Technological exaptation and crisis management: Evidence from COVID-19 outbreaks

Lorenzo Ardito\textsuperscript{1,2,*}, Mario Coccia\textsuperscript{3} and Antonio Messeni Petruzzelli\textsuperscript{4}

\textsuperscript{1}Department of Mechanics, Mathematics and Management, Polytechnic University of Bari, Via E. Orabona, Bari, 4-70125, Italy.
\textsuperscript{2}Institute for Innovation and Entrepreneurship, Mount Royal University, 4825 Mt Royal Cir SW, Calgary, AB T3E 6K6, Canada. lorenzo.ardito@poliba.it
\textsuperscript{3}Research Institute on Sustainable Economic Growth, CNR – National Research Council of Italy, Collegio Carlo Alberto, Via Real Collegio, Moncalieri, Torino, 30-10024, Italy. mario.coccia@cnr.it
\textsuperscript{4}Department of Mechanics, Mathematics and Management, Polytechnic University of Bari, Via E. Orabona, Bari, 4-70125, Italy. antonio.messenipetruzzelli@poliba.it

One of the key issues in the field of technology analysis and innovation management is how new technologies origin and evolve in the presence of environmental threats. We confront this problem focusing on emerging innovative solutions to cope with unexpected and harmful problems posed by crises and needing a rapid, effective response. We specifically analyze the patterns of critical innovations to cope with new coronavirus disease (COVID-19) that is generating public health and economic issues worldwide. Accordingly, in the context of the theory of technological exaptation, we adopted a narrative approach examining vital innovations that ended up treating COVID-19 even though they were originated to treat other diseases (more or less distant from the COVID-19 domain), as the antiviral drug Remdesivir and the antirheumatoid arthritis drug Tocilizumab. Results reveal that technological exaptation, especially if characterized by a longer exaptive distance, is a potential driving force of innovation to cope with COVID-19 in the short-term and other similar issues. On this basis, we provide propositions for a more general crisis model of innovation. This study adds a new perspective that may be helpful to explain the evolution of innovation in the presence of crises, considering technological exaptation in a context of environmental threats.

\textbf{1. Introduction}

One of the fundamental questions in the field of economics and management of technological innovation is how new technological solutions origin and evolve in society (Arthur, 2009; Coccia and Watts, 2020). A particular issue in this research field is the evolution of innovation in the presence of problems originating from harmful and unexpected events beyond more conventional (albeit potentially turbulent/disruptive) economic/market dynamics – i.e., crises – which have to be solved in a limited amount
of time to minimize possible losses for a worst-case scenario. Despite the urgency and unexpectedness of the crisis, it is very unlikely that its generated problems will be solved by an ad hoc action, hence, requiring systematic planning and coordination, that is, crisis management (Pearson and Clair, 1998; James et al., 2011), where innovation is a vital element (Laperche et al., 2011; Bessant et al., 2015).

The recent public health and socioeconomic issues created by the Coronavirus Disease 2019 (COVID-19) global pandemic crisis fall into the on-going debate. However, in contrast with the systematic nature of crisis management (Coombs, 2015), innovative activities aimed at addressing COVID-19 are often performed with improvisation and without a strategic plan to innovate in time of crisis. Consequently, some relevant questions are still unanswered after many months the crisis is active (Azoulay and Jones, 2020) – e.g., how do we achieve these solutions [effective vaccines, new therapies, or other solutions] quickly? What principles should guide management of innovation strategy to cope with COVID-19?

That is, despite the relative infrequency of crises, the COVID-19 pandemic (among others) has stressed the need of crisis models of (problem-driven) innovation, which appear to be still absent or underdeveloped in the literature (Azoulay and Jones, 2020; Chesbrough, 2020). Therefore, the goal of the study here is to explain, whenever possible, what may support problem-driven innovation in the presence of crisis, such as COVID-19 pandemic, at least for the short term. In a context with the number of crisis predicted to increase, based on the theory of technological exaptation (Andriani and Cohen, 2013), we analyze this problem and seek to provide general propositions that may guide innovation processes when a crisis occurs, offering firms/policymakers insights on how to better direct innovation efforts to manage crises.

The development of this study is based on a narrative approach à la Garud et al. (2016) focused on two different drugs as case studies: Remdesivir and Tocilizumab. We propose a crisis model of innovation, for the short term, focused on technological exaptation to explain how effective solutions are due to exaptive innovation from moderate-to-distant source domains to destination domains.

