. For Swiss Re in particular, inventors are predominately located in Switzerland and the USA.

Following the time trends of the performance measures, technological activities, and the average insured losses due to disasters, we see that the development of patent families and net premiums written is close to parallel in many periods. We also see some co-movements of average insured loss and the average patent family count between 2003 and 2007. However, this does not allow for a causal interpretation.

With the in-depth econometric analyses, we explore the relationships between the patented knowledge stock of a company and its performance. We see that an increase in the knowledge stock is significantly related to an increase in 'Net Profits' and 'Equity (Surplus)'. We also see - in particular for smaller firms - that knowledge drives net profits as a % of net premiums written (net profits divided by net premiums written). By using an instrumental variable approach, we deliver credibility that those relationships might

[1] In the remainder of the study, we will talk about the 14 conglomerates as re/insurance companies or the re/insurance industry.

be interpreted as causal. Hence, patented technological activities essentially contribute to the competitiveness of re/insurance companies. The accumulation and appropriation of knowledge is gaining strategic importance and it is important to systematically record and monitor them.

1 Introduction

The worldwide annual number of natural disasters nearly doubled between 1987 and 2016 – it increased from 100 to 192. Also the amount of insured losses (inflated) due to disasters increased considerably from 6.4 billion in 1987 to 46.6 billion in 2016, with two exceptional peaks in 2005 (103 billions) and 2011 (120 billions). This certainly imposes big challenges for companies in the (re)insurance industry. This is visible in the inverse of the non-life underwriting results (total underwriting expenses non-life minus total underwriting income non-life), which has been increasing since 2001, indicating that the profits from the core business are decreasing (see Swiss Re Institute, 2018). Moreover, constantly low interest rates lead to lower returns on investments. In the longer term, also the reliability of the existing risk models might be challenged by a number of factors, such as the uncertain consequences of climate change or the impact of advanced technologies (e.g. nanotechnology or advanced digital technologies). While studies for the manufacturing industries show that research and development (R&D) and innovative behaviour increase the resilience against an adverse economic environment (Hombert and Matray, 2018), the role of "technological" innovations for the performance in the re/insurance sector is largely unknown. Given that the re/insurance market is - in terms of revenues - the largest industry in the world, this is not only a question of the competitiveness of a single company; it is also of broader economic interest (Mills, 2005).

Against this background, we investigate the relationship between R&D efforts and the performance of companies in the re/insurance sector. We use patent filings as proxy for R&D activities and "new knowledge" since we are lacking more specific R&D data. In particular, we examine in which technological fields (areas of knowledge) new knowledge is generated, which technological fields are important for new developments, where new developments take place and what consequences new knowledge has for the performance of companies in the re/insurance sector. The period under review for the performance effects covers 20 years.

In order to address these research questions, we compiled a comprehensive dataset comprising financial information from the 14 principal companies in the re/insurance sector, data on disasters worldwide, and information about their patent activities. The data have been provided by A.M.Best (a company providing rating services and market information for the insurance sector) and Swiss Re, while the authors matched the datasets with patent information from PATSTAT. This is a unique data set and it allows – for the first time – for a comprehensive empirical study about the relationship between the technological activities and the commercial success in this specific sector.

Re/insurance companies are not typical technology-driven companies as for example companies in the electronics or machinery sector. Moreover, they are acting in oligopoly-like markets with few principal competitors worldwide. Our descriptive analysis shows that only few re/insurance companies are patenting in the relevant insurance technologies and that technological progress in such technologies is paced by companies like NEC Corporation, IBM, or FUJITSU. This is in line with Bader (2008) who concedes that only few firms in the knowledge intensive business services (KIBS) sector have an IP strategy. He found that Swiss Re is one of the first re/insurance companies having a patent department. This points to the development of new technologies and knowledge being an asset for knowledge-driven businesses, which emphasises the importance of this analysis.

The descriptive analysis further shows that Swiss Re performs considerably well in terms of patent quality and quantity in the relevant insurance technologies. However, its patent activities have decreased tremendously compared to the pre-2008 period and is still a marginal phenomenon. Our analysis also shows that most of the "technological competitors" in the relevant patent space are large ICT companies.

A more in-depth econometric analysis of the relationship between patented knowledge activities and the business performance of re/insurance companies shows a significant and positive relationship between the size of the companies' knowledge stock and Net Profits as well as Equity (Surplus). There are, however, some differences according to firm size. The knowledge stock is positive and significantly related with 'Net Profits' and Net Profits/Equity (Surplus) in particular for larger corporations with total assets above the median level. The "knowledge effect" on 'Equity (Surplus)' is also considerably stronger for large compared to smaller companies. Net profits as a % of net premiums written (net profits divided by the net premiums written) are significantly linked to the knowledge base in both types of companies. However, for this measure, the economic effect is larger in smaller companies.

Our study is organized as follows: Section 2 presents the research questions. In section 3, we discuss the dataset and in section 4, we conduct the descriptive analysis of the patent activities and the performance in the re/insurance industry. In section 5, we present the econometric analysis to investigate the relationship between the knowledge activities of companies and their performance.[2]

2 Research Questions

2.1 Which Fields of Technology are Re/Insurers Active in?

Technological differentiation: Based on the patent activities of the investigated re/insurance companies, we investigate to which technological areas their patents are assigned to. We define technological areas by the International Patent Classification (IPC) scheme that provides information at various levels of detail. This descriptive analysis makes it possible to compare the patent portfolios of different companies not just on a quantitative but also on a qualitative level.

2.2 Where does Knowledge for new Technologies in the Re/Insurance Industry Originate?

Differentiation in content: Using backward citations (i.e. the patents cited by reinsurers' patents) and co-applications (patent applications filed together with other companies), we can analyze from which companies the knowledge for new inventions originates or which companies collaborate in the knowledge generation.

[2] We are grateful to Birte Gernhardt, Mariella Greutmann, Sanyat Mapara and Abir Shah for their contribution in preparing the data and helping with the visualization of the descriptive results. We also want to thank Oliver Schelske and Daniel Staib for their support in getting access to relevant data and their valuable comments.

2.3 Which Regions Mainly Generate Knowledge?

Geographical differentiation: We use address information in our patent data to determine regions in which a great deal of knowledge relevant to the re/insurance industry is generated (e.g. in foreign research centers). We calculate a fractional count of inventors by country to determine the geographical locations – which provides a nuanced view on the geographical sources of knowledge.

2.4 Which Companies are Active in the Relevant Areas of Knowledge and Technology?

Technological competition: Many of the patents of the insurance industry fall into the technology area G06Q 40/08 ("Insurance, e.g. risk analysis or pensions"), according to the International Patent Classification (IPC). However, a brief analysis in the patent search engine Espacenet shows that many large IT companies from outside the sector are also active in this area. We will therefore investigate whether and to what extent 'outsiders' are driving invention activity in the relevant technologies. This allows a conclusion to what extent the re/insurance industry develops technologies itself or whether companies outside the industry make significant contributions to the technological development in the insurance industry. This is also an indication of possibilities for R&D collaborations.

2.5 Is there a Relation between the Development of new Technologies and Corporate Performance?

Causal analysis: Although the descriptive analysis suggests a significant relationship between the patented technological activities of a re/insurance company and its performance, it is difficult to say if an increase or decrease in performance is indeed driven by its technological performance. Unobserved factors like the quality of the management or the experiences of the employees might cause the observed correlation and we would mistakenly attribute the change in performance to the patented technology. Advanced econometric procedures help deal with unobserved factors. We use instrumental variable regression to further analyze the causal relationship between the patented knowledge stock of a corporation and its performance. In this way, we can improve our analyses and answer the following question more precisely: Is it profitable to invest in new technological developments?

3 Data

For our investigation, we used four different sources of data: Names and the legal structure of re/insurance companies, financial performance data of re/insurance companies (1997-2017), information about patents (1992-2013), as well as data on natural disasters (1970-2016). KOF, Swiss Re and A.M. Best (mandated by Swiss Re) provided the data. Swiss Re identified the main competitors in their business, provided access to data on names and legal structures of competitors, and delivered information on disasters. KOF provided the patent statistics, processed and merged all data. In the following, we describe the four data sources in more detail.

3.1 Conglomerates and their Legal Structure

Swiss Re compiled a dataset of the 14 most important conglomerates in the re/insurance business (see box on competing conglomerates). The dataset contains the development of their organizational structure (subsidiaries), for instance, which companies they bought or sold, which stakes they increased or decreased. The private provider A.M. Best extracted the data.

The full set of names included duplicates since many subsidiaries occur several times in the organizational structure over the years. After extracting unique names, we used the resulting list to find the respective companies (including all subsidiaries) in the patent database, as described below. It also served as a link to the financial data we used to assess the conglomerates' performance.

14 Competing Conglomerates

- Alleghany Corporation
- Allianz SE
- Assicurazioni Generali S.p.A.
- AXA S.A.
- Berkshire Hathaway Inc.
- China Investment Corporation
- Everest Re Group, Ltd
- Haftpflichtverband der Deutschen Industrie (HDI)
- Munich Reinsurance Company
- PartnerRE Ltd
- Scor SE
- Swiss Re Ltd
- XL Group Ltd
- Zurich Insurance Group Ltd

3.2 Conglomerates' Financial Performance

The data from A.M. Best also includes the financial data for the years 1997 to 2017of the 14 conglomerates. The data provides a wide variety of financial indicators to assess a conglomerate's performance – especially in terms of the performance in their core (insurance) business. The data also contains overall financial measures in absolute and relative values (e.g. total assets). Unfortunately, the data is partly incomplete and we do not have all financial indicators for all the companies in every year. In the subsequent analysis, we mostly use indicators with absolute values due to their high degree of completeness.

3.3 Patents

We used PATSTAT, the worldwide patent database provided by the European Patent Office (EPO). The database contains bibliographic information for a large number of countries and patent offices with very detailed information on technology fields and citations. In order to assign patents to the re/insurance companies, we needed to match the list of re/insurance companies mentioned above with applicant names showing up in the patent database.

Merging companies from an external dataset with the names of applicants in a patent database is challenging, as the matching of company names is necessary. Name matching is complicated due to several reasons (Raffo and Lhuillery, 2009): Typically, there are many spelling mistakes in the applicant names in the patent data. In addition, company names in the patent database are often ambiguous which means that a specific company can occur under a variety of names (e.g. Swiss Reinsurance Company Ltd., SWISS REINSURANCE CO or SWISS REINSURANCE CO., ZUERICH).

To find the re/insurance companies from our list in the patent database, we proceeded in two steps. First, we manually searched for every company from the list of names in the patent database. To minimize the chance of missing a company in the list we checked for different spellings and looked for alternative names for companies we could not find. To avoid false positives, we checked the content of a company's patents in cases when a company's name was ambiguous. Second, we used the found names from the first step to search for variations of the names within the patent database to avoid the problems of duplicate companies mentioned above. We conducted the automated search in the second step based on trigrams. This technique splits text (e.g. company names) into fragments with the size of three, compares the resulting vectors and calculates the similarity between different pieces of text.
From the final list of identified companies, we derived the subsequent information on single patents and patent families – under the restriction that we excluded subsidiaries with a core business outside the re/insurance industry. It is important to note that the sample of patenting conglomerates is rather small (see descriptive analyses).

3.4 Disasters

The Swiss Re Institute (2018) provided us with information on natural disasters comprising incidents on continent level and by year. The data goes back to 1970, lasts to 2016 and contains information for the following six regions: Africa, Asia, Europe, Latin America and the Caribbean, North America as well as Oceania and Australia. The dataset contains information on the extent / intensity of the disaster (e.g. number of victims, economic loss and insured loss – both inflation-adjusted). We use this data for the descriptive analyses.[3]

4 Descriptive Analysis

4.1 Patent Activities in the Re/Insurance Industry

In the first section of our descriptive analysis, we look at the patent activity in the re/insurance industry, based on our sample of 14 conglomerates. We found patents for all the 14 conglomerates except Alleghany, Everest RE, PartnerRE, and Scor. Concerning Berkshire Hathaway – a very broad conglomerate in terms of its subsidiaries' business areas – we removed all the subsidiaries that are not active in the insurance industry (e.g., BNSF Railway).

We use patent families (see box) to count the number of patents per conglomerate or company to prevent double counting of inventions. Patent families come closer to a measure of unique inventions, while a count of single patent filings – due to the

Patent Families

Patent activities of the re/insurance companies are measured on the basis of patent families. Patent families contain all applications or grants in different jurisdictions that are based on the same invention.

