R&D MANAGEMENT

Innovation management in crisis: patent analytics as a response to the COVID-19 pandemic

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Crises like the COVID-19 pandemic affect firms' innovation management and decision making. On the downside, crises lead to detriments like budget constraints, to which firms often respond by reducing their innovation activities. On the upside, crises are opportunities, where some firms exploiting changing market requirements and necessities excel. No matter in which direction, decision makers must react quickly but often rely on ad-hoc decisions or even gut feeling when drafting their crisis response strategies. Through a series of distinct cases, we demonstrate that innovation management may fill this void through patent analytics. Drawing on biochemical expertise, we particularly describe the functions and effects of COVID-19. To counter downside detriments, firms may circumvent budget constraints by discerning patents that can be (1) monetized, for example via sales or licensing deals, or (2) abandoned to achieve cost-savings, allowing firms to maintain their innovation activities. To realize upside opportunities, firms and governments may use patent analytics to detect key biotechnology firms that are likely to successfully develop treatments and vaccinations against pandemics like COVID-19. Promulgated U.S. interest in relocating foreign firms to the United States is not without technological and commercial reasoning. Herein, the insights of this study contribute to a better understanding of the use of patent information, such as smart patent indicators, harmonized patent data, novel annuity fee measures, and hand-collected datasets of COVID-19 and related antibodies' patents to the management of innovation in times of crisis.

1. Introduction

The recent outbreak of the novel virus SARS-CoV-2 has developed into a worldwide pandemic from late 2019 onwards (e.g., Rothan and Byrareddy, 2020). Firms all over the world suffer from economic detriments due to lockdown-induced demand reductions, resulting in budget constraints, uncertain innovation prospects, and unpredictable future developments (Paunov, 2012; Tietze et al., 2020). Whilst most prior crises were limited to specific industrial sectors, countries, or firms, the COVID-19 pandemic is truly global, affecting everyone.

On the downside, prior research investigating innovation management in crises found crises to intensify 'uncertainty, complexity, ambiguity and unpredictability' (Davis et al., 2009; Martin-Rios and Pasamar, 2018). Corporate decision makers have to react quickly, consider future effects, and simultaneously generate options to overcome the crisis here and now (Teece et al., 2016). These reactions are typically ad hoc and based on gut feelings instead of sufficient information (e.g., Müller, 1985; Cooper and Edgett, 2010; Bessant et al., 2015). For example, firms often cut their innovation investments despite negative long-term consequences, as visible in reduced patent filings, forfeiting the firms' future (Archibugi et al., 2013b; Hingley and Park, 2017).

On the upside, prior research since Schumpeter's (1934) seminal work simultaneously demonstrated that crises-induced financial constraints foster innovation (Hoegl et al., 2008). For example, Archibugi et al. (2013a) found that whilst crises lead to concentrations of innovative activities for growing and innovative firms, expanding explorative strategies enable firms to better cope with and overcome crises. In addition to those firms that suffer from the crises, some winners emerging stronger also exist (Archibugi et al., 2013b). For example, firms like AirBnB and Uber emerged like a phoenix arising from the ashes after the recent financial crisis, with innovative offerings matching crises' Zeitgeist and market requirements (e.g., Oskam and Boswijk, 2016; Zervas et al., 2017). However, success stories become success stories ex-post only, not when they begin.

In fact, it is challenging and often a mere chance to successfully bet on future winners without sufficient data to back decisions, and even more difficult though in crisis situations (e.g., Sah and Stiglitz, 1986; Christensen and Knudsen, 2010; Denrell and Fang, 2010). It is surprising that only little scholarly attention has been paid to investigating the possibilities that publicly available information offers for organizational decision making, not only in the global COVID-19 pandemic, but in crises in general. In this paper, we address this gap by studying how *innovation management decisions in times of crisis like the COVID-19 pandemic can be improved through publicly available data*.

To address this research question, we turn to patent analytics (Campbell, 1983; Ashton and Sen, 1988; Ernst, 2003). We show how patent analytics may shape innovation management during crises (e.g., Campbell, 1983; Archibugi et al., 2013a; Guderian, 2019). By drawing on longitudinal and cross-sectional patent data, we present four distinct case studies. The first two cases address the downside, i.e., how locked-down firms can reduce expenses, free budget to continue innovation efforts, and may generate excess revenue based on data-driven decisions, for example by identifying technology licensing and abandonment candidates. The latter two cases address the upside, i.e., how success stories are identifiable ahead of time using data on their technologies and innovation activities, for example, to detect the most promising candidates to develop COVID-19 treatments and vaccinations.

The insights of this study yield several contributions to the literature on innovation management in times of crises and patent analytics in innovation management (e.g., Döner, 2017; Jung et al., 2018; Tietze et al., 2020; Antonioli and Montresor, 2019). We show that decision makers can use patent information and analytics to find data-driven innovation management solutions to overcome crisis situations, as in the COVID-19 pandemic. This includes the firm-internal view on own technologies and innovation activities as well as the firm-external view on incumbent and novel competition and technology evolvement. Using cross-disciplinary insights from natural sciences and strategic patent management, we identify COVID-19 and related immunology-based' patent families, detect key biotechnology firms already possessing experience in developing cures, treatment, and vaccination to related coronavirus diseases using smart patent indicators and harmonized patent data. Moreover, we highlight why a promulgated U.S. interest in relocating firms like CureVac might not be without technological and commercial reasoning. Further, we demonstrate how firms like Adidas can optimize their budget constraints by detecting patent families that can be monetized, e.g., via sales or licensing deals, as well as potentially saving costs by focusing on impactful patent families and novel annuity fee measures. This provides firms with options to maintain innovative activities in crisis situations. Taken together, these case studies show how patent analytics support firms' managements in mitigating crises like the COVID-19 pandemic and thus enabling them to emerge stronger eventually as a success story. Herein, we provide concrete recommendations for management and depict arrays for future research.

2. Theoretical background

2.1. Innovation management in crises

Crises influence innovation management (Döner, 2017; Teplykh, 2018; Antonioli and Montresor, in press). On the downside, prior research found crises to intensify 'uncertainty, complexity, ambiguity and unpredictability' (Davis et al., 2009; Martin-Rios and Pasamar, 2018; Teplykh, 2018). Compared to favorable contexts, in which innovation thrives, innovation is hindered in more unfavorable scenarios, creating innovation barriers, as in crises (Ferreira and Teixeira, 2016; Teplykh, 2018). For example in the financial crises of the late 2000', firms changed their innovation behavior (Cruz-Castro et al., 2018). Disoska et al. (2020) found an indication that crises have a negative influence on firms' willingness to innovate. Some firms only maintain their innovation activities in exchange for public support, which implies a de-facto reduction in proprietary innovation efforts (Antonioli and Montresor, in press). Decreases in firms' revenues directly affect research and development, hence innovation outputs (Döner, 2017).

On the upside, crises do not only entail adverse effects, but offer opportunities stimulating innovation (Carmeli and Schaubroeck, 2008; Ulmer et al., 2011; Cefis and Marsili, 2019; Heyden et al., 2020). When firms manage to meet the shifting market requirement and crises-induced necessities, they can emerge even stronger from these situations (Archibugi et al., 2013a; Mayr et al., 2017). For example, Nemlioglu and Mallick (2020) interpret innovation as a path out of crisis-induced valuation uncertainty, where financially less-constrained, innovative firms yield higher values and experience less uncertainty. In the same vein, Heyden et al. (2020) identified that corporate management benefits from enabling radical change initiatives instead of cutting costs. Innovative activity may support firms in shielding themselves from crises' effects, while other supposed resilience fostering actions, such as marginal production cost reductions, fail (Gupta, 2019). Cefis et al. (2020) found that innovations grant a survival premium. Regardless of firms' financial conditions, innovative firms have higher probabilities than non-innovative firms to survive crises (Cefis et al., 2020).

2.2. *Innovation management and patent analytics*

In addition to the link between crises and innovation management, prior research has also established a relation between innovation management and patent analytics (Candelin-Palmqvist et al., 2012; Holgersson, 2013). To profit from innovation, firms often rely on intellectual property rights like patents to appropriate returns (Greenhalgh et al., 2001; Somaya, 2012; Di Minin and Faems, 2013; Bican et al., 2017). In industries like pharmaceuticals, this is particularly prevalent (Hemphill and Sampat, 2012; Conley et al., 2013a; DiMasi et al., 2016). Patents are publicly available and serve as objective data sources on firms' innovation activities (Ashton and Sen, 1988; Buehler et al., 2017; Guderian, 2019). Patents offer unique insights into technology and business activities of firms that could not be assessed by external parties otherwise (e.g., Ernst, 2003; Ernst and Omland, 2011). Patenting firms commonly rely on more than one patent, generating patent portfolios with multiple patents in multiple jurisdictions through their inventive activities (Conley et al., 2013b).

Measuring the impact of research and development or innovation activities proves difficult (Bican and Brem, 2020). Commonly, innovation managers turn to patent analytics (e.g., Pavitt, 1985; Arundel and Kabla, 1998; Hall et al., 2005). For this purpose, various patent indicators have been applied, from patent portfolio sizes and patent citations toward data mined from patents and smart patent indicators (Allison et al., 2004; Buehler et al., 2017; Fankhauser et al. 2018; Guderian, 2019). This variety in patent indicators stems from the skewness of patent values and commercial applicability (e.g., Chesbrough et al., 2006; Gambardella et al., 2008; Webster and Jensen, 2011).