2. Theoretical framework

2.1. Problem-driven innovation for crisis management

Crisis management can be defined as ‘a set of factors designed [i.e., a systematic attempt] to combat crises and to lessen the actual damage inflicted by a crisis’ that entails three sets of actions, namely (i) prevention and preparation before a crisis (when possible), (ii) response during the crisis, and (iii) learning and revision after the crisis (Coombs, 2015). Against this backdrop, we claim that some technological innovations are the outcome of specific problem-solving activity (Coccia, 2017), and crises often generate complex problems that need to be solved through new technological solutions within a crisis management framework, that is, through a systematic crisis model of innovation (Pearson and Clair, 1998; Pedersen et al., 2020).

Specifically, factors requiring a critical model of innovation are usually: (a) a threat to the organization and/or society, (b) the element of surprise, (c) a short decision time to cope with environmental threats (Groh, 2014). If organizations/policymakers do not decide timely a solution to crisis-induced problems, and sources of risk are left unaddressed, they can permanently damage firms, organizations, and population with consequent socioeconomic and health problems. Thus, a critical model of innovation is mainly problem-driven, with the implicit assumption that the problem can be solved. In fact, scholars show that new problems are the basis for new technologies and innovations (Coccia, 2017). However, in contexts of crisis management with problems to be solved in a limited amount of time, it is reasonable to assume that problem-driven innovations cannot be the result of conventional innovation processes, which are long, expensive in R&D, and especially not adapted to respond to critical and unforeseen conditions (Cankurtaran and Beverland, 2020). Still, although relevant crises have hit our society only in the last two decades (e.g., Ebola epidemic, September 11 attacks in 2001, 2008 financial crisis, etc.), crisis models of innovation have yet to be defined, except for some recent attempts because of the COVID-19 pandemic (Chesbrough, 2020). Consequently, when crises occur, many technological options emerge under environmental pressure with rationality and/or improvisation (e.g., Scheiner et al., 2015), thus, leading to poor decisions by organizations/governments and wrong/suboptimal solutions to crisis-induced problems.

In this context, we suggest that technological exaptation can be one of the approaches to innovate within a crisis management framework, especially in the short term.

2.2. Exaptation and exaptive distance

Dew and Sarasvathy (2016, p. 167) state that ‘[e]xaptation draws our attention to the repurposing of
artifacts, technologies, processes, skills, organizations, and resources for emergent uses that they were not (initially) designed for. As a result of exaptation, innovation often occurs. The current literature provides many examples in this sense. For instance, Envoid, originally developed for treatments of gynecologic disorders, was also used for contraception given its side effect of allowing controlling fertility, discovered by chance. Likewise, Marsilid was an antituberculosis drug with the unknown side effect of making people happy; it was afterward used as antidepressant once the side effect was accidentally discovered.

A key aspect related to innovations resulting from exaptation is, among others, that such innovations emerge without starting an innovation project from scratch since part of the work has already been done and ‘only’ needs development in new domains, hence, benefiting short-term responses. This approach recalls the idea that innovative opportunities emerge through a recombinant search of existing and novel components (Savino et al., 2017). This approach has a connection with analogical thinking and Kauffman’s theoretical concept of the ‘adjacent possible’ that consists of all those ‘things’ (e.g., ideas, molecules, genomes, technological products, etc.) that are one step away from what actually exists, and hence, can arise from modification and recombination of existing material, also to solve problems not intended to be solved initially (Tria et al., 2014). Every time a novelty occurs, the adjacent possible expands. In this research field, technological exaptation is an underexplored mechanism of innovation generation, and exaptive innovations are the outcomes of a different search mechanism and problem-solving approach from deliberate innovation (Andriani et al., 2017).