Patent families are a better measure of inventions compared to single patent filings because double counting of similar inventions in different jurisdictions is avoided.

[3] The data can be accessed online at www.sigma-explorer.com

possible application in multiple jurisdictions – might be biased and overestimate the inventiveness of a company or industry. If not specified differently, we use the count of patent families throughout the descriptive report as well as in the econometric analysis.

Table 1: Number of patent families at conglomerate level (families with at least one granted patent are displayed, only insurance businesses) (Patstat, 2017)

Conglomerate	Family Count
Berkshire Hathaway Inc. (Insurances only)	798
Swiss Re Ltd	61
China Investment Corporation	29
Allianz SE	20
Munich Reinsurance Company	6
AXA S.A.	5
Zurich Insurance Group Ltd	3
Assicurazioni Generali S.p.A.	1
Haftpflichtverband der Deutschen Industrie (HDI)	1
XL Group Ltd	1

Table 1 shows the count of patent families per conglomerate. We only counted the patent families with at least one granted patent that is assigned to an insurance business and we considered all patent families that can be identified in the PATSTAT database (version autumn 2017)[4]. Table 2 displays the number of patent families at the level of a single corporate entity. Looking at the identified patents within our sample, we see that the distribution between conglomerates and companies is highly skewed. We see a small set of firms being highly active in terms of patenting, while the majority of companies show only minor patent activities. On the conglomerate level, Berkshire Hathaway, Swiss Re., China Investment and Allianz are the conglomerates with the bulk of patent activities. On the company level, the Columbia Insurance – belonging to Berkshire Hathaway – accounts for the majority of patent activities in the Berkshire group, as far as the insurance business is concerned.

Table 2: Number of patent families at company level (families with at least one granted patent are displayed, only insurance businesses) (Patstat, 2017)

Company	Conglomerate	Family Count
Columbia Insurance Company	Berkshire	785
Swiss Reinsurance Company Ltd	Swiss Re	60
Bank of China Limited	China Investment	29
Allianz-Zentrum für Technik GmbH	Allianz	5
Allianz Versicherungs-Aktiengesellschaft	Allianz	5
Applied Underwriters, Inc.	Berkshire	5
GUARD Insurance Group Inc	Berkshire	5
Hartford Steam Boiler Inspec & Ins	Munich	5
AXA S.A.	AXA	2
Allianz Life Insurance Co Ltd	Allianz	2
Allianz Life Insurance Co of NA	Allianz	2
Government Employees Insurance Company	Berkshire	2
Zurich Insurance Company Limited	Zurich	2
AXA Equitable Funds Management Group, LLC	AXA	1

[4] Due to the lag in granting patents, we only show descriptive statistics until 2013.

AXA Equitable Life Ins Co	AXA	1
AXA Equity & Law Lf Assur Soc	AXA	1
Allianz Deutschland AG	Allianz	1
Allianz Global Investors U.S. LLC	Allianz	1
Allianz Lebensversicherungs-Aktiengesellschaft	Allianz	1
Allianz S.p.A.	Allianz	1
Allianz SE	Allianz	1
Allianz Telematics S.p.A.	Allianz	1
Boat America Corporation	Berkshire	1
Farmers Insurance Exchange	Zurich	1
Genertel S.p.A.	Generali	1
International Insurance Co	HDI	1
VICTORIA Lebensversicherungs AG	Munich	1
Westport Insurance Corporation	Swiss Re	1
XL Group Ltd	XL Group	1

In terms of time trends, we see a massive expansion in the patent activity over the last two decades. Figure 1 depicts the number of patents (filed and granted) between 1992 and 2013 by their filing year. We see a steep drop in the year 2007 that is mostly due to the Colorado Insurance Company registering about 50 patents less than in 2006. From 2010 onwards, we see a second drop in the number of filed patents that seems to come to a halt in 2012. It is not possible to conclude yet, if this is a real recovery since it is not clear to what extent filed patents in this year will be granted. Overall, the difference between filed and granted patents is rather small indicating a reasonably good performance of the patent applications.

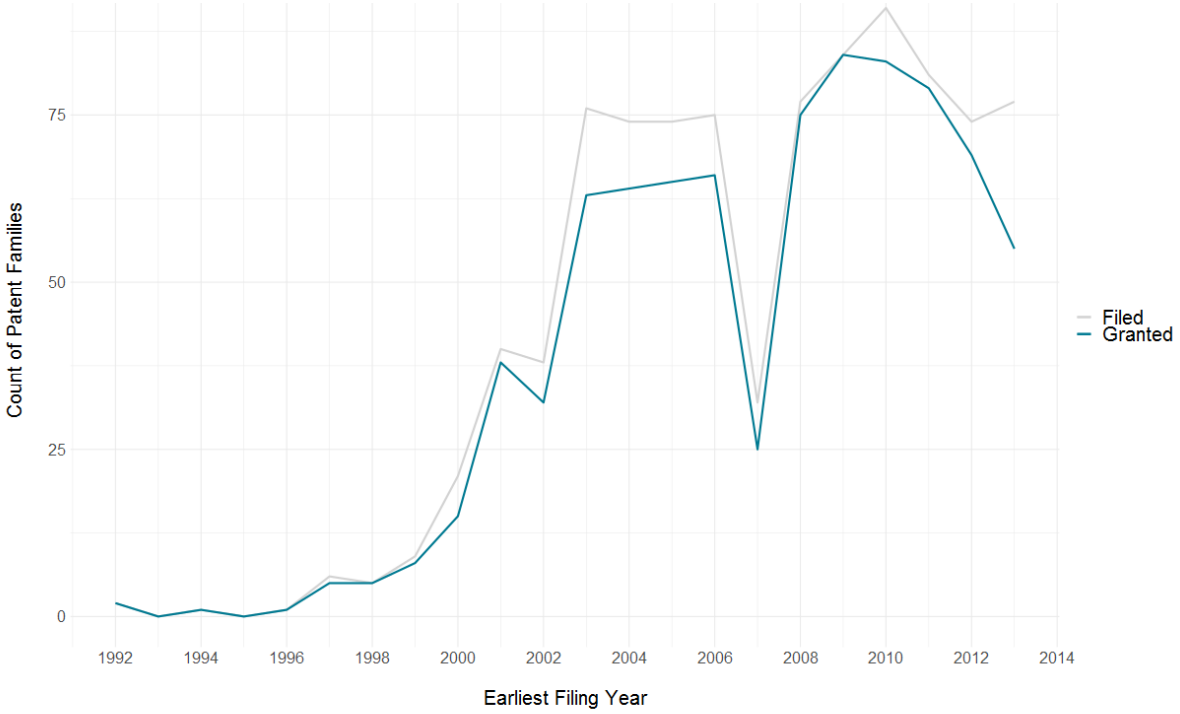

Figure 1: Patent activities of the 14 selected conglomerates including their subsidiaries (Patstat, 2017)

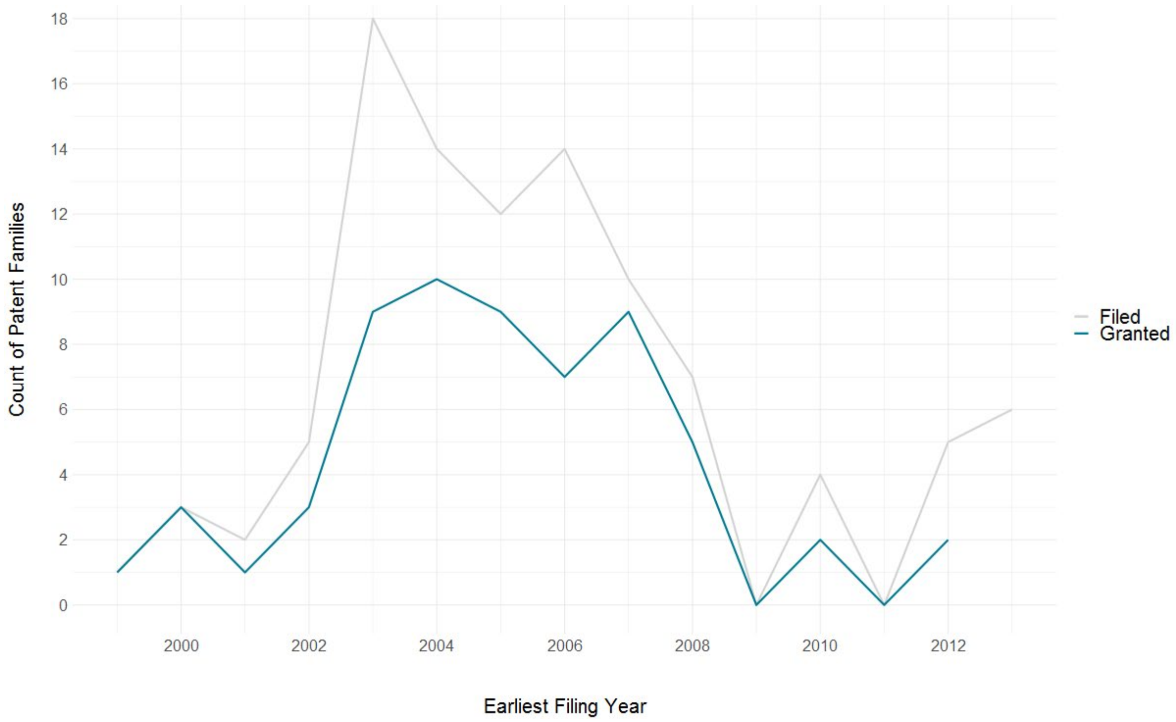

Figure 2: Patent activities by Swiss Re (Patstat, 2017)

For Swiss Re, we see a strong increase in patent activities from 2001 to 2004 followed by a stagnation and a decrease from 2007 onwards (Figure 2). There are again more activities from 2011 onwards, however, it is hard to judge if this reflects the start of a longer lasting expansion of the patenting activity. During the years from 2003 to 2006, the efficiency of Swiss Re's patenting activity was rather low as can be seen from the share of granted patents within all applications. The share of Swiss Re's patents among the patents of all 14 competitors is not huge, but as we will see in the following chapter, Swiss Re performs well in the relevant technological classes.

4.2 Patent Activities in Relevant Technological Fields

This chapter provides a closer look at the two IPC subclasses G06F and G06Q – Electric Digital Data Processing and Data Processing Systems or Methods (see box: IPC Subclasses G06F and G06Q). Those are the two most important technological classes in Swiss Re's patent portfolio. We compare Swiss Re to the companies in our sample and look at the most important companies within the two IPC subclasses, as well as the IPC group G06Q 40/08 – Insurance, e.g. risk analysis or pensions.

In Figure 3, the patent families with at least one granted patent by Swiss Re and the 13 other competitors) are displayed. Among the 14 competitors, Swiss Re has by far the biggest share of granted patent families in the two subclasses. Hence, it is not surprising that there is a quite similar time trend for both – Swiss Re's and the overall portfolio. We see a steep rise from 2001 to 2004 and an increasingly sharp decline afterwards. While Swiss Re's patent activities in these technological fields reached its peak in 2004, respective activities of the other companies peaked one year later.

IPC Subclasses G06F and G06Q

The International Patent Classification (IPC) provides a system to classify patents by technological areas.

The majority of patents in our sample that are filed by Swiss Re are in the two IPC subclasses G06F and G06Q. These technologies also seem to be closest to potential R&D activities of insurance companies. A more fine-grained level in the IPC is the group level: The IPC group G06Q 40/08 is the group where technologies for insurance businesses are named explicitly.

G06F: Electric Digital Data Processing

G06Q: Data Processing Systems or Methods, specially adapted for administrative, commercial, financial, managerial, supervisory or forecasting purposes

G06Q 40/08: Insurance, e.g. risk analysis or pensions.