2.3. *Patent analytics in crises: the COVID-19 pandemic*

Patents are cost-intensive over their entire lifetime, as filing and maintenance costs are due in each jurisdiction where patent protection is sought (Duhigg and Lohr, 2012; Cho et al., 2018). Consequently, maintaining existing or filing new patents is challenging when budgets are constrained, as in crisis situations (e.g., Archibugi et al., 2013a; De Rassenfosse and van Pottelsberghe de la Potterie, 2013; Hud and Hussinger, 2015). Here, cost-reduction is crucial when it comes to patents, while simultaneously ensuring the continued protection of relevant innovations and technologies (Helfgott, 1993; Harhoff et al., 2009). This ensures interpreting patents as strategic assets, which allow leveraging existing capabilities and deploying promising business opportunities (Rivette and Kline, 2000; Di Minin and Faems, 2013; Bican et al. 2017). However, this strategic view of intellectual property is underrepresented in the extent literature on innovation management in crises: Only a few early attempts to link propositions to overcome the crisis and intellectual property exist (e.g., Machuca-Martinez et al., 2020; Tietze et al., 2020). Although scholars have acknowledged that patent information can be used, among others, for technological forecasting, business planning, or strategic

R&D planning, the value and use of patent information in crises have largely been overlooked, resulting in a knowledge gap (Campbell, 1983; Ashton and Sen, 1988; Ernst, 2003). By means of this research, we fill this void.

In the current COVID-19 pandemic, this approach implies an understanding of the biology of the peculiarities, root causes, and effects of the virus. Otherwise, strategies to cope with the pandemic become arbitrary, ad hoc, and rely on gut feelings (Müller, 1985; Cooper and Edgett, 2010; Bessant et al., 2015). In the case of the COVID-19 virus, the human body reacts in the following manner: Cytokines are the proteins released as immune response against infections, genetic disorder, or autoimmune diseases (Testar, 2020). They cause localized inflammation in the region of attack (Van Der Meide and Schellekens, 1996). However, in exceptional cases, there is an uncontrolled release of pro-inflammatory cytokines that ultimately cause the body's own immune system to work against itself leading to multiple organ failures and even death (Wang and Ma, 2008). This unrestrained expression of cytokines and other immune response cells and mediators leading to unchecked activation of the immune system is referred to as 'cytokine storm' (Dance, 2020). Cytokine storm has been encountered in patients during the outbreak of SARS-CoV (Huang et al., 2005) and H5N1 influenza virus (Yuen and Wong, 2005). It is also associated with non-infectious diseases like graft-versus-host disease (Ferrara, 1993), multiple sclerosis (Link, 1998), pancreatitis, juvenile arthritis (Goodman, 2020), lupus, and Still's disease.

The COVID-19 virus triggers a similar response once it enters the lungs of the infected patients (Van Der Meide and Schellekens, 1996; Goodman, 2020). When the immune response to this infection becomes uncontrolled it results in uninhibited production of cytokines that cause cell death at the tissue lining the walls of the lungs leading to pneumonia and oxygen shortage. This initiation of lung failure further leads to acute respiratory distress syndrome ARDS (Ye et al., 2020) and is followed by the failure of other organs. Thus, drugs that act as immunosuppressants and thus block the immune cell mediators (cytokines) are being tested to treat the COVID-19 infection. The COVID-19 infection causing SARS-Cov-2 virus belongs to the beta class of the family of coronaviruses termed Coronaviridae like the SARS-CoV and Middle East respiratory syndrome (MERS) virus (MERS-CoV) (Liu et al., 2020). These are single-stranded RNA viruses with four kinds of structural proteins (Sidedell et al., 2010; Aronson, 2020). The membranes of these viruses have glycoprotein spikes which are responsible for their 'crown' like or 'corona' like appearance under the microscope (ScienceDirect, 2020; Zhang, 2020). These spike proteins anchor the virus onto the host human cell; this process is the same in SARS-Cov, Mers-CoV, and SARS-Cov-2 viruses (Li et al., 2020). There is more than 70% similarity between the genetic sequence of SARS-Cov-2 virus and the SARS-CoV virus and more than 50% with MERS coronavirus (Park et al., 2020).

There is no known antidote against the SARS-Cov-2 virus. In the current crisis, research in treatment methods for COVID-19 infections is based on the knowledge that is available from the SARS and MERS epidemic in the past and treatment methods so far have been adopted from these past infectious respiratory disease epidemics (Park et al., 2020). One of the treatment methods under study is the development of antibodies that target the Spike protein of the virus (Liu et al., 2020). The other method that is pursued is the development of an mRNA vaccine that can trigger the body's immune response to attack the virus (Evans and Longstaff, 2020).

3. Method

3.1. Data

To address the identified gap in the literature, we chose an exploratory, qualitative multiple case study research approach (Yin, 2018). Due to the lack of prior empirical substantiation as well as the nature of our research question ('how'), such qualitative research design was required (Eisenhardt, 1989; Yin, 2018). We rely on four distinct situations of cases that are based on longitudinal and cross-sectional patent data (Yin, 2018); two of which address the downside and two the upside of crisis situations for innovation. We searched cases that address the downside to study how patent analytics can be used to circumvent budget constraints by discerning patents that can be monetized (Case 1: Adidas AG's Patent Families) or abandoned to achieve cost-savings (Case 2: Adidas AG's Annuity Fees), and cases that address the upside to investigate how patent analytics can be used to detect key biotechnology firms (Case 3: CureVac's Patent Portfolio) that are likely to successfully develop treatments and vaccinations (Case 4: COVID-19 Treatment and Vaccination) against COVID-19.

The respective cases were identified in the business press related to the COVID-19 pandemic at the height of the April 2020 lockdown in Europe. Adidas had been in the news for surprisingly obtaining a state-backed loan from the federal German bank KfW, while CureVac drew a prolonged relocation interest by U.S. authorities (e.g., Bennhold and Sanger, 2020; Erhardt, 2020). We obtained the corresponding data, including all measures, from the PatentSight Business Intelligence Analytics Software as of May 7, 2020. For the first two case studies, we queried information on the patent portfolio owned by Adidas AG, including its subsidiaries and subsidiaries' subsidiaries, using the databases' interface. The unit of analysis is the patent family, i.e., the 'set of either patent applications or publications taken in multiple countries to protect a single invention by a common inventor(s) and then patented in more than one country' (European Patent Office, 2017). The Adidas patent portfolio comprises a total of 875 patent families, of which 434 are active. The empirical unit for case study one is the patent family. The empirical unit for case study two is the annuity fees due per patent office and year.

For case study three, we queried information for the patent portfolio owned by CureVac AG, including its subsidiaries and subsidiaries' subsidiaries, using the databases' interface. The unit of analysis is the patent portfolio. The CureVac patent portfolio comprises a total of 123 patent families, of which 105 are active. The empirical unit for case study three is the patent portfolio strength (Ernst and Omland, 2011).

For case study four, we identified patent families related to Coronaviridae viruses. For the patent searches, we use keyword combinations in patents' titles and abstracts as well as Cooperative Patent Classification classes (Swiss Federal Institute of Intellectual Property, 2018; Guderian, 2019). The unit of analysis is the patent family. Cytokine storm treatment, COVID Spike protein treatment, COVID Spike protein vaccine, and COVID mRNA vaccine-related patent search yield totals of 9,494, 271, 115, and 452 patent families, of which 3,059, 128, 48, and 266 patent families are active for these individual technologies on May 7, 2020, respectively. The empirical unit is the number of patent families per owner and their average quality (Ernst and Omland, 2011).

3.2. Analyses

Our analyses are conducted in the PatentSight Business Intelligence Analytics Software. For Adidas' patent portfolio, we use the values of the Internal Technology Relevance on the abscissa and the External Technology Relevance on the ordinate (see Appendix for corresponding patent indicator definitions). Each patent family owned by Adidas is plotted according to its remaining lifetime values. For the second case study, we filter for all of Adidas' patent families and the two subsamples derived in the first case study to detect the annuity fees. For the third case study, we filter for CureVac's patent portfolio and display the Patent Asset Index for their technology clusters longitudinally from 2001 to 2019. Moreover, we also filter for the Patent Asset Index of other firms' patent families that build on CureVac's patent families as prior art. In addition, we collect data on protected authorities and inventor locations. For the fourth case study, we search for patent families concerning Coronaviridae viruses and related treatment methods. In light of the crisis, it is necessary to search for patent families and their owners that possess the required preliminary inventive know-how in this field. Our approach in patent searching is to identify these key players who have already performed the groundwork for the fight against the COVID-19 infection in terms of treatment methods such as for cytokine storm. The keywords related to the cytokine storm treatments are searched for in patents' titles and abstracts. Diagnostic methods in this field are not being considered which means that the corresponding CPC class G01N has been excluded. This process ultimately reveals the patents that explicitly disclose inventions concerning treatment methods of cytokine storm. Searching for patents based on the inventions made after the SARS and MERS outbreak can provide the already available knowledge base regarding the ongoing approaches against the virus. The patent search is focused on the inventions in the treatment of SARS or MERS infection targeting the Spike or S protein or the mRNA vaccine. Each of the specific treatment options is investigated more closely by analyzing the patents related to each of the Spike protein-based methods and mRNA-based methods separately. The Spike protein-based keywords are searched in patents' titles and abstracts, while the SARS- and MERS-related keywords are searched in patents' titles, abstracts, and claims. A similar approach for mRNA vaccine-based patents is followed.

4. Results

4.1. Case 1: Adidas AG's patent families

Figure 1 depicts the Adidas' patent portfolio. The patent families are plotted according to their Internal Technology Relevance and External Technology Relevance values. The bubble sizes represent the remaining lifetimes. All 434 Adidas patent families active on May 7, 2020, are spread out across the two axes. Most patent families are located close

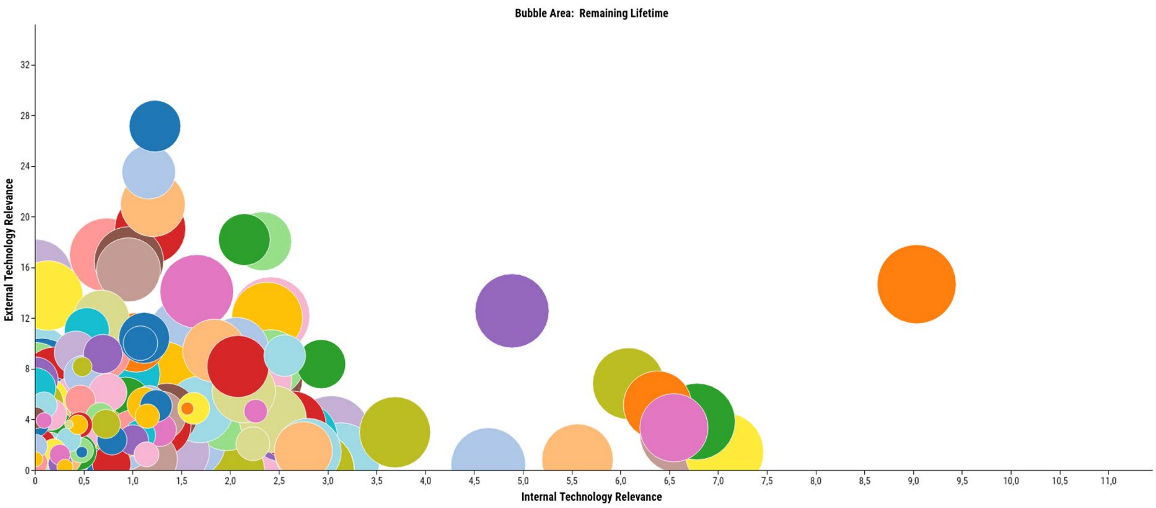

Figure 1. Adidas' patent portfolio: Internal- vs. external technology relevance. *Source:* PatentSight Business Intelligence Analytics Software, own export, May 7, 2020.