The concepts of exaptation and recombinant search across the ‘adjacent possible’ through analogical thinking bring with them the notion of distance (Andriani et al., 2017; Savino et al., 2017) between the source domain and the destination domain of a technology after exaptation (hereafter, exaptive distance). The following definitions are crucial elements of the theoretical framework of this study here. Exaptive space is the structure in which an element (e.g., a product/technology) and other inter-related elements of environment develop. Exaptive distance is, for an element in the exaptive space, the extent to which the source domain is close to or far away from a destination domain. That is, the exaptive distance is a generalization in the exaptive space for describing the similarity and/or dissimilarity of the application of a current technology from a source domain to a destination domain. Particularly, when the source domain of a technology is far away from the destination domain (i.e., there is a relevant dissimilarity between domains) one could talk of long exaptive distance (e.g., Marsilid drug originated in virology and applied in psychiatry). Conversely, short exaptive distance is when the source domain is close to destination domain (e.g., Envoid originated for gynecologic disorders and applied in gynecology with another function given by controlling fertility). Figure 1 depicts a general representation of the concept of exaptive distance within an exaptive space. This concept is important because the distance between initial and destination domains may have relevant effects on dynamics of innovation processes and technological trajectories since linking distant domains requires more efforts but, at the same time, may lead to more creative and innovative solutions of problems for which there is no basis to start or scant improvement possibilities in the problem-domain (Carnabuci and Operti, 2013). Andriani et al. (2017) noticed that nearly all the exaptive radical innovations they studied have an origin in areas very distant from the current one. In our terms, Andriani et al. (2017) noted that more radical exaptive innovations origin from technological pieces with a long exaptive distance.

Herein, we argue that in a context of crisis management existing innovations/technologies, resulting from problems unrelated to those posed by a crisis, may be exapted through processes of recombinant search, leading to new (tentative) innovative solutions that address new and unrelated problems posed by the crisis. In this context, we endeavor to explore the role that exaptive distance may have in the generation of exaptive innovations for managing crises, with particular regard to the COVID-19 pandemic. Understanding the process of (short-term) innovation in the presence of crisis management can provide main theoretically breakthroughs to explain crisis models of innovation and support appropriate strategies and innovation policies for coping with emergencies and for reducing health and socioeconomic issues in nations.

3. Study design

3.1. Research setting

The research setting for this study is the COVID-19 pandemic, a viral infection that is generating a severe acute respiratory syndrome with serious pneumonia to manifold people worldwide that may result in progressive respiratory failure and death (Coccia, 2020). To reduce the number of total deaths and infected individuals,
many countries have accelerated the scientific research production generating new knowledge about this new infectious disease. This on-going accumulation of knowledge, based on an accelerated velocity of scientific production driven by COVID-19 pandemic, is due to a combination of systematic research in labs and creative imagination that can generate a potential innovations and technologies to cope with negative effects of COVID-19 before effective vaccines, new therapies, and new antiviral drugs can counteract this global public health threat (Coccia, 2020).

3.2. Narrative perspective as a method of inquiry

The narrative approach is an appropriate method to analyze the evolution of technology with technological exaptation (Garud et al., 2016; Beltagui et al., 2020). Garud et al. (2016, p. 16) argue that: ‘by drawing upon the past that is familiar to potential users, projective narratives depict future possibilities in a manner that is comprehensible’. In this approach, it possible to visualize new applications for preexisting technologies in emerging contexts of crisis, reactivating some technologies and previous ideas. This approach is appropriate to analyze manifold sources of technological exaptation that generate different uses of existing innovation, the co-optation of innovation not yet in use, and the co-option because of accidental elements of discovery. Most narrative studies focus on historical analysis of one or two cases to derive valuable theoretical and practical implications (e.g., Ansari et al., 2016).

3.3. Case study here

In this study, the narrative approach is applied to analyze two critical drugs, that is, our case studies: (i) Remdesivir, which is a broad-spectrum antiviral medication and (ii) Tocilizumab, which is an immunsuppressive drug, mainly for the treatment of rheumatoid arthritis (RA). These were selected for three main reasons. First, they are drugs not supposed to be used to treat COVID-19; hence, they are exaptive innovations. Second, they pertain to different domains, one close and one distant to the COVID-19 (see Section 4 for more details), hence, allowing us to analyze the role of exaptive distance. Third, they are the first applications of solutions exapted for treating patients with severe COVID-19, hence, letting us examine what happened in the short-term and build a narrative story presenting indications of the effectiveness of these solutions in the new domain of application.