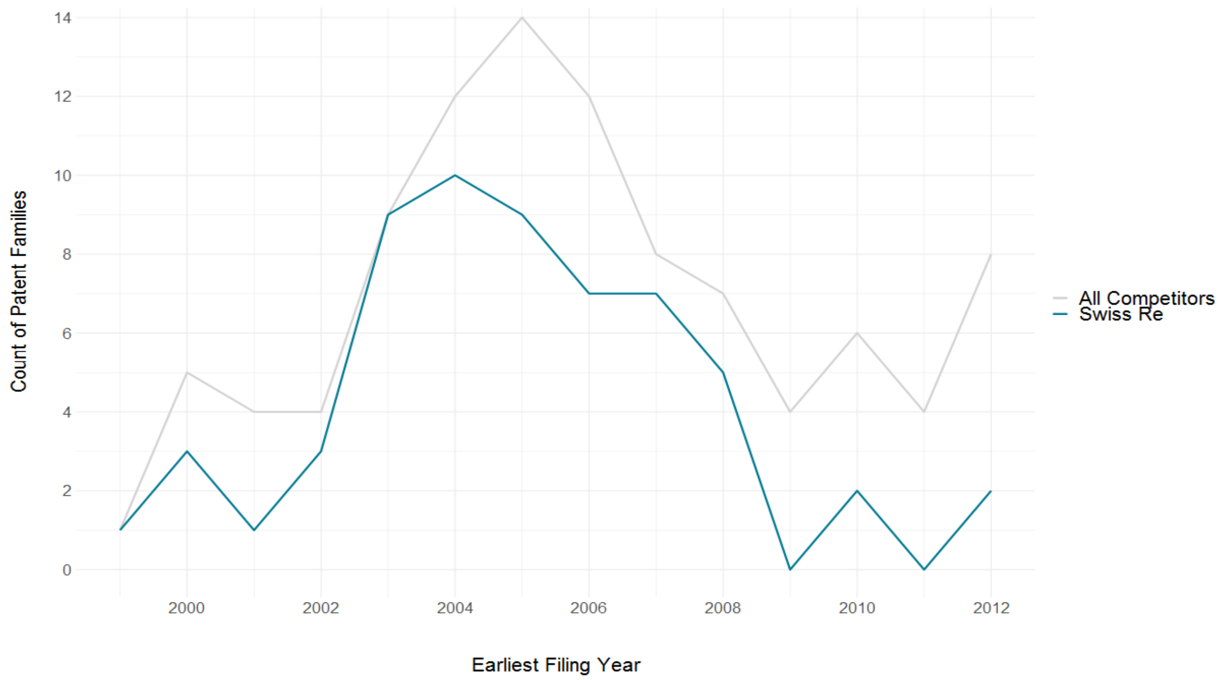

Figure 3: Patenting activities by Swiss Re and all 14 competitors in the two IPC subclasses G06F and G06Q (families with at least one granted patent) (Patstat, 2017)

Table 3 shows that Swiss Re and China Re (China Investment is the parent company of China Re) are the most active conglomerates in the technologies that are immediately relevant for the insurance business (all patents available in PATSTAT were counted – version autumn 2017). Interestingly, Berkshire's patent activities in these fields are modest meaning that the Columbia Insurance Company mainly files patents in areas outside the core business. This behaviour is known from other industries. Companies amass patent portfolios in order to make profits from licensing and trading technologies. Zurich, AXA, HDI and Munich Re have only very sparse patent activities in the relevant technologies.

Table 3: Number of patent families at company level in G06F and G06Q (Patstat, 2017)

Company	Technology	Number of patent families
Swiss Re	G06Q	94
	G06F	37
China Re	G06Q	65
	G06F	104
Allianz	G06Q	21
	G06F	5
Berkshire	G06Q	3
	G06F	14
Zurich	G06Q	9
AXA	G06F	1
	G06Q	5
HDI	G06F	1
	G06Q	1
Munich Re	G06F	3

Table 4 shows the main patent applicants and their number of patent families in technology subclass G06F. Not surprisingly, all companies are major players in the ICT (information and communication technology) sector as the technology pertains to data processing.

Table 4: Main patent applicants in G06F (Patstat, 2017)

Company	Number of patent families
NEC CORPORATION	72487
IBM (INTERNATIONAL BUSINESS MACHINES CORPORATION)	67800
FUJITSU	62274
HITACHI	54878
TOSHIBA CORPORATION	48254
CANON	45934
PANASONIC CORPORATION	32297
SAMSUNG ELECTRONICS COMPANY	30069
RICOH COMPANY	26835
MITSUBISHI ELECTRIC CORPORATION	26428
MICROSOFT CORPORATION	24652
SONY CORPORATION	23078
SHARP CORPORATION	19004
NTT (NIPPON TELEGRAPH AND TELEPHONE CORPORATION)	18337
FUJI XEROX COMPANY	15669

Technology G06Q also pertains to data processing. As a result, large ICT companies (Table 5) again dominate the field.

Table 5: Main patent applicants in G06Q (Patstat, 2017)

Company	Number of patent families
HITACHI	9881
FUJITSU	7832
TOSHIBA CORPORATION	7682
IBM (INTERNATIONAL BUSINESS MACHINES CORPORATION)	7666
NEC CORPORATION	6992
SGCC(STATE GRID CORPORATION OF CHINA)	4471
OKI ELECTRIC IND COMPANY	3606
PANASONIC CORPORATION	3584
NTT (NIPPON TELEGRAPH AND TELEPHONE CORPORATION)	3332
SONY CORPORATION	3193
MICROSOFT CORPORATION	3170
RICOH COMPANY	2862
MITSUBISHI ELECTRIC CORPORATION	2764
CANON	2558
GOOGLE	2508

Table 6 shows the counts of all patent families in the more specific group G06Q 40/08 that is especially relevant for insurance businesses ('Insurance, e.g. risk analysis or pensions'). Actually, insurance companies dominate this technological group, however, most of them are not reinsurers and thus not direct competitors of Swiss Re. Swiss Re also shows up in the list of the top 15 applicants as the only company that is dedicated to re/insurance businesses. Again, large ICT companies are highly active in this technological group.

Table 6: Main patent applicants in G06Q 40/08 (Patstat, 2017)

Company	Number of patent families
HARTFORD FIRE INSURANCE COMPANY	146
HITACHI	83
STATE FARM MUTUAL AUTOMOBILE INSURANCE COMPANY	69
MITSUI SUMITOMO INSURANCE COMPANY	57
ALLSTATE INSURANCE COMPANY	47
FUJITSU	44
TOKIO MARINE & FIRE INSURANCE COMPANY	42
TOSHIBA CORPORATION	36
AIOI INSURANCE COMPANY	35
THE TRAVELERS INDEMNITY COMPANY	35
IBM (INTERNATIONAL BUSINESS MACHINES CORPORATION)	32
DAI-ICHI MUTUAL LIFE INSURANCE COMPANY	28
PING AN TECHNOLOGY (SHENZHEN) COMPANY	26
SUMITOMO LIFE INSURANCE COMPANY	25
SWISS REINSURANCE COMPANY	24

To summarize, patent activities of re/insurance companies are very sparse even if we look into technologies that are targeted at insurance businesses. Swiss Re is one of the few companies that performs reasonably well in terms of the number of patent families in the relevant technology group. The sparseness of patent activities in this market can have several reasons: Some companies might not file patents and instead keep new technologies secret. Other companies might not perform R&D at all and rather buy technologies from large ICT suppliers. However, it might also be caused by lacking IP strategies and the fact that it might be very hard to compete technologically with large ICT companies. With the data at hand, we cannot dig deeper into possible reasons. A regular patent monitoring might help companies to identify potential collaboration partners for the development of new technologies and develop a comprehensive IP strategy.

4.3 Technological Value of Inventions

The mere size of a patent portfolio provides only limited information on a company's inventiveness and technological ability. In this chapter, we therefore assess the quality of the firms' patent portfolios, at the level of conglomerates as well as companies.

The quality of a patent or patent family can be assessed by the count of citations they receive (see box: Patent Citations). Here we assume that frequently cited patents are of higher technological quality than those with fewer citations. It is also important to consider that the citation behavior across industries or technological fields is quite different.

Patent Citations

Patent documents comprise citations to prior art, i.e. other patents that are relevant for the development of the technology. The applicant mainly adds citations in the US system. In the European System, they are added by the patent examiner. A count of patent forward citations (i.e., the number of times a patent is cited by other patents) is often used in order to assess the quality and value of a patent.

To adjust for this, we assess the patent portfolio of Swiss Re within its two most relevant IPC subclasses G06F and G06Q and make a comparison with the average forward citation counts within these two subclasses. We count citations of families with at least one granted patent per family. For G06Q, Swiss Re shows a below-average citation count of 11.8 received citations per patent family (the average is 14.5). In contrast, for G06F, Swiss Re performs above average with 16.6 forward citations per family (mean is 11.4 received citations). To put this into perspective, Swiss Re performs reasonably well taking into account that the bulk of patent activities is done by very large ICT companies that invest enormous sums in R&D.

Table 7: Forward citations in G06Q by Swiss Re and for all patents in the class (Patstat, 2017)

Data Processing Systems or Methods*	**Average Citations**	**Total Citations**	**Patent Families**
Swiss Re in G06Q	11.81	638	54
Total G06Q	14.54	2'452'679	168'683

Table 8: Forward citations in G06F by Swiss Re and for all patents in the class (Patstat, 2017)

Electric Digital Data Processing	**Average Citations**	**Total Citations**	**Patent Families**
Swiss Re in G06F	16.62	349	21
Total G06F	11.36	11'932'699	1'050'180

Further, we compare our sample of conglomerates and their subsidiaries in terms of received patent citations. As already mentioned above, this measure can be biased due to diverging citation practices in different technological fields. Nevertheless, it gives us an indication of how the different conglomerates perform in terms of the quality of their portfolios. Table 9 and Table 10 show sizable differences between the conglomerates and companies. On the conglomerate level, HDI, Munich and Swiss Re are the three companies with the highest citation counts. While HDI and Munich have an extremely small patent portfolio with few highly cited patents (in case of HDI, one patent family received all the 36 citations), Swiss Re seems to perform well both in terms of patent quality and quantity as compared to its direct competitors.

Table 9: Patent citations at conglomerate level (Patstat, 2017)

Conglomerate	**Average Citation**	**Total Citations**	**Patent Families**
HDI	36	36	1
Munich	13.25	53	4
Swiss Re	10.56	644	61
Berkshire (Insurance only)	5.43	880	162
Allianz	4.2	21	5
Union Life	4	4	1
Zurich	4	4	1
China Investment	1.5	3	2

Table 10: Patent citations at company level (Patstat, 2017)

Company	**Conglomerate**	**Average Citations**	**Total Citations**	**Patent Families**
International Insurance Co	HDI	36	36	1
Allianz Life Insurance Co of NA	Allianz	17	17	1
Westport Insurance Corporation	Swiss Re	16	16	1
Swiss Re Life & Health America Inc	Swiss Re	14	14	1
Hartford Steam Boiler Inspec & Ins	Munich	13.25	53	4
Swiss Reinsurance Company Ltd	Swiss Re	10.41	614	59
GUARD Insurance Group Inc	Berkshire	6	36	6
Columbia Insurance Company	Berkshire	5.45	840	154
Farmers Insurance Exchange	Zurich	4	4	1
Union Life Insurance Company	Union Life	4	4	1
Boat America Corporation	Berkshire	2	2	1
Kyoei Fire and Marine Ins Co (UK) Ltd	Berkshire	2	2	1
Bank of China Limited	China Investment	1.5	3	2
Allianz Life Insurance Co Ltd	Allianz	1	4	4

4.4 Knowledge Sources for the Development of Technologies

In contrast to forward citations, backward citations are citations that link a patent to other patents in the past. In this study, they are used to analyze which firms' patents are mainly cited by Swiss Re's patents. This indicates potential knowledge sources for the development of own technologies. Firms showing up in cited patents might be potential collaboration partners for technology development. Table 11 shows the companies that received the largest number of citations as indicated in Swiss Re's patents. For example, Panasonic received 17 citations from Swiss Re. Most remarkably, among the top cited companies are not any insurance companies. Swiss Re's patents seem to build on knowledge generated by large ICT companies.

Table 11: Companies with the largest numbers of citations in Swiss Re's patent families (Patstat, 2017)

Company	Number of citations in Swiss Re's patent families
PANASONIC CORPORATION	17
TOSHIBA CORPORATION	16
CANON	12
HITACHI	10
NEC CORPORATION	8
FUJITSU	7
RICOH COMPANY	7
MITSUBISHI ELECTRIC CORPORATION	6
FUJIFILM CORPORATION	5
PANASONIC ELECTRIC WORKS	5
GE (GENERAL ELECTRIC COMPANY)	4
IBM (INTERNATIONAL BUSINESS MACHINES CORPORATION)	4
MITSUBISHI HEAVY INDUSTRIES	4
MITSUI CHEMICALS	4
NIPPON STEEL CORPORATION	4

We scanned Swiss Re's patents for co-applications, i.e. patents on which two or more different companies show up (or one firm and one or several universities or research institutes) as applicants. The number of co-applications is an indicator of R&D collaboration that we can retrieve from patent data. In high-tech companies, R&D collaborations and the 'openness' of the development process are widespread as a company often needs to supplement its own knowledge base with external knowledge in order to be able to develop complex technologies. In Swiss Re's patents, we cannot find any co-applications. This means that Swiss Re does not collaborate with other companies or universities in the development of patents.[5] Again, with our data we can only capture collaborations indicated by patents. Of course, there could also be other collaborations outside the patent space that we cannot observe.