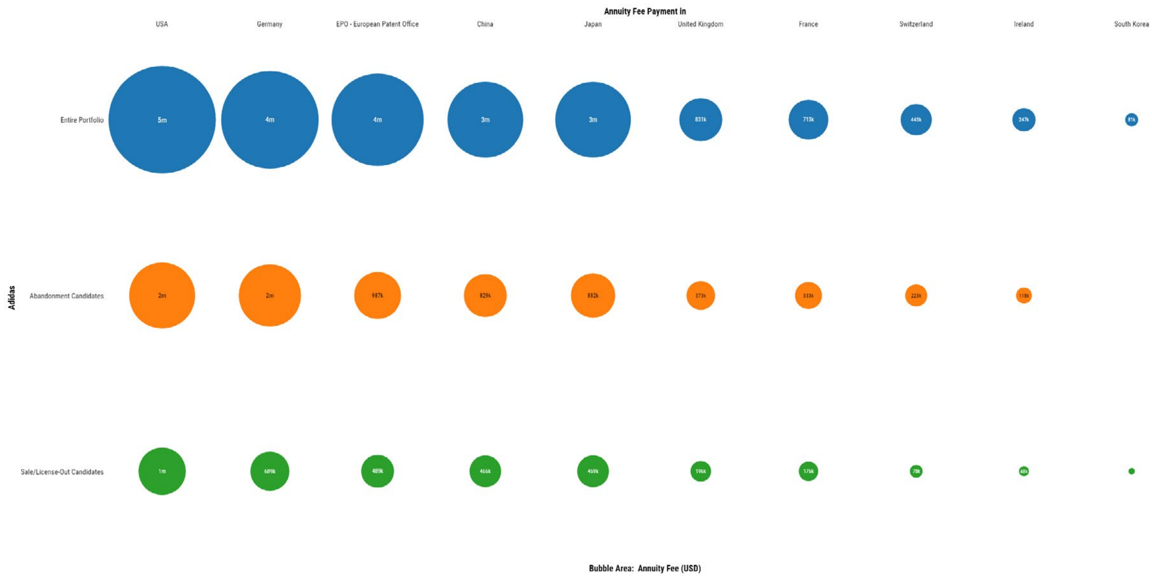

Figure 2. Adidas' patent portfolio: Annuity fee payment in USD at various patent offices. *Source:* PatentSight Business Intelligence Analytics Software, own export, May 7, 2020.

to the origin, hence have low Internal and External Technology Relevance values. The average Internal Technology Relevance and External Technology Relevance is 0.79 and 2.92, respectively.

4.2. *Case 2: Adidas AG's annuity fees*

Figure 2 depicts the patent office annuity fees of Adidas' patent portfolio due until the end of the patents' lifetimes. While the first row depicts the entire portfolio, the second and third rows depict the annuity fees for the patents that may be abandoned and sold or licensed-out, as identified in the first case study. In total, Adidas has to pay approximately USD 20 million in annuity fees to the respective patent offices like the USPTO and EPO (see Figure 2). For the abandonment candidates, Adidas has to pay about USD 7 million in annuity fees, while for the sale and licensing-out candidates, about USD 4 million have to be paid. The cost-saving potential of USD 11 million accounts for 55% of all annuity fees due.

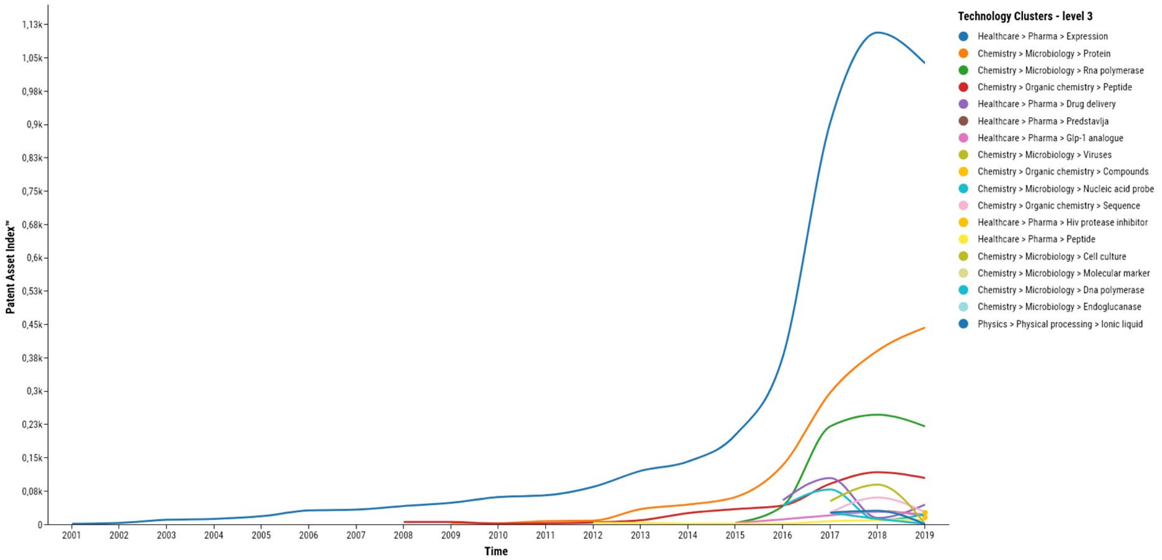

Figure 3. CureVac: Patent Asset index by technology cluster (level 3) from 2000 to 2019. *Source:* PatentSight Business Intelligence Analytics Software, own export, May 7, 2020.

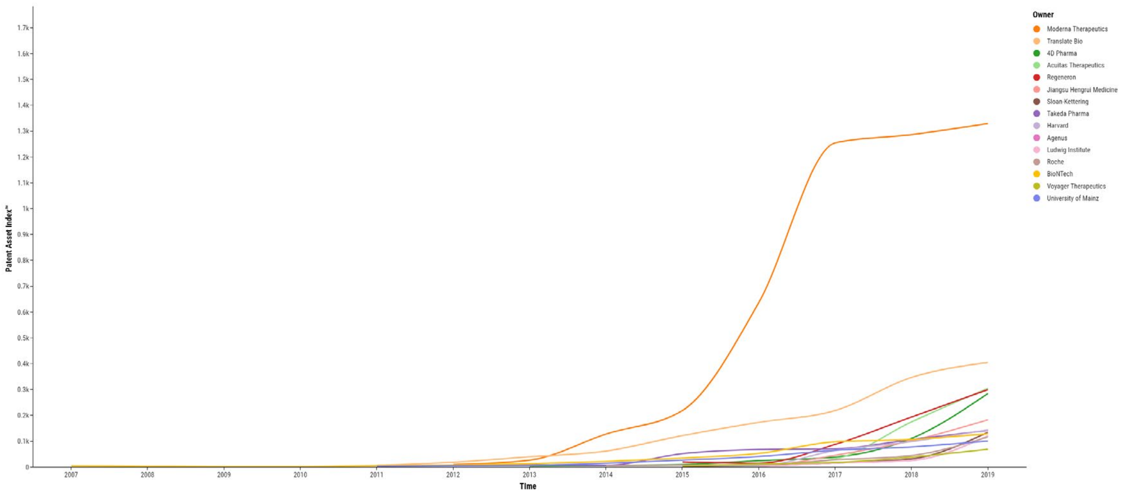

Figure 4. CureVac: Patent asset index for firms' patents citing CureVac from 2007 to 2019. *Source:* PatentSight Business Intelligence Analytics Software, own export, May 7, 2020.

4.3. Case 3: CureVac's patent portfolio

Figure 3 depicts the Patent Asset Index of CureVac's patent portfolio separated by the technology cluster to which its patent families are classified using semantic rules of similarity (Hartmann, 2020; PatentSight GmbH, 2020). All 18 technology clusters between the first patent family in 2001 and 2019 (105 patent families) grew substantially, with a Patent Asset Index of 2,017 in 2019. For protein, the Patent Asset Index grew from 3 in 2009 to 442 in 2019, while mRNA polymerase patent families had a Patent Asset Index of 3 in 2005 and 220 in 2019. All virus-related patent families showed a Patent Asset Index of 26 in 2019.

Figure 4 presents the Patent Asset Index of the patent families owned by other firms that cite CureVac's patent families. This allows to identify closely related firms that build on CureVac's patent families as prior art. Among the top 15 firms that build on CureVac's patent portfolio with the strongest patent portfolio, we identified biotechnology firms such as Moderna Therapeutics and Acuitas Therapeutics, but also established pharmaceutical firms such as Roche, universities such as Harvard University and the University of Mainz as well as research institutes like the Ludwig Institute.