3.4. Data sources and data analysis procedure

Case studies are narrated mainly using secondary data, which play more and more a vital role in scientific research. Secondary data of cases study are investigated in terms of chronologies of relevant events for the development of innovative drug applications to cope with COVID-19 crisis. Following Ansari et al. (2016), a narrative for technology analysis of our case studies is based on a range of secondary data sources given by different articles in
relevant journals, such as Autoimmunity Reviews, Blood, Journal of Translational Medicine, Nature, Proceedings of the National Academy of Sciences, Scientific Reports. In particular, information and dates from these different sources of journals, in a historical perspective, are described in narrative and represented a chronology of major events of drugs investigated, from which intertwined past, present, and future notions are analyzed to suggest general prepositions of technological exaptation in a context of crisis management. For instance, Tocilizumab is investigated starting from the discovery of Interleukin 6 (1980s), through the development of Tocilizumab by Chugai Pharmaceuticals in 1997 and applications for Castleman’s disease by Nishimoto et al. (2007), to the treatment of COVID-19 in China (Fu et al., 2020). The underlying mechanisms of the technological exaptation in the cases studied here reflect the use of inventive analogies in the development of these innovative drugs in the presence of the COVID-19 pandemic crisis because analogies can be helpful to support innovative solutions in the presence of environmental threats. In short, the role of innovative analogies is critical to generate innovations that solve complex problems (Bonnardel, 2000).

4. Findings of the technological exaptation in COVID-19

4.1. Remdesivir, antiviral drug

West African Ebola virus epidemic of 2013–2016 caused a lot of deaths and socioeconomic issues in many African regions. Remdesivir is a broad-spectrum antiviral drug that was originally investigated as a treatment for Ebola virus. The antiviral medication of Remdesivir is developed by Gilead Sciences, an American biopharmaceutical company headquartered in California. In October 2015, the United States Army Medical Research Institute of Infectious Diseases announced preclinical results that Remdesivir had blocked the Ebola virus in Rhesus monkeys (Warren et al., 2016). Scholars subsequently discovered that Remdesivir had antiviral activity in vitro against multiple filoviruses, pneumoviruses, paramyxoviruses, and coronaviruses (Lo et al., 2017). Thus, it was used in the emergency of the Kivu Ebola epidemic that started on August 2018, in the eastern region of Kivu in the Democratic Republic of the Congo but clinical trials until August 2019 suggested that Remdesivir is significantly less effective than another monoclonal antibody treatment. In January 2020, in the presence of COVID-19 pandemic crisis in China, as there was not drugs to treat this novel coronavirus, the antiviral Remdesivir was also tested against SARS-CoV-2, because this drug was active against previous Severe Acute Respiratory Syndrome (SARS-CoV) and Middle East Respiratory Syndrome (MERS-CoV) in animal models (de Wit et al., 2020). However, in a clinical trial of China over February-March 2020, Remdesivir was not effective for the improvement of patients from COVID-19 and caused various side effects (Wang et al., 2020). Instead, in March 2020, a small trial of Remdesivir in rhesus macaque monkeys with COVID-19 found that it prevents disease progression. A controlled trial carried out by the U.S. National Institutes of Health suggests that Remdesivir can reduce the recovery time from 15 to 10 days in people seriously ill with COVID-19 (Wang et al., 2020), however, resulting far from being a fully comprehensive solution to COVID-19. This may be explained by the fact that Remdesivir is not able to expand its medical effectiveness further within its (strict) domain of application (i.e., treating other viruses beyond the viruses it can treat), thus, calling for solutions that are either specifically devoted to treat COVID-19 (that do not exist and cannot be developed in the short term) or supposed to treat other pathologies but – for whatever reason – hinder/cure COVID-19 anyway. Stated differently, we can argue that Remdesivir – just like any other drugs in the domains of virology – has reached a technological lock-in, whereby further effective recombination opportunities to solve new problems in the domain of virology (local search) are unlikely to happen (Carnabuci and Operti, 2013). Figure 2 shows the timeline of the evolution of Remdesivir and exaptation timing in 2020 because of COVID-19 outbreak worldwide.