[5] Swiss Re is not the only re/insurance company that shows such characteristics. Allianz and China Re do also not have collaboration partners listed on their patent applications.

4.5 Important Geographical Regions for the Generation of Technology

Patent activities are spread all over the world. In this chapter, we provide descriptive statistics about where inventions in the insurance industry are made. To assess the geographical origins, we use the information on the countries where inventors of patents are located as provided in the patent dataset and calculate a fractional count (see box). It is important to mention that country information is not available for all inventors – therefore the patent counts will diverge from other statistics provided in this report.

Fractional Count of Inventors

To describe geographical origins of a patent, i.e. the location of knowledge creation, we use a fractional count of inventors for patent families. The fractional count of inventors counts the contribution of inventors by country.

A patent invented by two Swiss and one German inventors will be counted as 2/3 Swiss and 1/3 German patent. For a count per country, we sum up the fractions country by country.

Figure 4 provides an overview for all 14 competitors, based on the summarized fractional counts – the darker the color, the more inventors we see in a country. For the 14 competitors, the United States, Switzerland and China can be identified as main inventor countries. For Swiss Re alone (see Figure 5), we see most inventors being located in Switzerland and the United States. There is no inventor activity in China or other emerging economies in Asia so far.

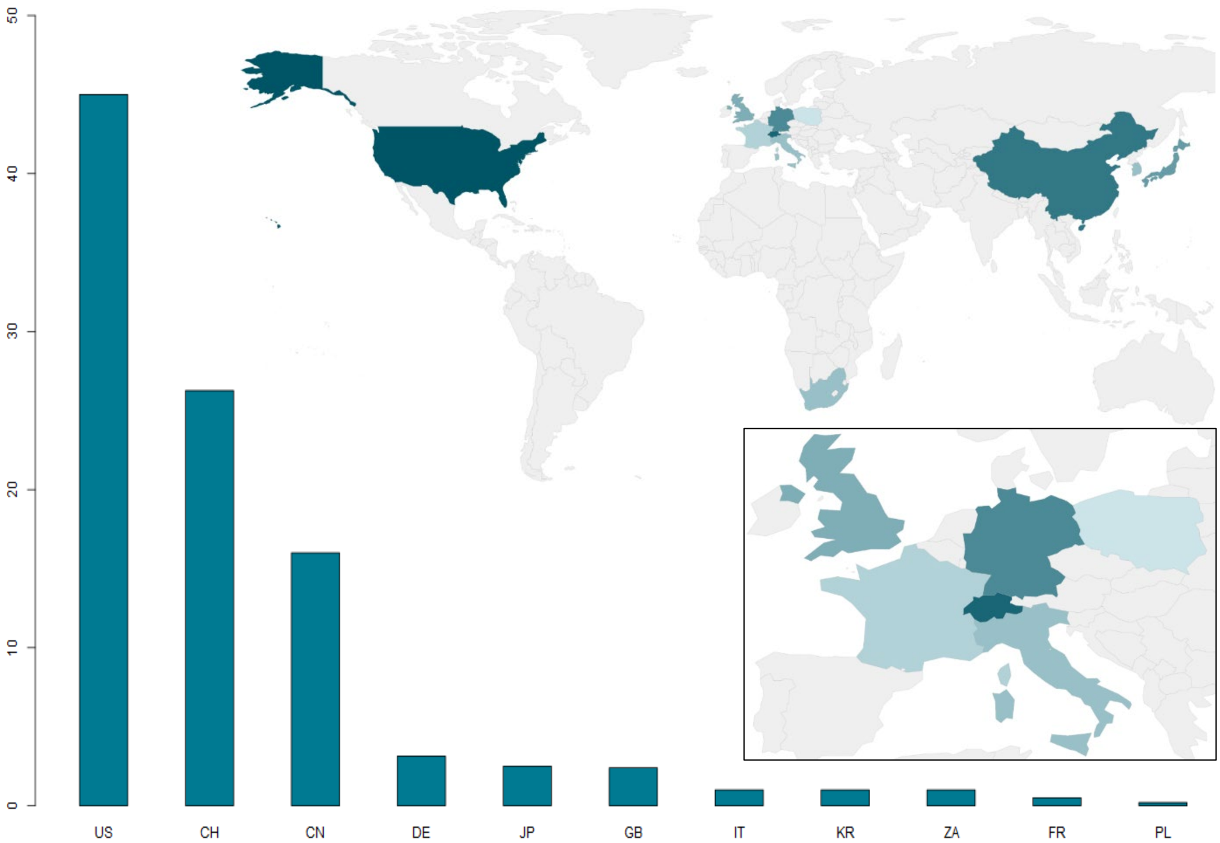

Figure 4: Important geographical regions in the generation of knowledge for all 14 competitors, according to patent activity. Scale on the y-axis is the fractional count of patents for an inventor country. Darker colour means higher activity. (Patstat, 2017)

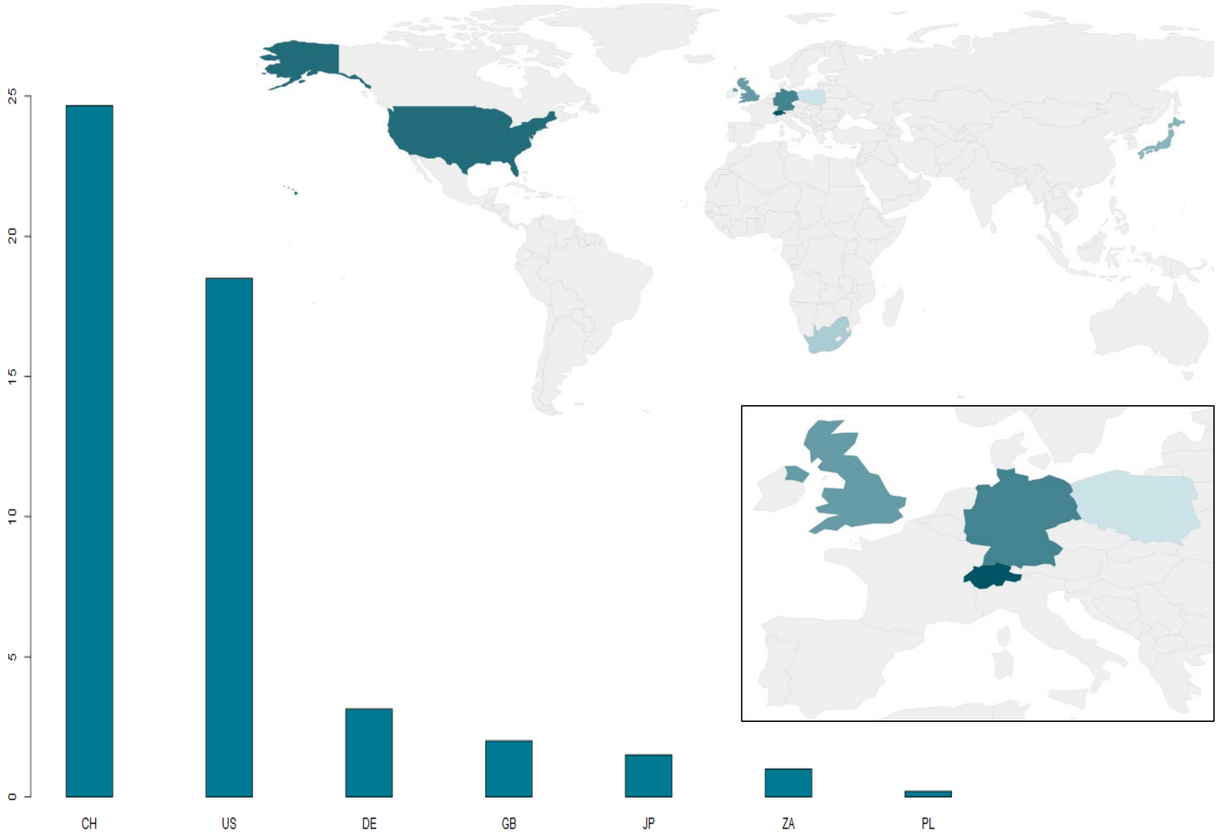

Figure 5: Important geographical regions in the generation of knowledge for Swiss Re, according to patent activity. Scale on the y-axis is the fractional count of patents for an inventor country. Darker colour means higher activity. (Patstat, 2017)

4.6 Performance of Re/Insurance Companies

This chapter provides a series of different performance indicators relevant to the insurance industry. We look at the frequency and magnitude of natural disasters, in terms of *Economic loss* and *Insured Loss*. The two measures are reported in billion US dollar and are inflation adjusted. Concerning the financial performance of firms, we look at *Net Premiums Written*, *Net Profits* and the ratio between the two indicators – we report the three measures in billion US dollar. For Net Premiums written, we only use the measures reported for non-life. Finally, we include the count of *patent families* as a measure of innovative performance. We take all patent families (including all technology classes) into account and not just the ones granted in order to show the industry's full effort in developing innovations.

List of Indicators

Disasters:

- Economic Loss in USD
- Insured Loss in USD

Financial Indicators:

- Net Premiums Written
- Net Profits
- Net profits as a % of net premiums written Equity (Surplus)
- Total Assets

Innovative Performance:

- Patent families

For the natural disasters (Swiss Re Institute, 2018),
depicted in Figure 6, we see Economic Loss and Insured Loss following each other closely. Further, there are four peaks – in 1999, 2005, 2008 and 2011 – with increasingly higher magnitude. The depicted

values are the sum in billion US dollar of the following six geographical regions: Africa, Asia, Europe, Latin America and the Caribbean, North America as well as Oceania and Australia.

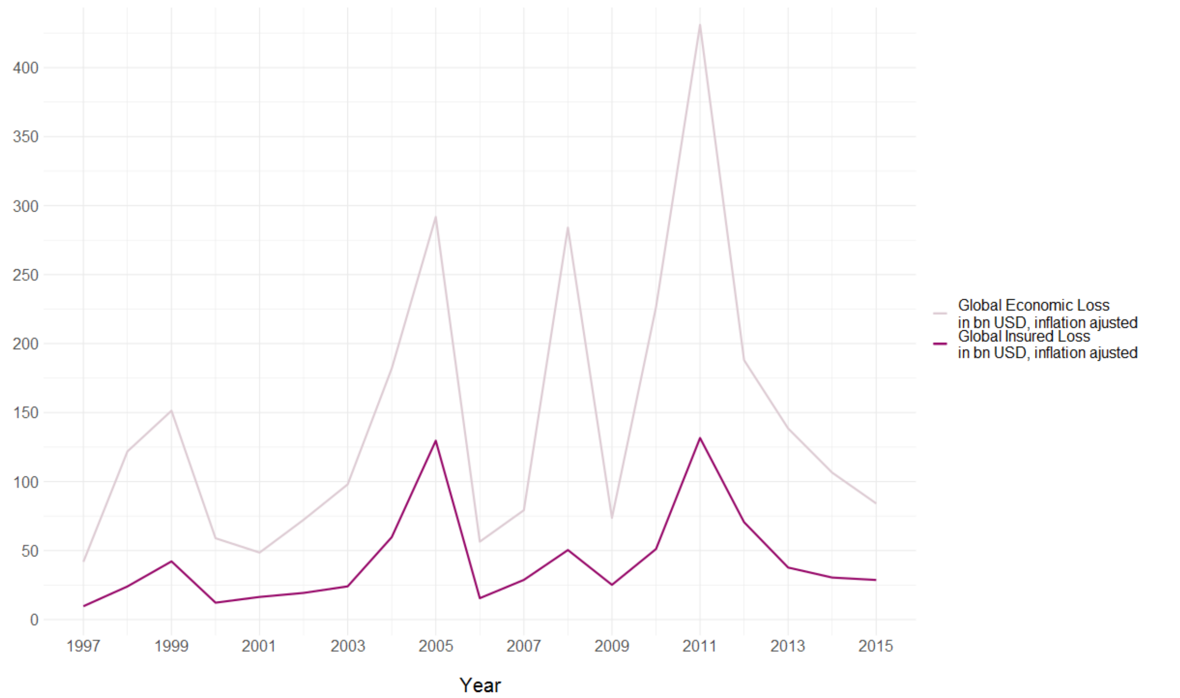

Figure 6: Natural disasters over all continents (Swiss Re Institute, 2018)

Figure 7: Financial and technological measures of conglomerate sample (A.M. Best, 2017 and Patstat, 2017)

Figure 7 shows the average financial and innovative measures of all 14 conglomerates. It is important to note that financial data is not available for all the conglomerates in all years. We use *Net Premiums Written (non-life)* and *Net Profits* as financial indicator variables – reported in billion US dollar. For the patent families we use the earliest filing year within a family since it is closest to the date when the invention was made. Interestingly, the development of patent families and Net Premiums Written is close to parallel in many periods. For some periods we see a parallel movement between the innovation and the financial measures, namely in the period between 1999 and 2007. After 2007, the financial performance declined which is most likely due to the global financial crisis. From around 2010 on, financial indicators started to rise while the patent count declined. As already discussed above, the decrease in patenting activity is mostly due to the company with the major patent activity – Columbia Insurance.