On a world map, Figure 5 highlights where CureVac's patent families are active and Figure 6 shows where the patent families have been invented

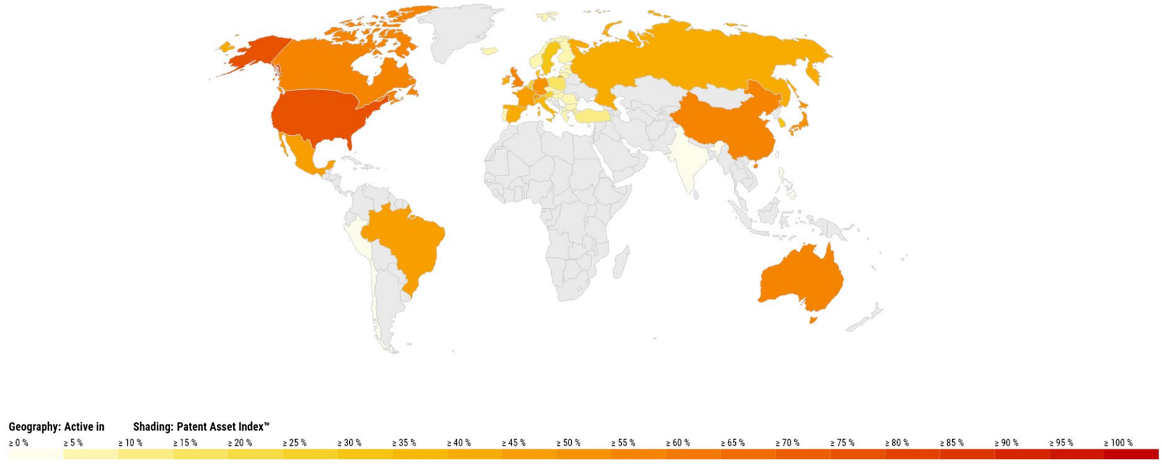

Figure 5. CureVac: Protected authorities. *Source:* PatentSight Business Intelligence Analytics Software, own export, May 7, 2020.

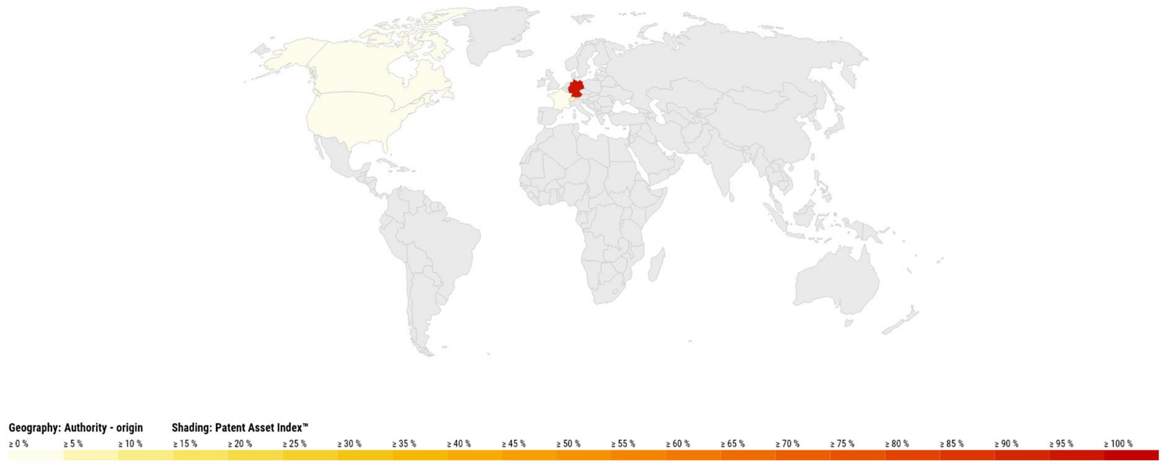

Figure 6. CureVac: Inventor locations. *Source:* PatentSight Business Intelligence Analytics Software, own export, May 7, 2020.

based on inventor locations. CureVac's patent families originate in Germany, with few co-origin authorities (e.g., Switzerland, USA). In contrast, CureVac protects its patents across the globe, with the strongest portfolios active in the United States.

4.4. *Case 4: COVID-19 treatment and vaccination – competitive landscape*

Figure 7 depicts the top 15 patent owners of Cytokine storm treatment with their respective portfolio sizes, average Competitive Impacts, and Patent Asset Index values. Moreover, besides big pharma (e.g., Bristol-Myers Squibb), small biotech firms (e.g., Ono Pharmaceutical) are active in Cytokine storm treatment. Focusing on COVID Spike protein treatment, Figure 8 illustrates the filing activities on patents for this treatment. Incorporating active, inactive, and pending patents in green, red, and yellow color, the filing activities show peaks for 2003 to 2004 as well as 2013 to 2017, following the SARS and MERS outbreaks, respectively.

The most prominent case is Gilead Sciences, whose Remdisivir is the frontrunner in the race toward the treatment of cytokine storm in covid-19 infections (PMGroup, 2020). Aduro Biotech and Ono Pharmaceutical's portfolios feature low numbers of patent families but high average qualities. These firms are known to possess drugs that target inflammatory and autoimmune diseases and have already been taken note of in the current pandemic scenario (Aduro Biotech, 2020; Liu et al., 2020). Regeneron has reported the trial test of its arthritis drug Kevzara to treat cytokine storm in COVID-19 patients

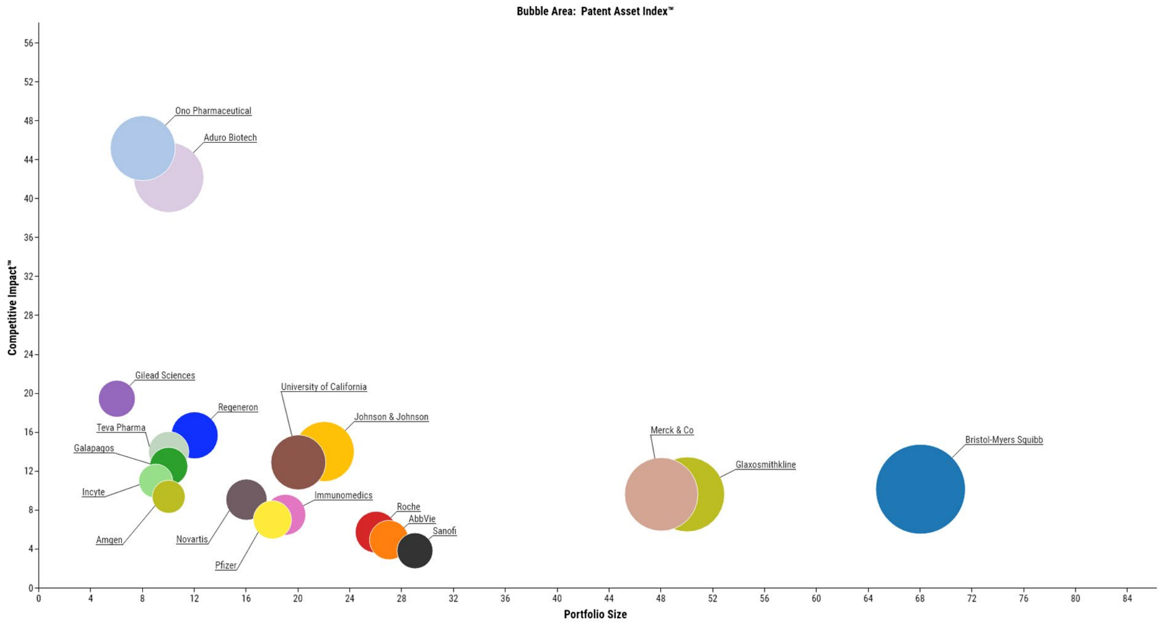

Figure 7. Cytokine storm treatment: Top 15 firms by the patent asset index. *Source:* PatentSight Business Intelligence Analytics Software, own export, May 7, 2020.

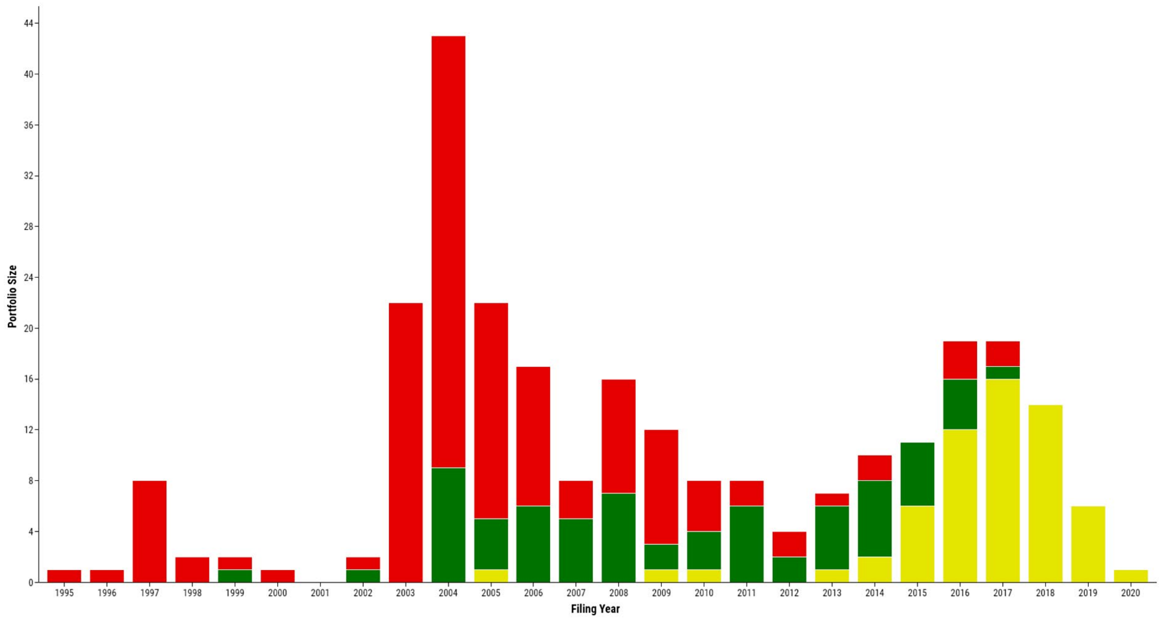

Figure 8. COVID-Spike protein treatment: Filing activities and patents' legal statuses. *Source:* PatentSight Business Intelligence Analytics Software, own export, May 7, 2020.