4.2. Tocilizumab from treatments of rheumatoid arthritis

One of the health issues in society is rheumatoid arthritis (RA): a chronic inflammatory disorder in which the body’s immune system attacks its joints, and it is one of the most common autoimmune diseases (Cooper and Stroehla, 2003). In this context, Interleukin 6 (IL-6) is a cytokine that plays an important role in immune response and is implicated in the pathogenesis of many diseases, such as autoimmune diseases like RA. Interleukin 6 and its receptor are discovered and cloned by Kishimoto in the 1980s. In 1997, to treat RA, Chugai Pharmaceuticals began the clinical development of Tocilizumab: a humanized
monoclonal antibody against the IL-6 receptor. Since its approval, Tocilizumab has mainly been used as an immunosuppressive drug for the treatment of RA. In 2005, Tocilizumab started to be tested for Castleman's disease in Japan, a rare benign tumor of B cells for which no cure existed in the oncology domain. After the first study regarding Tocilizumab use in Castleman's disease by Nishimoto in 2005, it was found out that Tocilizumab was effective for patients with HIV-negative/HHV-8-negative Multicentric Castleman Disease (fever and fatigue resolved immediately after Tocilizumab administration, and laboratory markers, such as hemoglobin, albumin, started to improve within a few days). However, recurrence of the disease was reported 2 weeks after therapy cessation. In 2007, Nishimoto et al. (2007) published an extension of the previous study, in which they examined the efficacy and safety of Tocilizumab in a long-term, >5 years, follow-up. Tocilizumab was administered to 35 patients and the effect of Tocilizumab on lymphadenopathy, constitutional symptoms, and laboratory markers was sustained. In sum, Tocilizumab was (effectively) exapted to treat a disease that is different from the disease it historically treated (RA) and for which (conventional) innovation projects were run. In other words, Castleman's disease in Japan was an emerging problem to be solved (as soon as possible) but launching new R&D projects would have not allowed addressing the issue in the short term. Thus, ‘someone’ came up with the solution of applying something already existing to solve a former problem (i.e., Tocilizumab) to solve the new problem.

More recently, this drug was also discovered to have a high potential to treat different diseases with unclear pathophysiology. In particular, scholars identify in patients with COVID-19 that pathogenic T cells and inflammatory monocytes incite inflammatory storm with a large amount of Interleukin 6, that is, IL-6 that impedes alveolar gas exchange and contributes to the high mortality (Fu et al., 2020). Tocilizumab, as said, is an innovative humanized monoclonal antibody against the IL-6 receptor. In the absence of vaccines and appropriate drugs for the treatment of the novel Coronavirus Disease (COVID-19), in a context of crisis management, scholars had the idea, in a perspective of analogical thinking, to apply Tocilizumab to target the IL-6 pathways and likely curb inflammatory storm created by SARS-CoV-2, reducing the respiratory disorders and mortality of patients affects by COVID-19. Consequently, in the presence of COVID-19 outbreak started in China, Tocilizumab once more started to move toward an exaptive space (from source domain of RA to destination domain of new infectious diseases) to treat individuals having the novel Coronavirus (beginning of 2020, Alzghari and Acuña, 2020). Tocilizumab treatment, blocking IL-6 receptors, shows inspiring clinical results including the reduction of temperature quickly and improvement of respiratory function.
Thus, (again) Tocilizumab has been exapted to solve a (second) problem different from the one underlying its initial R&D. The drivers of exaptation here are due to high mortality of COVID-19 that stimulates a problem-driven innovation for advancing novel therapeutic development in a crucial moment of crisis management, yet, by avoiding starting R&D activities from scratch (i.e., by adopting existing approved drugs, as Tocilizumab, to solve or, at least, attenuate the crisis in the short term). On March 2020, Tocilizumab appeared to be effective in severe cases of COVID-19 in Italy: three of the six treated patients in Naples (Italy) had shown signs of improvement prompting the Italian Pharmacological Agency to expand testing in five other hospitals. Roche and the WHO are each launching separate trials for its use in severe COVID-19 cases. Meleveedu et al. (2020) show that anti-IL-6/IL-6-R therapy can be effective in managing early cytokine release syndrome related to COVID-19: clinical responses to anti-IL-6/IL-6-R therapy were accompanied by significant decreases in temperature, oxygen requirement, C-reactive protein, IL-6, and IL-10 levels. Finally, this study based on Tocilizumab for severe COVID-19-related illness shows that 87% of patients are alive and 24 (77%) have been discharged from the hospital.

In sum, Tocilizumab was subject to analogical search paths, which are aimed at getting advantage from a recombinant search approach to innovation and involve ‘structural comparison between a base and a target domain (often with unrelated content)’ (Lopez-Vega et al., 2016, p. 127). Indeed, applying an existing solution that spans domains can provide new insights to solve newly posed problems for which prior (related) knowledge is not sufficient to address it, at least in the short-term (Carnabuci and Operti, 2013). In this context, technological exaptation of Tocilizumab, in the presence of the COVID-19 global pandemic crisis, is driven by an inventive analogy to solve respiratory disorders and other problems created by SARS-CoV-2.

Figure 3 shows the timeline of the evolution of Tocilizumab and exaptation timing in 2020 because of COVID-19 outbreak worldwide (Guo et al., 2020).