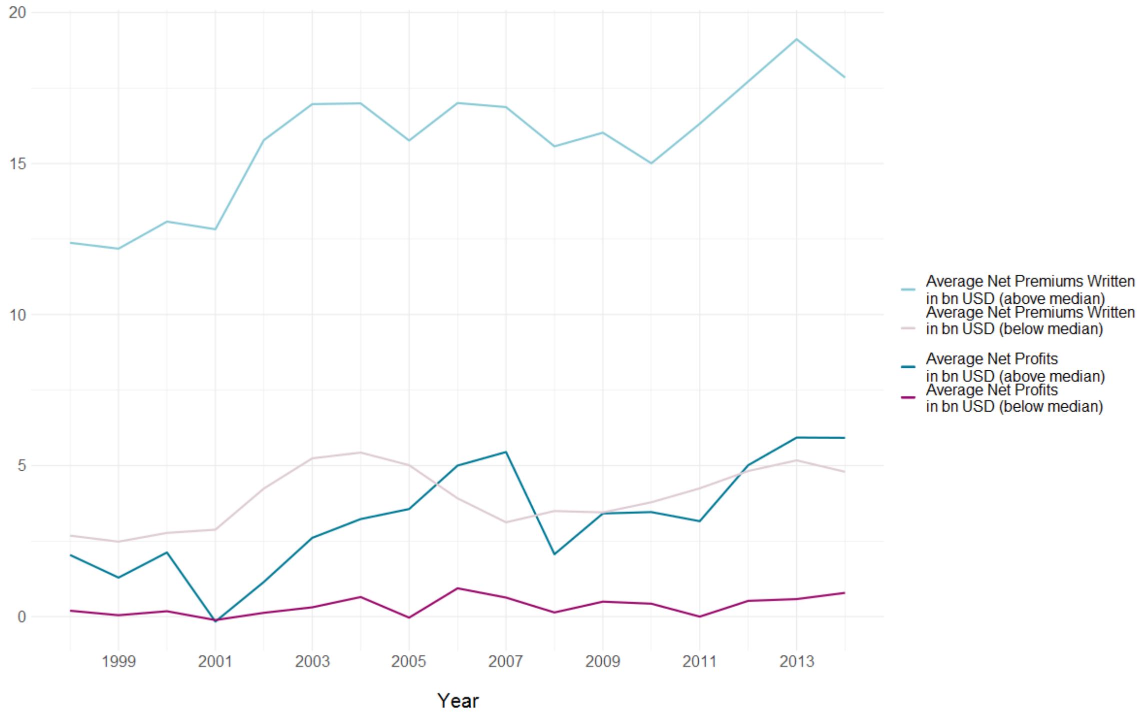

Figure 8: Absolute financial performance of conglomerate sample grouped by above and below median patent assignees (A.M. Best, 2017 and Patstat, 2017)

Further, we compare financial performance for conglomerates with patent activities above and below the median. The financial indicators (Net Premiums Written and Net Profits) in Figure 8 and Figure 9 are depicted by green shades of colour for the group of companies with patent activities above the median and by red shades of colour for the group below the median. In Figure 9, we introduce a relative performance measure Net profits as a % of net premiums written. The most important descriptive finding from Figure 8 and Figure 9 is that financial indicators for both types of companies move in parallel over time, however, companies with above median patent activity are at a clearly higher performance level. Even though this cannot be interpreted in a causal way (this investigation is left to the econometric analysis in chapter 5), it might indicate a potential relationship between patent activities and firm performance.

Finally, we show a selection of disaster, financial and innovative indicators together in Figure 10. As a financial indicator, we use the more general measure of *Net Profits*. To report natural disasters, we use the more insurance relevant measure of *Insured Loss.* Innovation performance is again measured by the average number of patent families applied for by the 14 conglomerates in a given year. This provides us with a summary of already discussed properties of the data. There are four peaks in the average insured loss, the dent in 2007 in patenting (mostly due to Columbia Insurance) and the general upwards trend in net profits and patenting. Figure 10 suggests s as well, that the connection between disasters, financial performance and innovation activity is not trivial, thus motivating the subsequent econometric analysis.

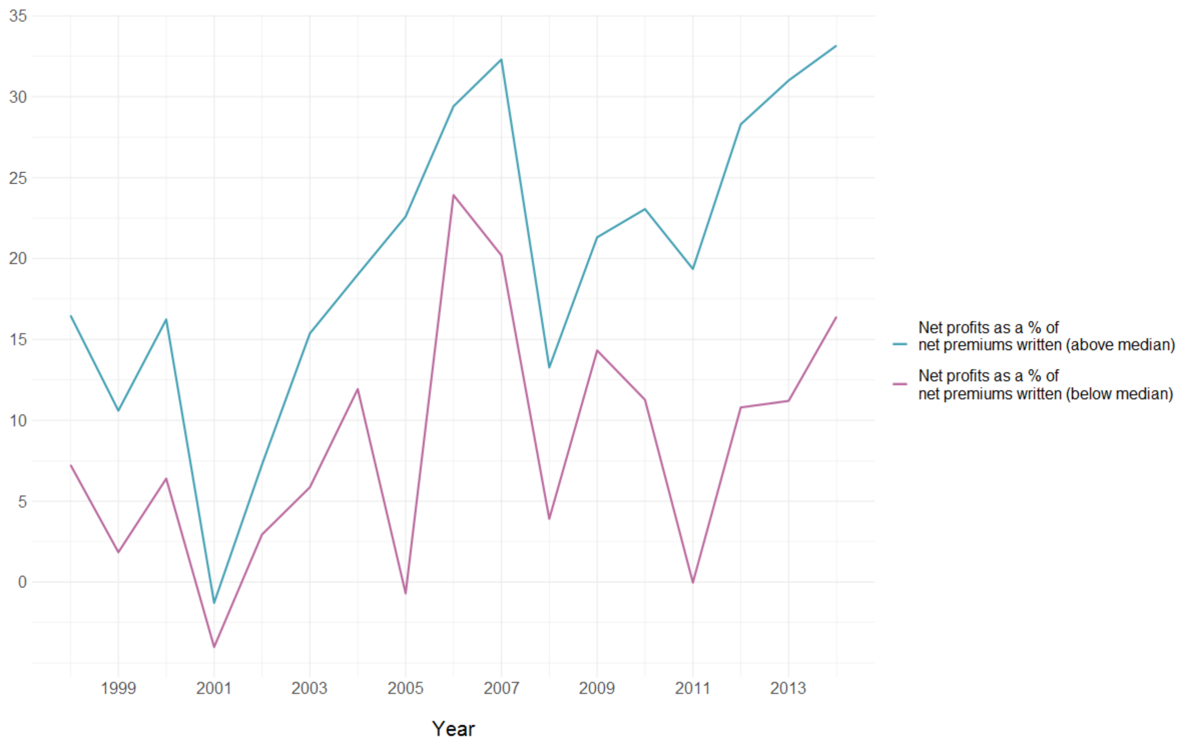

Figure 9: Relative financial performance of conglomerate grouped by above and below median patent assignees (A.M. Best, 2017 and Patstat, 2017)

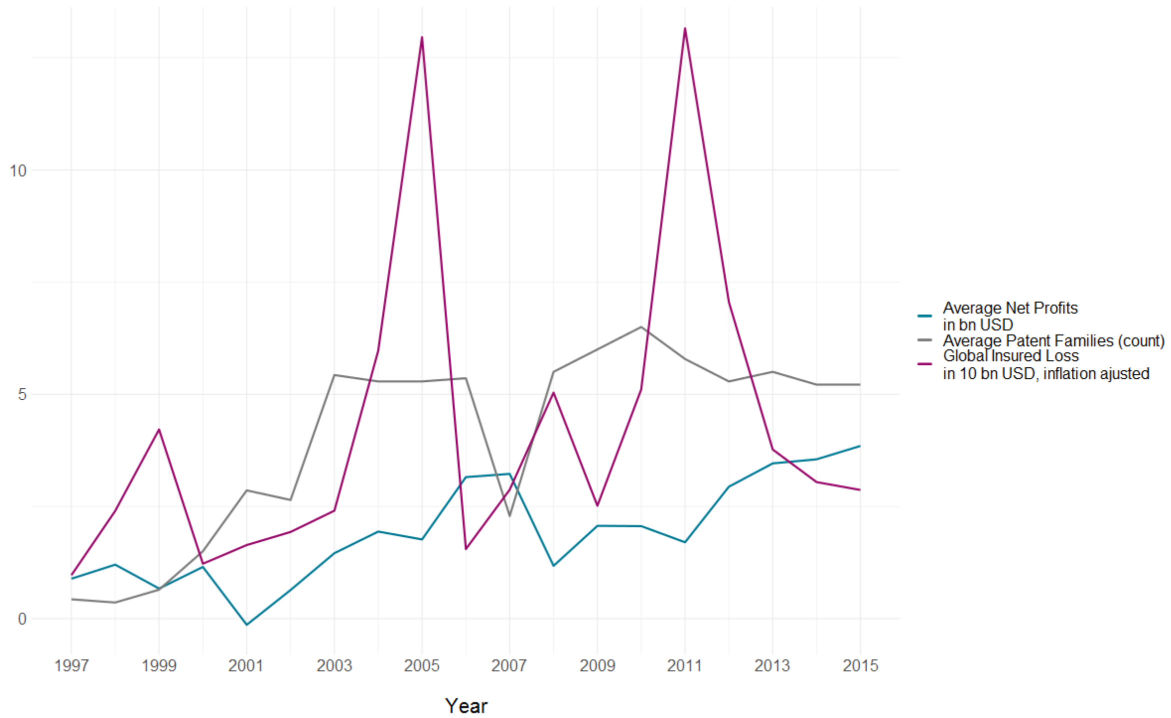

Figure 10: Natural disasters, financial and technical performance indicators (A.M. Best, 2017; Patstat, 2017; Swiss Re Institute, 2018)

5 Technology and Performance

5.1 Motivation and Research Question

There is ample empirical evidence that R&D increases the performance of firms (e.g. Hall et al., 2010, Ugur et al., 2016). Hall et al. (2010) showed that the rate of return (elasticity) of R&D investments is between 0.01 and 0.25 and centred at around 0.08. There are significant differences for different time periods, different countries, and industries (Griliches, 1980; Hall et al., 1993; Harhoff, 1998). Moreover, recent research has shown that R&D can increase the resilience to adverse economic environments in the manufacturing industry (Hombert and Matray, 2018).

According to Bader (2008), IP strategies in the service sector are quite a new phenomenon that are mainly driven by Anglo-American and Japanese companies. This is especially true for the financial services industry including the re/insurance industry. Even a decade later, the situation has not changed significantly. Remarkably, the figures for Swiss Re show a decrease in patent activities even before the last financial crisis. Patenting business models and software solutions might give rise to first-mover advantages and increase market entry barriers since patent activities stimulate the inventiveness of a company and lead to the accumulation of knowledge that can be drawn upon to generate new ideas. At the end, it can be boiled down to the question whether new technologies (in this industry mainly business models and software) can increase a firm's profitability. Although there is evidence for the manufacturing industries (see, e.g., Hall et al., 2010), service industries are rarely studied. Especially for the re/insurance industry there is a lack of evidence regarding the link between the development of technologies and profitability.

The focus of this study is the re/insurance sector and the most important competitors in this market (see data description above). In particular, we investigate the relationship between R&D efforts and the performance of re/insurance companies, emphasising the meaning of firm size for the observed performance effects. We use patent filings as proxy for R&D activities and "new knowledge" since we are lacking more specific R&D data. The period under review for the performance effects covers 20 years.