(Erman and Threlfall, 2020). Roche is also conducting tests on its arthritis drug ACTEMRA (DeArment, 2020b; Liu and Miller, 2020) to treat COVID-19 pneumonia, while Incyte has reported its plan for the trial of its blood cancer drug as a potential treatment for COVID-19 cytokine storm (DeArment, 2020a).

For the COVID Spike protein-based search, only 48 active patent families with a Patent Asset Index of 86 are identified. Discerning them by owner type (Figure 9), 64% are owned by firms, 35% by research and governmental bodies, and 1% is co-owned. University of Oxford features among the top patent-owners and the retrieved patents include the one disclosing the specific adenovirus vector ChAdOx1 based on which the current vaccine the whole world is waiting for and which has been

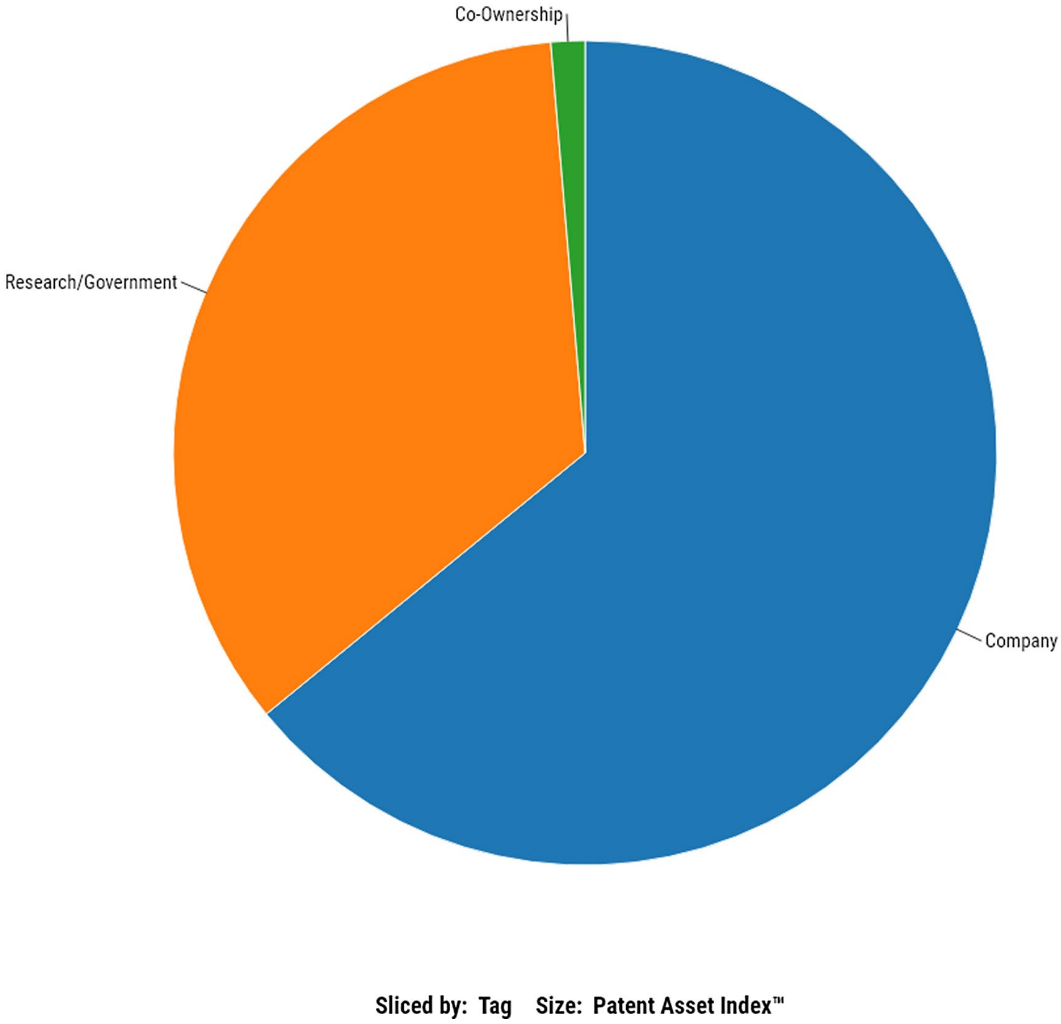

Figure 9. COVID Spike protein vaccine: Owner types by patent asset index. *Source:* PatentSight Business Intelligence Analytics Software, own export, May 7, 2020.

licensed to AstraZeneca, has been developed. In the mRNA-based vaccine-related patents, the two strongest patent portfolios as per the bubble area that indicates portfolio strength, are owned by CureVac and Moderna Therapeutics, where CureVac owns five and Moderna Therapeutics three patent families. The average Competitive Impact values are quite high, but portfolio sizes relatively low with single patent family for firms like Sanofi, while Emory University has six patent families with lower Competitive Impact (see Figure 10).

Latest news states that Moderna's pioneer vaccine technique with its mRNA-1273 in treating COVID-19 infection has got FDA approval to proceed to the second phase of testing (Saplakoglu, 2020). This vaccine is based on the research Moderna was conducting for the MERS vaccine (Harbert, 2020). CureVac has received an 80 million grant from the European Union to develop an mRNA based COVID-19 vaccine (Bahrke and Grammenou, 2020).

5. Discussion

Innovation management may rely on patent analytics to overcome crisis situations like the current COVID-19 pandemic based on data-driven instead of ad-hoc decisions. As shown in the case study one, patent analytics can be applied to identify patent families that can be abandoned, sold, or licensed-out. Using citation metrics, we show that patent families with below-average internal citations may be considered candidates. Looking at external citations from third-party patent portfolios and considering above- or below-average values may further support abandonment, sale, or licensing decisions.

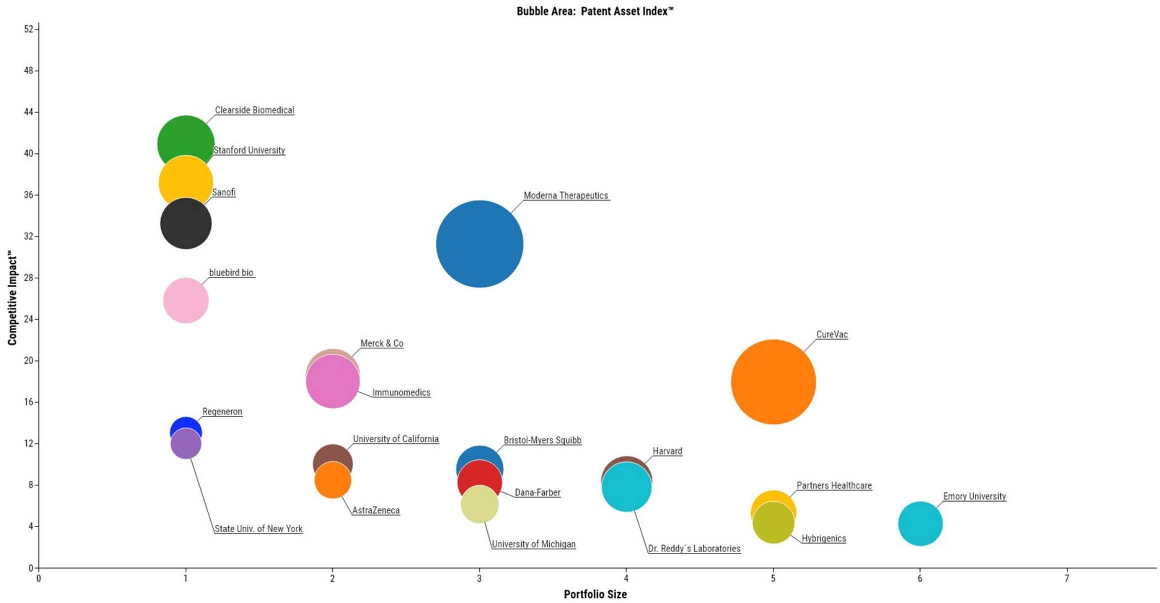

Figure 10. COVID mRNA: Top 20 firms by the patent asset index. *Source:* PatentSight Business Intelligence Analytics Software, own export, May 7, 2020.

Adding annuity fee considerations, as shown in case study two, provides the first indication of potential cost-saving opportunities. However, these annuity fees cover patent office fees only. Consequently, associated legal fees for attorneys or patent enforcement costs diminish. Proceedings from the sale of patent families or licensing fees improve the financial position further.

Patent analytics allow for a better understanding of firms' strategies through their patent portfolios, as shown in case study three. For example, firms may identify where to seek protection, where to create R&D centers, where white spots exists, or where to find collaboration partners (e.g., Ernst, 2003; Somaya, 2012; Di Minin and Faems, 2013; Guderian, 2019). Applying patent value indicators to detect firms with above-average patent portfolios related to Coronaviridae virus treatment and vaccination, allows for data-driven innovation management decisions. For example, CureVac's average Competitive Impact (at 18.1) as a measure of average patent quality is about 18 times higher than the average of all active patent families worldwide. Hence, local governments' inclinations to shield these firms from acquisition by foreign entities or relocation through foreign governments, become comprehensible. Also, in terms of the patents' origins and the geographical scope of protection, we see stark differences.

Information mined from patents allows measuring innovation output and future knowledge flows, as shown in case study four (Buehler et al., 2017; Ernst et al., 2020). The innovation-driven patent activity shows a rise after the SARS and the MERS outbreaks in the past. This brings forth the trend of increased innovative activity after pandemics. In addressing crisis situations, the conventional patent searching process where the field of search is kept broad needs to be substituted by more narrow, focused approaches to bring into light the information about those entities as in patent owners that explicitly disclose the R&D and invention in a particular area. Consequently, firms like Moderna and Curevac as well as institutions like the University of Oxford are identified. Innovations are lengthy processes and in their development, they leave behind footprints that can be identified through various methods, one of which is patent analytics.