5.2 Data for the Econometric Estimations

We merged two data sets (see also data section above). First, the financial data for the 14 most important re/insurance companies worldwide. A.M.Best (2018) provided these balance sheet data for the period 1997 to 2017. Second, we used PATSTAT information about their patent activities. It was quite challenging to identify patent activities of single companies since there have been many spelling mistakes and comprehensive acquisition activities by these companies (see section 3 for details). The data for the econometric estimations comprises the period 1997 to 2017. Since patent information goes further back in time, we can calculate the knowledge stock of a company according to the perpetual inventory method (see below) well before 1997. This has the advantage that we can estimate the knowledge stock out of sample. This implies that our assumptions about the growth rate, which is necessary to calculation the initial knowledge stock, is hardly influencing our estimation. The combined data allows us to estimate several performance measures, total assets of a company, and their knowledge stock (see Table 12 for the descriptive information).

5.3 Measurement and Econometric Estimations

We measure the economic performance (P) of a re/insurance company threefold. First, we use information of Net Profits and second, we use information about Equity (Surplus). Both variables are available on the company's balance sheet (see information box: list of indicators).[6] Equity (Surplus) is measured by the total value of assets minus liabilities in the balance sheet (except to shareholders). It is influenced by the stock markets as far as the assets comprise equity holdings. This might be partly influenced by the general economic environment and the related variability of the stock markets; however, given the setting of our estimations including firm fixed effects and time fixed effects (see below), such fluctuations should not bias the results. Net Profits/Equity(Surplus) is the third performance measure and it is calculated by Net Profits divided by Equity(Surplus). This measure directly takes into account the size of a company. In our base estimation (1), we investigate the relationship between the knowledge stock of a company (i) in time (t-1) and its performance (P) in time (t).

$$P_{it} = \alpha_0 + \alpha_1 K_{it-1} + Assets_{it} + u_i + t_t + \varepsilon_{it} \qquad (1)$$

$$P \epsilon \left\{ Net\ Profits, Equity(Surplus), Net\ Profits/Equity(Surplus) \right\}$$

K_{it-1} measures the "technological" knowledge stock of a company (i) with a lag of one year (t-1). We estimate the knowledge stock using the number of patented inventions (families in all technological fields) and depreciate them by 15% (d=0.15) according to the perpetual inventory method. We further assume a 15% growth rate (g=0.15) in order to estimate the initial knowledge capital stock. We also conducted robustness tests with other depreciation and grow rates. The results remain robust. Formula (2) and (3) present the calculations.

The initial knowledge capital stock in 1987: $\frac{Patentfamilies_{i,1987}}{(d+g)}$ (2)

Perpetual inventory method: $K_{it} = ((1 - 0.15) * K_{it-1}) + Patentfamilies_{it}$ (3)

The variable "Assets" refers to the total assets in the balance sheet of the firm and is used as a firm-size proxy in the equations. We further control for firm fixed effects and time fixed effects. Time fixed effects (t_i) prevent the estimation coefficients from being biased by general economic developments like business cycle fluctuations or stock market turbulences, and firm fixed effects (u_i) control for unobserved time invariant heterogeneity. This means that unobserved factors that do not change across time do not influence the observed relationships. Examples for such factors are sector affiliation, technological potential or the appropriability conditions of firms. ε_{it} is the stochastic error.

It is likely that the knowledge stock of a company affects the performance with a time lag. In all estimation we lagged the knowledge stock by one year, however, we also experimented with two and more year lags. The precision (significance) of the results is not affected by the lag structure, however, the size of the coefficients changes.

[6] We also used alternative performance variables like balance on general technical account over net premiums written (non-life) and profit after tax over net premiums written. However, for both measures we do not find robust results.

Although great parts of unobserved factors are already considered by the "fixed effects", the presented setting does not allow for a causal interpretation of the relationship. Still, unobserved *time-variant* heterogeneity might bias the coefficient. Such factors are unobserved in our equation and change across time. For instance, the quality of the management, the use of new, efficiency-enhancing digital technologies, or a change in the corporate strategy might have an influence on the relationship between the knowledge capital of a corporation and its performance. In order to address these issues, we run instrumental variable regressions (IV).

IV estimation

It is crucial to find a valid and effective instrument that is related with the endogenous variable – the knowledge capital stock – and uncorrelated with the residuum of the estimation. External shocks, like disasters or other unpredictable events, show the characteristics of a valid instrument. Given the available data we use the inverse of the non-life underwriting results, which is the sum of total underwriting expenses (non-life) minus total underwriting income (non-life), as an instrument. It expresses how strong a disaster affects the technical accounts. The greater the underwriting expenses compared to the underwriting income the greater a disaster affects a corporation and the larger is the value of the general technical accounts. Although some fluctuation in this figure is considered as normal, extreme values should have an effect on the knowledge creation activities of the corporation. Hence, we took events in the highest decile (90^{th}) to measure the shock triggered by a disaster. We built a dummy variable that receives the value 1 if such an event caused a significant imbalance in the technical accounts exceeding the value at the 90^{th} percentile and 0 otherwise.

Of course, strongly unbalanced technical accounts also affect the financial performance of a corporation in the re/insurance business and consequently this would disqualify it as an instrument. The expected effect is, however, immediately visible, i.e. in the same year of the event or one year after. If we lag the instrumental variable for more than two years, the relationship with the used financial indicators becomes statistically insignificant (see Appendix Table 16), but the positive relationship with the knowledge capital stock (K) remains. This qualifies our "shock" variable as a valid instrument.[7]

First-stage:

$$K_{it} = \pi_0 + \pi_1 D_{it-2} + \tau_{it} \quad (4)$$

Reduced form (second-stage):

$$P_{it} = \alpha_0 + \alpha_1 \widehat{K}_{it-1} + \alpha_2 X1_{it} + f_i + t_t + \varepsilon_{it} \quad (5)$$

Equation (4) shows the first stage, which estimates the knowledge stock of a corporation (i) in time (t) as a function of past disasters (D_{it-2}). D is a binary variable indicating if an extreme event in the past affected the corporation. We experimented with several lags and found that extreme events significantly affect the knowledge stock with a two-year lag (see Appendix Table 15). We simultaneously estimate the first and second stage (reduced form) to analyse the relationship between the knowledge capital (K) of a corporation and its performance (equation 5). We control for total assets, firm-fixed effects (f_i) and time-fixed effects (t_t).

[7] Statistically speaking it passes the underidentification criteria (Kleibergen-Papp rank LM Statistic = 6.414***), meaning that the instrument is significantly correlated with the endogenous regressor, hence it is valid, and the Kleibergen-Paap (2006) rank Wald F-statistic (6.442) indicates that the instrument is not weak. The expected bias, according to the Stock-Yogo's (2002) critical values, amounts to about 20%.

5.4 Results

Table 12 presents the descriptive information for the variable and the number of observations available to our estimations. In total, we have 259 observations for all quantitative variables and 224 observations for our “shock” variable. On average, a corporation yields 2.2 billion USD net profits with a minimum of -3.44 billion and a maximum of 45.35 billion. The standard deviation is about twice the mean, similarly to equity (surplus) and total assets. The knowledge stock amounts to 20.24 on average with a standard deviation that is three times the mean value indicating great differences across firms and years. Since the binary variable representing the corporations’ exposure to a considerable “shock” is measured at the 90th percentile, 10% of the observations must be affected by the shock by construction. However, it is unclear how the impact is spread across the companies. In sum, six corporations in our sample have been hit by such a shock and four out of the six repeatedly. We hardly see any accumulation of incidences in a specific year; however, 2/3 of all incidences happened after 2011.

Table 12: Descriptive information (estimations)

Total	Net Profits (USD billion)	Equity (Surplus) (USD billion)	Net Profits/Equity (Surplus)	Knowledge Stock	"Shock 90pct"	Total Assets (USD billion)
N	259	259	259	259	224	259
mean	2.20	25.05	0.05	20.24	0.10	136.13
sd	4.47	44.32	0.37	64.61	.	230.91
min	-3.44	0.16	-5.60	0.00	0.00	1.26
max	45.35	351.95	0.36	358.06	1.00	1,064.80

Variable description: Net Profits, Equity (Surplus), and Total Assets are balance sheet information. Net Profits/Equity (Surplus) is calculated by dividing the Net Profits by Equity (Surplus). “Shock 90pct” is a binary variable that receives the value 1 if the “balance on technical accounts (total underwriting expenses (non-life) minus total underwriting income (non-life)” is above the 90th percentile of the distribution (all years). Knowledge stock is based on the number of patent family applications and depreciated by 15% p.a. using the “perpetual inventory method (see above)”. For descriptive information on single years, see Table 14.

Table 13 presents the main results of the estimations. The firm-level fixed effects estimations (FE) show that the knowledge capital stock of a corporation is positive and significantly related with both performance variables, i.e. Net Profits and Equity (Surplus)). The results hold if we introduce further time lags. We see that an increase of the knowledge stock by one unit would increase the net profits by about 40 million and the equity (surplus) by about 440 million USD. The significant relationship and the size of the effects remain similar if we introduce a further time lag in the knowledge stock.

Given the specification of the estimation and the controls for time fixed effects and firm-level fixed effects a potential bias can only be due to time-variant unobserved heterogeneity. Such biases are addressed by the instrumental variable regression (IV). The last two columns of Table 13 present the IV estimations. We use the “Shock 90pct” variable to instrument the knowledge stock variable. For the validity of the instrument, see the chapter on *IV estimation* and the Appendix. With this estimation procedure, the knowledge stock remains positive and significantly related with the performance variables and even the size of the coefficients hardly changes. Overall, the main results appear to be robust and they convincingly suggest that accumulation of knowledge as indicated by the patented invention activities of firms pays-off for the performance of a re/insurance company.

Table 13: Main results

	FE	FE	FE	FE	IV FE	IV FE
VARIABLES	Net Profits$_{it}$	Equity (Surplus)$_{it}$	Net Profits$_{it}$	Equity (Surplus)$_{it}$	Net Profits$_{it}$	Equity (Surplus)$_{it}$
Knowledge Stock$_{it-1}$	0.040***	0.437***			0.035*	0.324***
	(0.009)	(0.073)			(0.018)	(0.115)
Assets$_{it}$	0.011	0.115*	0.009	0.093**	0.003*	0.055***
	(0.008)	(0.064)	(0.005)	(0.043)	(0.002)	(0.007)
Knowledge Stock$_{it-2}$			0.047***	0.491***		
			(0.006)	(0.049)		
Observations	259	259	259	259	188	188
Number of id	14	14	14	14	14	14
Firm-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Cluster id	Yes	Yes	Yes	Yes	Yes	Yes

Note: Standard errors in parentheses are robust to heteroscedasticity and within-panel serial correlation; Fisher-type unit root tests (inverse Chi-Square and inverse normal) for “Net Profits” and “Equity (Surplus)” rejects H0 (H0: all panels contain unit roots). The knowledge stock is not significantly related with Net Profits/Equity (Surplus), hence we refrain from presenting this information in the table.

In Table 14, we split the sample into large corporations that are at or above the median according to total assets and small corporations that are below the median. The results show some differences according to this firm size measure. The knowledge capital is positive and significantly related with “Net Profits” and with Net Profits/Equity (Surplus) only for larger corporations and its effect on “Equity (Surplus)” is considerably stronger for large compared to smaller firms. However, if we divide the Net Profits by the Net Premiums written (NetProfits written) we see that the effects for smaller firms are significant and larger compared to large firms (columns 6 and 7). This means that an increases in the knowledge stock has a relative greater pay off concerning the share of net profits on net premiums written than it is the case for larger firms. A further lag in the knowledge stock variable does not change the pattern of the results.

Overall, we see that the knowledge stock of a corporation significantly increases the performance. The size of the effects is considerable. This emphasises that technological knowledge is a key component to increase the competitiveness of a corporation and it supports the sustainability of the business activity. Information about knowledge building activities other than patented inventions and additional indicators for innovativeness, like the number of new products/services, process innovations, and expenditures for R&D and innovation activities, would allow for a more detailed analyses of the performance contribution of knowledge. Aspects of “open innovation”, like the importance of external knowledge source, research contacts to universities, or R&D collaborations with other firms and institutions are likely to be key organizational aspects of the innovativeness. Such factors might play a role in the flexibility of companies to successfully face important challenges in the future, e.g., related to climate change or the emergence of new digital technologies (Artificial Intelligence, Blockchain). The monitoring of such activities lies in the interest of the company. So far, we know that technological knowledge is a key asset, the meaning of other aspects of innovation and their complementarities with the business activities are yet to be discovered.

Table 14: Heterogeneity (firm size split at the median)

	SMALL	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL	LARGE
	FE	FE	FE	FE	FE	FE	FE	FE
VARIABLES	Net $Profits_{it}$	Net $Profits_{it}$	Equity $(Surplus)_{it}$	Equity $(Surplus)_{it}$	Net Profits $written_{it}$	Net Profits $written_{it}$	Net Profits/Equity $(Surplus)_{it}$	Net Profits/Equity $(Surplus)_{it}$
Knowledge $Stock_{it-1}$	0.002	0.041***	0.023**	0.453***	0.005**	0.001***	-0.0001	0.0002***
	(0.003)	(0.010)	(0.008)	(0.080)	(0.002)	(0.000)	(0.0007)	(0.0000)
$Assets_{it}$	0.009***	0.016	0.109***	0.152	-0.002	-0.000	0.0038	-0.0001**
	(0.002)	(0.010)	(0.026)	(0.086)	(0.004)	(0.000)	(0.0076)	(0.0000)
Observations	130	129	130	129	117	129	130	129
Number of id	11	9	11	9	10	9	11	9
Firm-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cluster id	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: Standard errors in parentheses are robust to heteroscedasticity and within-panel serial correlation; the information for “NetProfits written” stems from the balance sheet information of the corporation and is calculated by Net Profits divided by Net Premiums Written. Fisher-type unit root tests (inverse Chi-Square and inverse normal) for “NetProfits written” rejects H0 (H0: all panels contain unit roots).

6 Conclusions

The objectives of this study were to identify the patented knowledge activities of the 14 largest re/insurance companies, to investigate in which technological fields they are active, and from which technological fields and geographic regions their technological activities originate. We also investigated which companies drive the knowledge generation process in the technological fields that are relevant for the re/insurance companies. In a further step, we went beyond the purely descriptive analyses and estimated the relationship between the patented knowledge stock of a company and its financial performance applying econometric methods.

For the research conducted in this study, we needed to merge patent information with the financial information of the 14 largest re/insurance companies worldwide. For the descriptive analyses, we also used information on natural disasters comprising incidents on the continent level by year.

Even though companies in the knowledge intensive business sector hardly use patents to protect their knowledge, we see a clear expansion of patent activities between 1992 and 2012. The observed 14 conglomerates filed about 75 patent families or more annually between 2003 and 2013. However, given the mass of patents in high-tech industries, this is still a relatively low number. Berkshire Hathaway, Swiss Re, China Investment, and Allianz are the main patent applicants in the re/insurance industry. According to the patent filing activities of Swiss Re, the technological fields ‘Electric Digital Data Processing’ (G06F) and ‘Data Processing Systems of Methods’ (G06Q) and the subgroup ‘Insurance, e.g. risk analysis or pensions’ (G06Q 40/08) are important technological fields for the re/insurance business. Of the reinsurers, Swiss Re and China Re (belonging to China Investment) are the companies that are most frequently patenting in these technological fields, and Swiss Re is the only re/insurance company that ranks among the 'top 15' applicants in the subgroup (G06Q 40/08). Interestingly, the overall filing activities of the re/insurance companies in those fields have been decreasing since 2005. Since we are lacking more detailed information, we cannot get to the heart of this issue. However, given that those technological fields are dominated by big players from the ICT sector such as NEC Corporation, IBM, Fujitsu, Hitachi, or Toshiba, it could have become more difficult for re/insurance companies to patent inventions in those fields which might have led them to choose other means to protect their inventions, such as secrecy.

The analysis of the backward citation revealed that companies like Panasonic Corporation, Toshiba, Canon, and Hitachi are also the most important source of knowledge for Swiss Re's patents. ICT and electronic companies are thus not only intensifying technological competition, they are also inspiring research in the re/insurance sector.

If we compare the time trends of the performance measures, the technological activities and the average insured losses due to disasters, interesting parallel trends emerge. We see that the development of patent families and Net Premiums Written is close to parallel in many periods. We also see some co-movements of Average Insured Loss and the average number of patent families between 2003 and 2007. A more in-depth econometric analysis of the relationship between patented knowledge activities and the business performance of re/insurance companies shows a significant and positive relationship between the size of the companies' knowledge stock and Net Profits as well as Equity (Surplus). There are, however, some differences according to firm size. The knowledge stock is positive and significantly related with Net Profits in particular for larger corporations with total assets above the median level. The latter also is true for Net Profits/Equity (Surplus). The "knowledge effect" on "Equity (Surplus)" is also considerably stronger for large compared to smaller ones. Net profits as a % of net premiums written (Net Profits divided by the Net Premiums Written) are significantly linked to the knowledge base in both types of companies. However, the economic effect is larger in smaller companies.

Overall, we see a clear positive relationship between the patented knowledge stock of a reinsurer and its performance. At the same time, however, it seems to get harder to patent inventions in the technologically relevant fields. Probably the efforts for such activities should be increased and/or alternative strategies for knowledge generation such as cooperation or other "open innovation strategies" should be considered. Patents also seem to be an important signal about the competitiveness of a company.

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8 Appendix I

8.1 Innovation in the Swiss Re/Insurance Sector

The ETH Zürich, KOF Swiss Economic Institute, conducts the Swiss Innovation Survey since the early 90s. This survey is based on stratified random sample of about 6000 corporations. Stratification is on 29 industries and within each industry on 3 firm-size classes. For more information about the survey and the KOF enterprise panel, see Spescha and Wörter (2018)[8].

Since this survey allows for descriptive analyses on the level of single industries, we can trace the most important innovation indicators for the Swiss insurance sector across time. Please note that this information goes beyond the re/insurance sector and includes all types of insurance companies (NACE 65 and 66). Moreover, the data is restricted to Switzerland. Hence, this analysis cannot be compared with the analyses of the patent data or the econometric analyses.

The descriptive information according to the Swiss Innovation Survey, shows that the number of innovative and R&D active firms in the Swiss insurance sector decreased (see Figure 11), while the expenditures for innovation activities and especially for the R&D activities of the remaining innovative and R&D active firms increased (see Figure 12). This indicates a concentration of the R&D activities among fewer insurance companies in Switzerland.

Only in the latest investigation period (2016) we see again an increasing share of R&D active corporations (see Figure 11), however the share of innovative firms further decreased. The fraction of firms that reduced their production costs by introducing process innovations decreased in the course of the time. While in the beginning of the 2000s more than 30% of the firms reduced their production costs, the respective share decreased to below 20% in most recent survey years. Moreover, we see that successful process innovators reduced their production cost by about 1% on average in 2017. The figure for the 75 percentile (firm) is below the average (see Figure 13). This indicates that very few firms drive the means value. Remarkably, not only the fraction of cost-reducing firms decreased, also the amount of production cost reductions decreased, too.

How successful were the newly introduced products and services? Here we distinguish new products from essentially modified products. Figure 14 shows the development of the sales figures for innovative products and services (new and essentially modified products) and new products and services. For both types of innovative products, however, we see a similar development. The commercial success decreased until 2013 and increased afterwards considerably. We also compare the development of the median firm with the means in order to analyse whether the trend is driven by some extreme values of few firms. This is not the case since both figures do not show very strong differences.

In Figure 15, we consider the size of the firm by dividing the innovative sales with the turnover of a company. The mean value of the sales share of innovative products does not show a clear trend. However, the median firm increased its “innovative share” in the course of time, indicating that in recent years the relative gains from innovative products and services are more equally distributed across firm size classes. The sales share of new products, however, is less equally distributed. Although the median and the mean value are similar in 2015, before and after this survey year, we observe considerable differences. This shows that we have few insurance companies with relatively successful products. The

[8] For more information about the KOF enterprise panel: https://www.kof.ethz.ch/en/surveys/structural-surveys/kof-enterprise-panel.html and the KOF Innovation Survey: https://www.kof.ethz.ch/en/surveys/structural-surveys/kof-innovation-survey.html .

mean value of the sales share of new products fluctuates between 5% and 15% in most of the observed periods.

Overall, this brief descriptive analysis shows that the fraction of innovative firms is decreasing in the Swiss insurance sector, however, the expenditures for developing new and innovative products and services are increasing, which indicates a concentration of such activities. Moreover, it seems that the cost pressure decreased, since fewer firms successfully reduced their production costs. In terms of innovative sales, we observed a couple of periods with a decreasing trend, however, the (remaining) innovative firms were again more successful with the commercialization of innovative products in recent years.

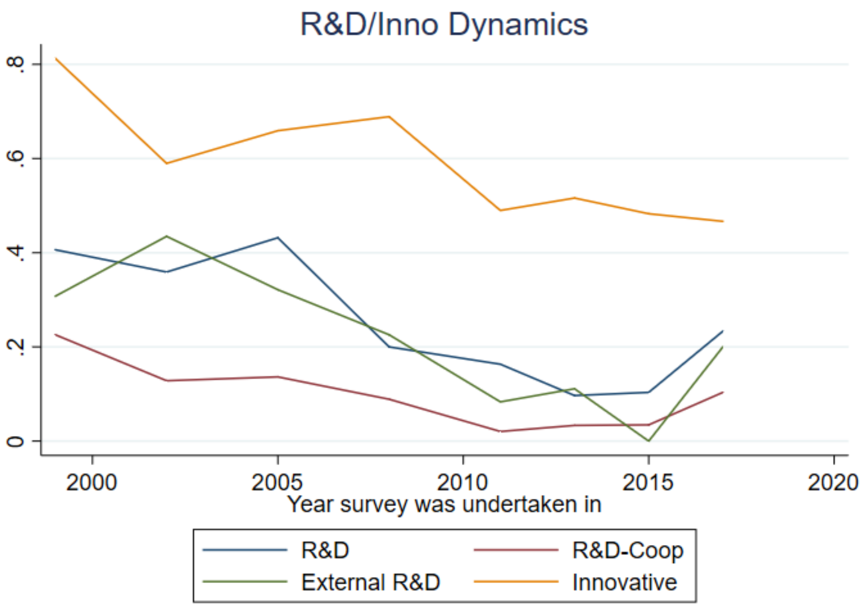

Figure 11: Fraction of R&D active firms and innovative firms (basis: all companies in the insurance industry – KOF Innovation Survey)

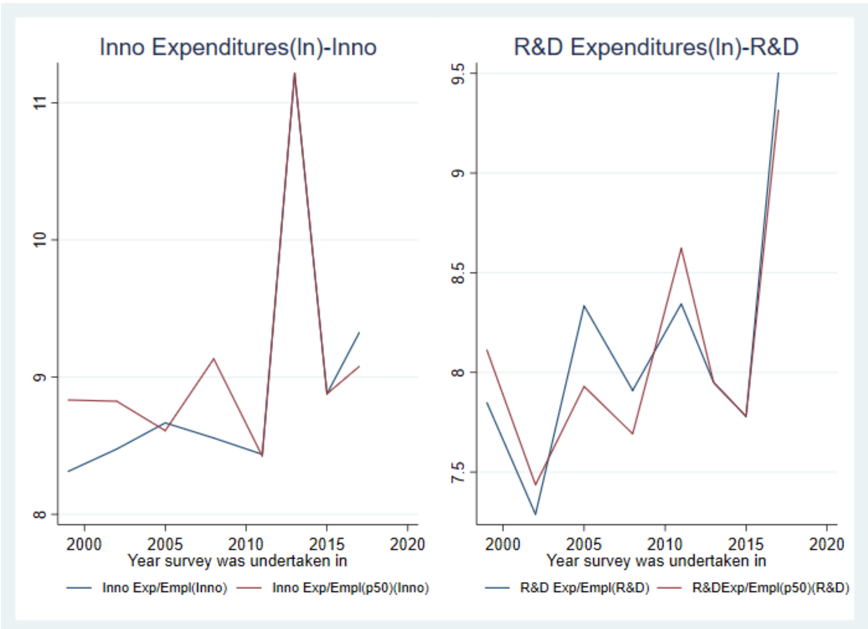

Figure 12: Innovation and R&D Expenditures by the Swiss insurance industry (basis: innovative firms (left figure), R&D active firms (right figure). P50 presents the median value rather than the means value. (KOF Innovation Survey)

Figure 13: Reduction in production costs (basis: all process innovative companies in the insurance industry). Left figure shows the fraction of companies with production cost reductions. Right figure show the share of production cost reduction on total production costs due to process innovations. (KOF Innovation Survey)