5.1. Theoretical implications

Prior research identified crises to impact innovation in firms (Döner, 2017; Teplykh, 2018; Antonioli and Montresor, in press). A frequent response to crisis-induced detriments is the reduction of innovation activities to cope with issues such as budget constraints (Döner, 2017; Cruz-Castro et al., 2018). Simultaneously, some firms manage to use crises for their benefits to emerge even stronger (Archibugi et al., 2013a; Cefis and Marsili, 2019). While in normal (non-crisis) times innovation management decisions are often crafted and executed using data like patent indicators, patent analytics have so far been largely neglected in responding to the challenges for innovation management imposed by crises. As our key theoretical contribution, we discuss and establish the relation between crises and patents. Thus, as shown in Figure 11, we

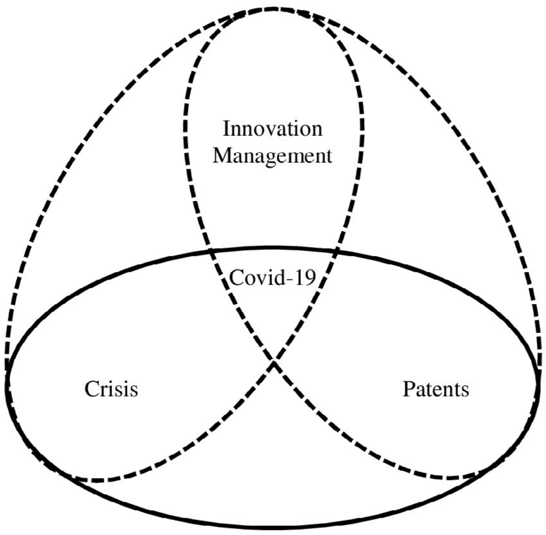

Figure 11. Triadic relation: Innovation management, crises, and patents. *Source:* Own illustration.

complement the two dyadic relations between (1) innovation management and crises and (2) innovation management and patents that have been established in prior research by transforming these into a triadic relation between innovation management, crises, and patents.

As visible in the findings from our four case studies, we address firms' internal and external spheres. Patent analytics allow innovation management to craft own or forecast third-parties' probable responses to crises by data instead of ad-hoc or gut-feeling decisions. Moreover, our case studies address multiple levels of analyses, spanning inventions/technologies, firms, and competitive behavior.

Herein, we expand on recent early attempts to link propositions to overcome the crisis and intellectual property (e.g., Machuca-Martinez et al., 2020; Tietze et al., 2020). The findings from the patent analytics presented above confirm Cefis and Marsili (2019) in that technological innovations might trigger firms' survivals in crises: 'R&D investment is shown to be a poor choice for general firms to survive; however, it is an effective strategy for firms that are innovative and capable of producing intellectual properties during recessionary periods' (Jung et al., 2018).

5.2. *Practical implications*

The insights of these studies yield valuable implications for innovation decision makers as well. First, innovation management can realize cost-savings by identifying patent families that do not add substantial value to own or third parties' business strategies. This budget may be used to maintain innovation activities in crises' toughened endowments or circumstances. Second, annuity fees show minimum prices or royalty payments that need to be achieved in sale or licensing negotiations to reach break-even. Third, assessing firms' patent portfolios allows to detect technological and strategic fit between business strategies, innovation capabilities, and patent portfolios. This becomes visible in CureVac's patent portfolio, as almost all of its patent families originate in Germany, whereas broad patent protection has been sought for in many developed and developing countries such as the G-7 and BRIC nations. Fourth, patent information may reveal data-driven predictions for firms that are likely to succeed in developing treatments and vaccinations.

5.3. *Limitations and future research*

As the COVID-19 pandemic is ongoing the results presented can only constitute preliminary assessments. Actual performance effects of management strategies and potential differences to non-data-driven decisions cannot be compared at this stage, requiring additional review once the pandemic has passed. Moreover, it is currently impossible to complement patent data with corporate data or actual decision -making schemes from corporate representatives to identify firms' internal reasonings. However, the data used for the case studies are derived from objective, harmonized, and publicly available information. This opens arrays for future research, particularly related to innovation management in times of crises like the current COVID-19 pandemic via the use of data-driven strategies derived from patent analytics. First, as firms proceed to cope with budget constraints and budget cuts, studying patent families actually sold, licensed, or abandoned, and comparing their patent quality and strength metrics might provide additional insights into value-driven patent management (Wurzer et al., 2016; Weibel and Freytag, 2019). Particular focus may be set on assessing quality differences for innovations generated in-house versus those externally acquired. Second, future research may move from qualitative analyses and case studies toward empirical analyses to study actual performance effects of patent data-driven decisions in crisis situations. A promising approach in this context may be to expand the existing models toward multilevel or hierarchical models to combine patent data on individual patents or patent portfolios with financial, economic, or medical data (e.g., Raudenbush and Byrk, 2002; Tabachnik and Fidell, 2018). Third, research may shift to longitudinal considerations, which is already partly performed in the case studies presented in this study. Looking at patent data trends and development patterns over time may yield additional insights into how firms overcame the crisis, allowing to make derivations for future pandemics or similar situations to come (e.g., Grover, 1999). This could support the detection of firms' development of Coronaviridae treatment and vaccination development to end the pandemic.

Acknowledgments

Open access funding enabled and organized by ProjektDEAL.

The authors gratefully acknowledge support by the FAU Emerging Talents Initiative (Grant 2019/2_WiSo_02).

Furthermore, the authors thank PatentSight GmbH, in particular Marco Richter, William Mansfield, Dr. Susann Lüdtke, Dr. Christoph Hartmann, Dr. Krisztina Perl, and Charlotte A. Robinson.

References

Aduro Biotech. (2020) *A Growing Pipeline of New Immunotherapies*. https://www.aduro.com/pipeline/, accessed May 11, 2020.

Allison, J.R., Lemley, M.A., Moore, K.A., and Trunkey, R.D. (2004) Valuable Patents. *Georgetown Law Journal*, **92**, 3, 435–479.

Antonioli, D. and Montresor, S. (2019) Innovation persistence in times of crisis: an analysis of Italian firms. *Small Business Economics*.

Archibugi, D., Filippetti, A., and Frenz, M. (2013a) Economic crisis and innovation: Is destruction prevailing over accumulation? *Research Policy*, **42**, 2, 303–314.

Archibugi, D., Filippetti, A., and Frenz, M. (2013b) The impact of the economic crisis on innovation: Evidence from Europe. *Technological Forecasting and Social Change*, **80**, 7, 1247–1260.

Aronson, J.K. (2020, March 25) *Coronaviruses – A General Introduction*. University of Oxford, Centre for Evidence-Based Medicine (CEBM). https://www.cebm.net/covid-19/coronaviruses-a-general-introduction/, accessed May 12, 2020.

Arundel, A. and Kabla, I. (1998) What percentage of innovations are patented? empirical estimates for European firms. *Research Policy*, **27**, 2, 127–141.

Ashton, W.B. and Sen, R.K. (1988) Using Patent Information in Technology Business Planning–I. *Research-Technology Management*, **31**, 6, 42–46.

Bahrke, J. and Grammenou, M. (2020, March 16) *Coronavirus: Commission Offers Financing to Innovative Vaccines Company CureVac*. European Commission. https://ec.europa.eu/commission/presscorner/detail/en/IP_20_474, accessed May 12, 2020.

Bennhold, K. and Sanger, D.E. (2020, March 15) U.S. Offered 'Large Sum' to German Company for Access to Coronavirus Vaccine Research, German Officials Say. *New York Times*. https://www.nytimes.com/2020/03/15/world/europe/cornonavirus-vaccine-us-germany.html, accessed May 15, 2020.

Bessant, J., Rush, H., and Trifilova, A. (2015) Crisis-Driven Innovation: The Case of Humanitarian Innovation. *International Journal of Innovation Management*, **19**, 6, 1540014.

Bican, P.M. and Brem, A. (2020) Managing innovation performance: Results from an industry-spanning explorative study on R&D key measures. *Creativity and Innovation Management*, **29**, 2, 268–291.

Bican, P.M., Guderian, C.C., and Ringbeck, A. (2017) Managing knowledge in open innovation processes: an intellectual property perspective. *Journal of Knowledge Management*, **21**, 6, 1384–1405.

Buehler, B., Coublucq, D., Hariton, C., Langus, G., and Valletti, T. (2017) Recent Developments at DG Competition: 2016/2017. *Review of Industrial Organization*, **51**, 4, 397–422.

Campbell, R.S. (1983) Patent trends as a technological forecasting tool. *World Patent Information*, **5**, 3, 137–143.

Candelin-Palmqvist, H., Sandberg, B., and Mylly, U.-M. (2012) Intellectual property rights in innovation management research: A review. *Technovation*, **32**, 9, 502–512.

Carmeli, A. and Schaubroeck, J. (2008) Organisational Crisis-Preparedness: The Importance of Learning from Failures. *Long Range Planning*, **41**, 2, 177–196.

Cefis, E., Bartoloni, E., and Bonati, M. (2020) Show me how to live: Firms' financial conditions and innovation during the crisis. *Structural Change and Economic Dynamics*, **52**, 63–81.

Cefis E., and Marsili O. (2019) Good times, bad times: innovation and survival over the business cycle. *Industrial and Corporate Change*, **28**, 3, 565–587.

Chesbrough, H. , Vanhaverbeke, W. , and West, J. (eds). (2006) *Open Innovation: Researching a New Paradigm*. Oxford: Oxford University Press.

Cho, Y., Kirkewoog, S., and Daim, T.U. (2018) Managing strategic intellectual property assets in the fuzzy front end of new product development process. *R&D Management*, **48**, 3, 354–374.

Christensen, M. and Knudsen, T. (2010) Design of Decision-Making Organizations. *Management Science*, **56**, 1, 71–89.

Conley, J.G., Bican, P.M., and Ernst, H. (2013a) Value Articulation: A Framework for the Strategic Management of Intellectual Property. *California Management Review*, **55**, 4, 102–120.

Conley, J.G., Bican, P.M., and Wilkof, N. (2013b) *WIPO Study on Patents and The Public Domain (II) – Impact of Certain Enterprise Practices*. Geneva, Switzerland: World Intellectual Property Organization White Paper.

Cooper, R.G. and Edgett, S.J. (2010) Developing a Product Innovation and Technology Strategy for Your

Business. *Research-Technology Management*, **53**, 3, 33–40.