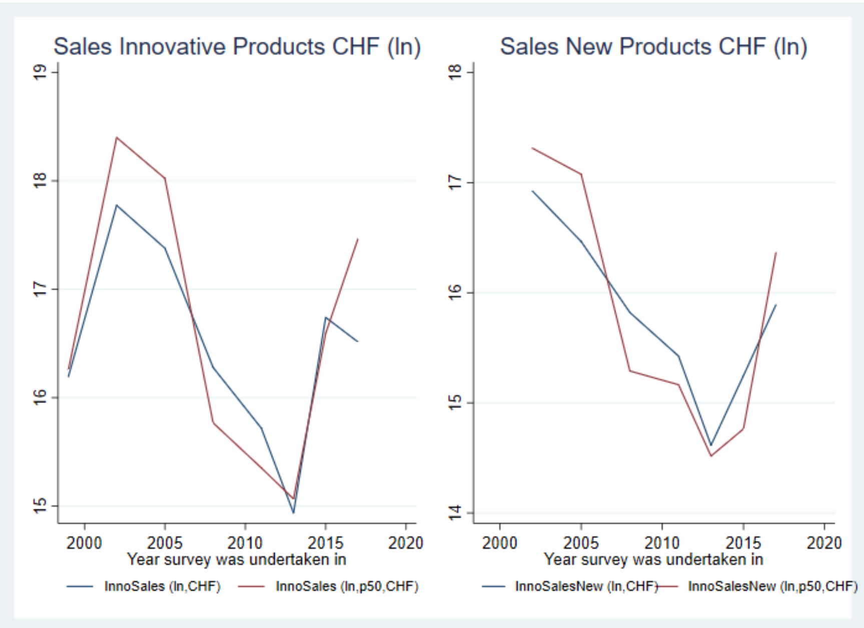

Figure 14: Sales in innovative products and new products (KOF Innovation Survey)

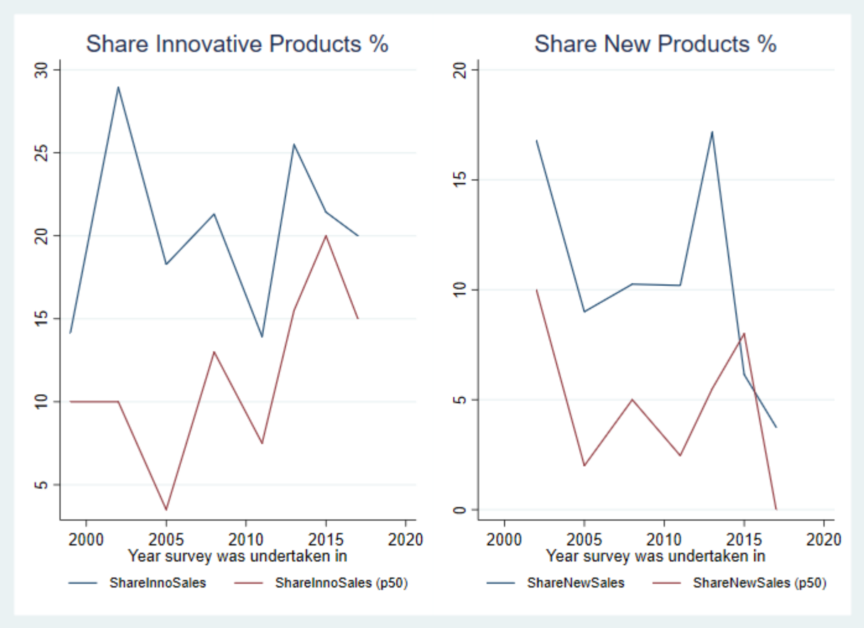

Figure 15: Share in innovative products and new products (KOF Innovation Survey)

9 Appendix II

Table 15: Annual descriptive Information

year	Statis-tics	Net Profits (USD billions)	Equity (Surplus) (USD billions)	Net Profits/Equity (Surplus)	Knowledge Stock	"Shock 90pct"	Total Assets (USD billions)
1997	N	11.00	11.00	11.00	11.00	10.00	11.00
	mean	0.89	9.03	0.12	0.89	0.00	69.47
	sd	0.79	10.45	0.10	2.09	0.00	117.24
	min	0.06	1.18	-0.02	0.00	0.00	3.59
	max	2.20	37.24	0.33	7.08	0.00	409.44
1998	N	11.00	11.00	11.00	11.00	10.00	11.00
	mean	1.20	11.29	0.10	1.21	0.00	81.00
	sd	1.33	12.38	0.07	3.27	0.00	129.63
	min	0.04	1.19	-0.02	0.00	0.00	4.50
	max	3.88	45.28	0.19	11.02	0.00	456.69
1999	N	12.00	12.00	12.00	12.00	11.00	12.00
	mean	0.67	10.13	0.04	1.70	0.00	80.77
	sd	0.99	12.00	0.10	4.38	0.00	142.50
	min	0.32	1.03	-0.18	0.00	0.00	4.84
	max	2.89	44.49	0.18	15.37	0.00	517.94

2000	N	12.00	12.00	12.00	12.00	11.00	12.00
	mean	1.15	10.77	0.09	3.19	0.00	79.90
	sd	1.65	11.69	0.11	6.57	0.00	125.18
	min	0.29	1.14	-0.18	0.00	0.00	5.24
	max	5.68	41.17	0.25	23.06	0.00	455.75
2001	N	12.00	12.00	12.00	12.00	11.00	12.00
	mean	0.14	9.53	-0.03	6.05	0.00	82.40
	sd	0.59	8.67	0.09	15.42	0.00	117.85
	min	1.26	1.22	-0.18	0.00	0.00	7.17
	max	0.78	27.15	0.08	54.60	0.00	430.24
2002	N	12.00	12.00	12.00	12.00	11.00	12.00
	mean	0.64	10.70	-0.04	8.22	0.00	97.21
	sd	1.90	9.58	0.39	21.67	0.00	129.07
	min	3.44	0.79	-1.08	0.00	0.00	8.21
	max	4.29	28.44	0.36	76.41	0.00	466.13
2003	N	12.00	12.00	12.00	12.00	11.00	12.00
	mean	1.46	14.63	-0.35	13.32	0.09	117.06
	sd	1.80	13.73	1.66	34.69	0.30	154.58
	min	0.87	0.16	-5.60	0.00	0.00	7.60
	max	5.69	40.82	0.25	120.95	1.00	564.10
2004	N	12.00	12.00	12.00	12.00	11.00	12.00
	mean	1.94	17.81	0.12	16.91	0.09	135.90
	sd	1.76	17.09	0.06	44.92	0.30	187.53
	min	0.02	1.13	0.01	0.00	0.00	8.56
	max	5.82	48.49	0.21	155.81	1.00	687.22
2005	N	12.00	12.00	12.00	12.00	11.00	12.00
	mean	1.76	17.90	0.05	20.54	0.00	134.87
	sd	3.54	17.34	0.11	55.47	0.00	185.22
	min	1.47	1.26	-0.15	0.00	0.00	7.43
	max	11.23	52.48	0.21	192.44	0.00	682.18
2006	N	11.00	11.00	11.00	11.00	10.00	11.00
	mean	3.15	24.67	0.14	25.82	0.20	180.99
	sd	2.51	22.56	0.06	66.27	0.42	271.96
	min	0.09	1.78	0.05	0.00	0.00	5.98
	max	7.60	62.35	0.28	220.57	1.00	960.59
2007	N	13.00	13.00	13.00	13.00	11.00	13.00
	mean	3.22	27.95	0.10	21.38	0.09	157.03
	sd	4.13	35.74	0.06	57.44	0.30	289.56

	min	0.00	1.13	-0.00	0.00	0.00	1.49
	max	13.57	120.73	0.17	206.49	1.00	1,064.80
2008	N	13.00	13.00	13.00	13.00	11.00	13.00
	mean	1.17	24.73	0.03	24.10	0.09	142.60
	sd	1.84	31.87	0.06	67.42	0.30	258.12
	min	0.82	1.07	-0.05	0.00	0.00	1.38
	max	5.60	109.27	0.16	243.51	1.00	949.46
2009	N	13.00	13.00	13.00	13.00	11.00	13.00
	mean	2.07	28.65	0.09	26.95	0.09	152.38
	sd	2.58	37.73	0.06	79.94	0.30	275.88
	min	0.02	1.12	0.00	0.00	0.00	1.40
	max	8.44	135.79	0.20	289.99	1.00	1,015.08
2010	N	13.00	13.00	13.00	13.00	11.00	13.00
	mean	2.06	30.13	0.06	29.90	0.09	152.75
	sd	3.65	44.11	0.03	89.52	0.30	268.48
	min	0.03	1.06	0.00	0.00	0.00	1.29
	max	13.49	162.93	0.12	325.49	1.00	969.31
2011	N	13.00	13.00	13.00	13.00	11.00	13.00
	mean	1.70	29.91	0.03	31.65	0.09	151.79
	sd	3.23	45.42	0.05	96.34	0.30	263.04
	min	0.58	1.06	-0.08	0.00	0.00	1.26
	max	10.75	168.96	0.11	350.66	1.00	941.73
2012	N	13.00	13.00	13.00	13.00	11.00	13.00
	mean	2.94	33.59	0.09	32.59	0.18	161.82
	sd	4.16	51.43	0.06	98.29	0.40	281.00
	min	0.03	1.05	-0.03	0.00	0.00	1.26
	max	15.31	191.59	0.16	358.06	1.00	1,007.03
2013	N	13.00	13.00	13.00	13.00	11.00	13.00
	mean	3.46	36.90	0.11	33.63	0.27	165.64
	sd	5.33	59.97	0.08	97.65	0.47	294.87
	min	0.10	1.58	0.00	0.00	0.00	1.65
	max	19.84	224.49	0.31	356.36	1.00	1,040.08
2014	N	13.00	13.00	13.00	13.00	11.00	13.00
	mean	3.55	38.20	0.11	34.20	0.36	164.56
	sd	5.35	64.93	0.05	90.14	0.50	294.53
	min	0.28	1.68	0.04	0.00	0.00	1.76
	max	20.17	243.03	0.17	327.90	1.00	1,021.19
2015	N	13.00	13.00	13.00	13.00	11.00	13.00

	mean	3.85	38.47	0.11	34.68	0.18	161.37
	sd	6.51	68.84	0.06	89.18	0.40	284.90
	min	0.11	1.77	0.02	0.00	0.00	1.84
	max	24.41	258.63	0.25	322.72	1.00	969.30
2016	N	13.00	13.00	13.00	13.00	10.00	13.00
	mean	3.73	41.05	0.10	24.81	0.20	165.76
	sd	6.50	75.85	0.04	76.05	0.42	287.16
	min	0.25	1.96	0.04	0.00	0.00	2.04
	max	24.43	285.43	0.17	276.31	1.00	940.75
2017	N	12.00	12.00	12.00	12.00	8.00	12.00
	mean	5.19	51.03	0.05	22.84	0.00	199.12
	sd	12.88	97.11	0.06	67.20	0.00	329.25
	min	0.49	4.15	-0.04	0.00	0.00	6.69
	max	45.35	351.95	0.14	234.86	0.00	1,042.45

Source: A.M. Best, 2017, calculation KOF.

Table 16: First stage

	(1)
	Tobit
VARIABLES	Knowledge stock
Shock 90pct$_{it-2}$	18.789***
	(6.615)
Total Assets$_{it}$	0.004
	(0.021)
Observations	200
Number of id	14

Note: Standard errors in parentheses;
*** p<0.01, ** p<0.05, * p<0.1; we use a Tobit estimator, since the dependent variable (knowledge stock) has a pile up with zeros;
As expected, the "Shock" variable is positive and Significantly related with the knowledge stock.

Table 17: Correlation between instrument and performance

	(1)	(2)
	FE	FE
VARIABLES	Net Profits	Equity (Surplus)
Shock 90pct$_{it-3}$	0.211	1.064
	(0.291)	(1.983)
Knowledge Stock$_{it-1}$	0.026***	0.278***
	(0.004)	(0.036)
Total Assets$_{it}$	0.004*	0.057***
	(0.002)	(0.012)
Observations	188	188
Number of id	14	14
Firm-fixed effects	Yes	Yes
Time-fixed effects	Yes	Yes
Cluster id	Yes	Yes

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; The "Shock" variable is unrelated with the performance variable. The lag structure matches with the lag structure in the main equation.

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