Cruz-Castro, L., Holl, A., Rama, R., and Sanz-Menéndez, L. (2018) Economic crisis and company R&D in Spain: do regional and policy factors matter? *Industry and Innovation*, **25**, 8, 729–751.

Dance, A. (2020, April 14) What Is a Cytokine Storm? *Discover Magazine*. https://www.discovermagazine.com/health/what-is-a-cytokine-storm, accessed May 11, 2020.

Davis, J.P., Eisenhardt, K.M., and Bingham, C.B. (2009) Optimal Structure, Market Dynamism, and the Strategy of Simple Rules. *Administrative Science Quarterly*, **54**, 3, 413–452.

De Rassenfosse, G. and van Pottelsberghe de la Potterie, B. (2013) The Role of Fees in Patent Systems: Theory and Evidence. *Journal of Economic Surveys*, **27**, 4, 696–716.

DeArment, A. (2020a, March 24) Incyte plans Phase III trial of blood cancer drug as potential Covid-19 cytokine storm therapy. *MedCity News*. https://medcitynews.com/2020/04/incyte-plans-phase-iii-trial-of-blood-cancer-drug-as-potential-covid-19-cytokine-storm-therapy/, accessed May 11, 2020.

DeArment, A. (2020b, March 24) Roche starts Phase III study of arthritis drug in Covid-19 pneumonia. *MedCity News*. https://medcitynews.com/2020/03/roche-starts-phase-iii-study-of-autoimmune-drug-in-covid-19-pneumonia/, accessed May 11, 2020.

Denrell, J. and Fang, C. (2010) Predicting the Next Big Thing: Success as a Signal of Poor Judgment. *Management Science*, **56**, 10, 1653–1667.

Di Minin, A. and Faems, D. (2013) Building Appropriation Advantage: An Introduction to the Special Issue on Intellectual Property Management. *California Management Review*, **55**, 4, 7–14.

DiMasi, J.A., Grabowski, H.G., and Hansen, R.W. (2016) Innovation in the pharmaceutical industry: New estimates of R&D costs. *Journal of Health Economics*, **47**, 20–33.

Disoska, E.M., Tevdovski, D., Toshevska-Trpchevska, K., and Stojkoski, V. (2020) Evidence of innovation performance in the period of economic recovery in Europe. *Innovation: The European Journal of Social Science Research*, **33**, 3, 280–295.

Döner, A.S. (2017) Innovation During and Beyond the Economic Crisis. In: Hacioğlu, Ü. and Dinçer, H. (eds), *Global Financial Crisis and its Ramifications on Capital Markets. Opportunities and Threats in Volatile Economic Conditions*. Cham: Springer International Publishing. pp. 643–659.

Duhigg, C. and Lohr, S. (2012, October 2) The Patent, Used as a Sword. *New York Times*. https://www.nytimes.com/2012/10/08/technology/patent-wars-among-tech-giants-can-stifle-competition.html?pagewanted=all&_r=1&, accessed August 31, 2020.

Eisenhardt, K.M. (1989) Building Theories from Case Study Research. *Academy of Management Review*, **14**, 4, 532–550.

Erhardt, M. (2020, April 15) Der Staat als Stütze milliardenschwerer Marken. [The State supports Brands Worth Billions]. *Deutschlandfunk*. https://www.deutschlandfunk.de/adidas-und-die-corona-hilfen-der-staat-als-stuetze.769.de.html?dram:article_id=474709, accessed on May 15, 2020.

Erman, M. and Threlfall, A. (2020, April 9) Data on arthritis drug to treat coronavirus could come within weeks: Regeneron executive. *Reuters*. https://www.reuters.com/article/us-health-coronavirus-regeneron-pharms/data-on-arthritis-drug-to-treat-coronavirus-could-come-within-weeks-regeneron-executive-idUSKCN21R2WN, accessed May 11, 2020.

Ernst, H. (2003) Patent information for strategic technology management. *World Patent Information*, **25**, 3, 233–242.

Ernst, H. and Omland, N. (2011) The Patent Asset Index – A new approach to benchmark patent portfolios. *World Patent Information*, **33**, 1, 34–41.

Ernst, H., Guderian, C.C., and Richter, M. (2020) *The Innovation Environment and Knowledge Diffusion: Improving Policy Decisions through Patent Analytics*. Working Paper, WHU – Otto Beisheim School of Management, Vallendar, Germany, and PatentSight GmbH, Bonn, Germany.

European Patent Office. (2017) *Patent families*. https://www.epo.org/searchingfor-patents/helpful-resources/ﬁrst-time-here/patent-families.html, accessed November 14, 2017.

Evans, R. and Longstaff, D. (2020) *COVID-19: mRNA vaccines – A promising approach to vaccine development*. Shelston IP Pty Ltd and Lexology. https://www.lexology.com/library/detail.aspx?g=fae5c89a-be0e-4c82-9bf1-321d7cc9d56c, accessed May 12, 2020.

Fankhauser, M., Moser, C., and Nyfeler, T. (2018) Patents as Early Indicators of Technology and Investment Trends: Analyzing the Microbiome Space as a Case Study. *Frontiers in Bioengineering and Biotechnology*, **6, Text 84**, 1–7.

Ferrara, J.L.M. (1993) Cytokine dysregulation as a mechanism of graft versus host disease. *Current Opinion in Immunology*, **5**, 5, 794–799.

Ferreira, A. and Teixeira, A.L. (2016) Intra-and Extra-Organizational Foundations of Innovation Processes – The Information and Communication Technology Sector under the Crisis in Portugal. *International Journal of Innovation Management*, **20**, 6, 1650056.

Fischer, T. and Leidinger, J. (2014) Testing patent value indicators on directly observed patent value – An empirical analysis of Ocean Tomo patent auctions. *Research Policy*, **43**, 3, 519–529.

Gambardella, A., Harhoff, D., and Verspagen, B. (2008) The value of European patents. *European Management Review*, **5**, 2, 69–84.

Goodman, B. (2020, April 17) *Cytokine Storms May Be Fueling Some COVID Deaths*. WebMD. https://www.webmd.com/lung/news/20200417/cytokine-storms-may-be-fueling-some-covid-deaths, accessed May 11, 2020.

Greenhalgh, C., Longland, M., and Bosworth, D. (2001) Technological Activity and Employment in a Panel of UK Firms. *Scottish Journal of Political Economy*, **48**, 3, 260–282.

Grover, V. (1999) From Business Reengineering to Business Process Change Management: A Longitudinal Study of Trends and Practices. *IEEE Transactions on Engineering Management*, **46**, 1, 36–46.

Guderian, C.C. (2019) Identifying Emerging Technologies with Smart Patent Indicators: The Example of Smart Houses. *International Journal of Innovation and Technology Management*, **16**, 2, 1950040.

Gupta, A. (2019) *R&D and Firm Resilience During Bad Times*. Working Paper, Research Paper 2019/12, Research Paper Series on Globalisation, Productivity and Technology, University of Nottingham, United Kingdom.

Hall, B.H., Jaffe, A., and Trajtenberg, M. (2005) Market value and patent citations. *The RAND Journal of Economics*, **36**, 1, 16–38.

Harbert, T. (2020) How Moderna is racing to a coronavirus vaccine. *MIT Sloan School of Management*. https://mitsloan.mit.edu/ideas-made-to-matter/how-moderna-racing-to-a-coronavirus-vaccine, accessed May 12, 2020.

Harhoff, D., Hoisl, K., Reichl, B., and van Pottelsberghe de la Potterie, B. (2009) Patent validation at the country level – The role of fees and translation costs. *Research Policy*, **38**, 9, 1423–1437.

Harhoff, D., Scherer, F.M., and Vopel, K. (2003) Citations, family size, opposition and the value of patent rights. *Research Policy*, **32**, 8, 1343–1363.

Hartmann, C. (2020) *PatentSight Technology Clustering*, Working Paper. Bonn, Germany: PatentSight GmbH,

Helfgott, S. (1993) Patent Filing Costs around the World. *Journal of the Patent and Trademark Office Society*, **75**, 7, 567–580.

Hemphill, C.S. and Sampat, B.N. (2012) Evergreening, patent challenges, and effective market life in pharmaceuticals. *Journal of Health Economics*, **31**, 2, 327–339.

Heyden, M.L.M., Wilden, R., and Wise, C. (2020) Navigating crisis from the backseat? How top managers can support radical change initiatives by middle managers. *Industrial Marketing Management*, **88**, 305–313.

Hingley, P. and Park, W.G. (2017) Do business cycles affect patenting? Evidence from European Patent Office filings. *Technological Forecasting and Social Change*, **116**, 76–86.

Hoegl, M., Gibbert, M., and Mazursky, D. (2008) Financial constraints in innovation projects: When is less more? *Research Policy*, **37**, 8, 1382–1391.

Holgersson, M. (2013) Patent management in entrepreneurial SMEs: a literature review and an empirical study of innovation appropriation, patent propensity, and motives. *R&D Management*, **43**, 1, 21–36.

Huang, K.-J., Su, I.-J., Theron, M., Wu, Y.-C., Lai, S.-K., Liu, C.-C., and Lei, H.-Y. (2005) An interferon-γ-related cytokine storm in SARS patients. *Journal of Medical Virology*, **75**, 2, 185–194.

Hud, M. and Hussinger, K. (2015) The impact of R&D subsidies during the crisis. *Research Policy*, **44**, 10, 1844–1855.

Jung, H., Hwang, J., and Kim, B.-K. (2018) Does R&D investment increase SME survival during a recession? *Technological Forecasting and Social Change*, **137**, 190–198.

Li, H., Liu, S.-M., Yu, X.-H., Tang, S.-L., and Tang, C.-K. (2020) Coronavirus disease 2019 (COVID-19): current status and future perspectives. *International Journal of Antimicrobial Agents*, **55**, 5, 105951.

Link, H. (1998) The cytokine storm in multiple sclerosis. *Multiple Sclerosis Journal*, **4**, 1, 12–15.

Liu, C., Zhou, Q., Li, Y., Garner, L.V., Watkins, S.P., Carter, L.J., Smoot, J., Gregg, A.C., Daniels, A.D., Jervey, S., and Albaiu, D. (2020) Research and Development on Therapeutic Agents and Vaccines for COVID-19 and Related Human Coronavirus Diseases. *ACS Central Science*, **6**, 3, 315–331.

Liu, R. and Miller, J. (2020, March 4) China approves use of Roche drug in battle against coronavirus complications. *Reuters*. https://www.reuters.com/article/us-health-coronavirus-china-roche-hldg/china-approves-use-of-roche-drug-in-battle-against-coronavirus-complications-idUSKBN20R0LF, accessed May 11, 2020.

Machuca-Martinez, F., Amado, R.C., and Gutierrez, O. (2020) Coronaviruses: A patent dataset report for research and development (R&D) analysis. *Data in Brief*, **30**, 105551.

Martin-Rios, C. and Pasamar, S. (2018) Service innovation in times of economic crisis: the strategic adaptation activities of the top EU service firms. *R&D Management*, **48**, 2, 195–209.

Mayr, S., Mitter, C., and Aichmayr, A. (2017) Corporate Crisis and Sustainable Reorganization: Evidence from Bankrupt Austrian SMEs. *Journal of Small Business Management*, **55**, 1, 108–127.

Müller, R. (1985) Corporate crisis management. *Long Range Planning*, **18**, 5, 38–48.

Nemlioglu, I. and Mallick, S.K. (2020) Do innovation-intensive firms mitigate their valuation uncertainty during bad times? *Journal of Economic Behavior & Organization*, **177**, 913–940.

Oskam, J. and Boswijk, A. (2016) Airbnb: the future of networked hospitality businesses. *Journal of Tourism Futures*, **2**, 1, 22–42.

Park, M., Thwaites, R.S., and Openshaw, P.J.M. (2020) COVID-19: Lessons from SARS and MERS. *European Journal of Immunology*, **50**, 3, 308–311.

PatentSight GmbH. (2020) *Technology Clusters – a hands on demonstration of PatentSight's newest feature*. https://www.patentsight.com/webinars, accessed May 11, 2020.

Paunov, C. (2012) The global crisis and firms' investments in innovation. *Research Policy*, **41**, 1, 24–35.

Pavitt, K. (1985) Patent statistics as indicators of innovative activities: Possibilities and problems. *Scientometrics*, **7**, 1-2, 77–99.

PMGroup. (2020, April 14) Gilead's coronavirus hopeful remdesivir shows early promise. *PMLive*. http://www.pmlive.com/pharma_news/gileads_coronavirus_hopeful_remdesivir_shows_early_promise_1338274, accessed May 11, 2020.

Raudenbush, S.W. and Bryk, A.S. (2002) *Hierarchical Linear Models: Applications and Data Analysis Methods*, 2nd edn. Thousand Oaks, CA: SAGE Publications Ltd.

Rivette, K.G. and Kline, D. (2000) *Rembrandts in the Attic. Unlocking the Hidden Value of Patents*. Boston, MA: Harvard Business School Press.

Rothan, H.A. and Byrareddy, S.N. (2020) The epidemiology and pathogenesis of coronavirus disease (COVID-19) outbreak. *Journal of Autoimmunity*, **109**, 102433.

Sah, R.K. and Stiglitz, J.E. (1986) The Architecture of Economic Systems: Hierarchies and Polyarchies. *The American Economic Review*, **76**(4), 716–727.

Saplakoglu, Y. (2020, May 8) Moderna's coronavirus vaccine has moved to second phase of testing. *LiveScience.com*. https://www.livescience.com/coronavirus-moderna-vaccine-moves-phase-2-trial.html, accessed May 12, 2020.

Schumpeter, J.A. (1934) *The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle*. New Brunswick and London: Transaction Publishers.

ScienceDirect. (2020) *Coronaviridae – an overview*. ScienceDirect Topics. https://www.sciencedirect.com/topics/medicine-and-dentistry/coronaviridae, accessed May 12, 2020.

Siddell, S.G., Ziebuhr, J. and Snijder, E. J. (2010) Coronaviruses, Toroviruses, and Arteriviruses. In: Mahy, B.W.J. and Meulen V.T. (eds.) *Topley & Wilson's Microbiology and Microbial Infections. Virology*. London: Hodder Arnold.

Somaya, D. (2012) Patent Strategy and Management: An Integrative Review and Research Agenda. *Journal of Management*, **38**, 4, 1084–1114.

Swiss Federal Institute of Intellectual Property. (2018) *Documentation to Technological Field Categorization of Patents*. Document 16-10377, Bern, Switzerland.

Tabachnik, B.G. and Fidell, L.S. (2018) *Using Multivariate Statistics*, 7th edn. London: Pearson Education, Inc.

Teece, D., Peteraf, M., and Leih, S. (2016) Dynamic Capabilities and Organizational Agility: Risk, Uncertainty, and Strategy in the Innovation Economy. *California Management Review*, **58**, 4, 13–35.

Teplykh, G.V. (2018) Innovations and productivity: the shift during the 2008 crisis. *Industry and Innovation*, **25**, 1, 53–83.

Testar, J. (2020) *Cytokines: Introduction*. British Society for Immunology. https://www.immunology.org/public-information/bitesized-immunology/receptors-and-molecules/cytokines-introduction, accessed May 11, 2020.

Tietze, F., Vimalnath, P., Aristodemou, L., and Molloy, J. (2020) Crisis-Critical Intellectual Property: Findings from the COVID-19 Pandemic. *IEEE Transactions on Engineering Management*, 1–18.

Ulmer, R.R., Sellnow, T.L., and Seeger, M.W. (2011) *Effective Crisis Communication. Moving From Crisis to Opportunity*, 2nd edn. Thousand Oaks, CA: SAGE Publications Ltd.

Van der Meide, P.H. and Schellekens, H. (1996) Cytokines and the immune response. *Biotherapy*, **8**, 3–4, 243–249.

Wang, H. and Ma, S. (2008) The cytokine storm and factors determining the sequence and severity of organ dysfunction in multiple organ dysfunction syndrome. *The American Journal of Emergency Medicine*, **26**, 6, 711–715.

Webster, E. and Jensen, P.H. (2011) Do Patents Matter for Commercialization? *The Journal of Law & Economics*, **54**, 2, 431–453.

Weibel, B. and Freytag, R. (2019) Why Digitalization Needs Value-Driven Intellectual Property Strategies. *les Nouvelles – Journal of the Licensing Executives Society*, **54**, 4, 268–273.

Wurzer, A.J., Grünewald, T., and Berres, W. (2016) *Die 360° IP-Strategie. So sichern Sie Ihren Innovationserfolg langfristig [The 360° IP Strategy. How to Secure Long-Term Innovation Success]*. Munich: Verlag Franz Vahlen GmbH.

Ye, Q., Wang, B., and Mao, J. (2020) The pathogenesis and treatment of the 'Cytokine Storm' in COVID-19. *Journal of Infection*, **80**, 6, 607–613.

Yin, R.K. (2018) *Case Study Research Design and Methods*, 6th edn. Thousand Oaks, CA: SAGE Publications Ltd.

Yuen, K.Y. and Wong, S.S.Y. (2005) Human infection by avian influenza A H5N1. *Hong Kong Medical Journal*, **11**, 3, 189–199.

Zervas, G., Proserpio, D., and Byers, J.W. (2017) The Rise of the Sharing Economy: Estimating the Impact of Airbnb on the Hotel Industry. *Journal of Marketing Research*, **54**, 5, 687–705.

Zhang, S. (2020, April 8) The Best Hopes for a Coronavirus Drug. *The Atlantic*. https://www.theatlantic.com/science/archive/2020/04/what-coronavirus-drug-will-look-like/609661/, accessed May 11, 2020.

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APPENDIX

Technology Relevance measures the number of forward citations patents receive from subsequent patents, corrected for three issues commonly impeding the usefulness of patent citations, namely patent ages, different citation propensities in different technology fields, and different citation propensities amongst different patent offices (Ernst and Omland, 2011).

The two derivative patent indicators to this patent indicator, i.e., Internal Technology Relevance and External Technology Relevance, are calculated in the same manner. However, for the Internal Technology Relevance, only citations that stem from patents belonging to the same owner are considered. In contrast, for the External Technology Relevance, only citations that stem from patents belonging to third-party patents, i.e., patents not owned by the same owner as the focal patent, are considered. Herein, it becomes possible to disentangle citations from the same portfolio of third-party citations while continuing to account for the issues impeding general forward citations patents receive. Further, it requires the consideration of ownership structures in defining complete patent portfolios as a prerequisite (e.g., Buehler et al., 2017; Guderian, 2019).

Referring to patents as territorial rights, the Market Coverage refers to the sum of the gross domestic product of all countries where member documents of a patent family are protected or pending relative to the gross domestic product of the United States of America as the largest world economy (Ernst and Omland, 2011). Contrasting measures of patent family sizes that simply sum the number of countries, the Market Coverage allows to consider differences in market sizes of the geographical scope of protection (e.g., Harhoff et al., 2003; Ernst and Omland, 2011; Fischer and Leidinger, 2014).

Competitive Impact refers to the product of patents' Technology Relevance and Market Coverage values, thereby representing their business value (Ernst and Omland, 2011). Combining patents' forward citations with the size of the markets where the patents are protected, allows an assessment of their quality; high-quality patents require both: impacts as prior art to subsequent patents as well as broad protection scopes given that patents are territorial rights that can only be enforced in markets where the patents have been established. The portfolio size refers to the number of patent families selected in the filter query. In the first three case studies, this refers to the number of patent families owned by all the firms that are a part of the corporate trees of Adidas and CureVac, i.e., their respective parent entity, subsidiaries, and subsidiaries' subsidiaries. For the fourth case study, this refers to the number of patent families identified using the Coronaviridae virus searches, irrespective of their owners.

Patent Asset Index is the sum of the Competitive Impact values of all patents constituting portfolios such as the aforementioned portfolios of Adidas, CureVac, and Coronaviridae virus (Ernst and Omland, 2011). Consequently, dividing the Patent Asset Index by the portfolio size for a selected patent portfolio yields the portfolio's Average Competitive Impact, i.e., the average quality of the patents belonging to this portfolio as measured by the Competitive Impact.