From these case studies, we may conclude that both drugs have followed an exaptation process, as they originated to treat specific diseases and ended up treating the COVID-19. Still, Remdesivir cannot be considered a potential full solution to COVID-19 as compared to Tocilizumab or, at least, Remdesivir has been proven to be less effective than Tocilizumab since it does not well treat the diseases but (just) provides advantages in terms of recovery time (albeit Remdesivir represent a partial solution to the COVID-19 anyway). By analyzing what differs among the two drugs in explaining their performance outcomes, in addition to the purely medical issues, one could recognize that their exaptive distance from the treatment of COVID-19 is different. Indeed, Remdesivir started from Ebola (source domain) and arrived in novel Coronavirus (destination domain): both diseases originate from viruses, hence, in the domain of virology. Instead, Tocilizumab started from RA (source domain) and arrived in novel

Figure 3. Timeline of Tocilizumab from 1997 to 2020.
Coronavirus (destination domain): these diseases pertaining to different domains (rheumatology and virology, respectively). Thus, the exaptive distance for the Remdesivir case is shorter than Tocilizumab one. That is, the advantages of pursuing a recombinant search approach to innovation spanning domains in the context of technological exaptation has paid off. Figure 4 shows the location of these drugs in the exaptive space according to exaptive distance from source domain to destination domain of treatments for COVID-19.

Following the foregoing discussion, findings can be systematized in the following two propositions:

**Proposition 1:** In the presence of crisis management, models of innovation are driven by exaptation in order to provide a rapid solution to a critical problem in the short term, avoiding launching long and expensive R&D projects from scratch.

**Proposition 2:** In the presence of crisis management, models of innovation based on exaptation are likely to be more effective when the exaptive distance is longer.

5. Discussion

Through a narrative approach focusing on two case studies, this study suggests that exaptation is a pivotal driver of innovation in crisis management. Specifically, we contend that, at least in the short term, crisis models for innovation should be based on technological exaptation. This result mirrors previous findings arguing that learning about a technology developed in a base domain (specialty) is important to solve problems in other different destination domains (specialties) of adjacent spaces (with a longer or shorter distance) that generated exaptation and evolution of technology (Coccia and Watts, 2020). Moreover, the study proposes that a longer exaptive distance may guide innovative solution and technological trajectories in addressing a new problem in time of crisis. This result may occur because a longer exaptive distance provides benefits in terms of reduction of cognitive myopia, expands the search space, promotes more creative problem-solving processes and analogical thinking (Carnabuci and Operti, 2013; Lopez-Vega et al., 2016), and hence, favors the identification/development of solutions to newly posed problems for which scant knowledge about it exists in the problem domain. Plus, if within the crisis domain (e.g., COVID-19 crisis) nothing can be effectively applied to solve crises-induced problems, it is likely required the search and application, per analogy, of (existing) solutions originated in other domains to better cope with emergency in the short-term (e.g., Tocilizumab is more promising than Remdesivir). Relatedly, it emerges that the process of technological adaptation of the exaptive solution from source to the destination domain comes with the need of learning processes that support the evolution of the innovative solution, especially if the exaptive distance is longer. For instance, in the case of Tocilizumab, the transition phase from the initial domain of RA to destination domain of novel Coronavirus disease requires finding the correct

![Figure 4. Type of exaptation considering distance from source domain to destination domain in the exaptive space of innovative drugs Tocilizumab (long distance: between domains, green arrow) and Remdesivir (short distance: within domain, orange arrow). [Colour figure can be viewed at wileyonlinelibrary.com]](image-url)
dosage regimen and timing of treatment and monitor possible side effects that can lead to incremental innovation during the process of exaptation for a fruitful direction of problem-driven technological trajectories. Until now, studies show that is less evident for Remdesivir, albeit not totally avoided in the long run with a pathway of incremental innovations driven by learning processes to cope with COVID-19. Thereby, even though new and expensive R&D projects have been circumvented due to the rapid diffusion of COVID-19, the process of exaptation of Tocilizumab, and at a lesser extent of Remdesivir, still needs a learning process for suggesting better solutions to treat new viral agents.

5.1. Theoretical implications

The theoretical implications of these findings are threefold. First, we add to the literature on management of innovation, by delving into and proposing insights on critical models of innovation in crisis management driven by new problems and technological exaptation. Indeed, on one side, innovators (ranging from individuals to broader ecosystems) ‘have to recognize the potential of new technologies at an early phase under conditions of uncertainty and incomplete knowledge’ (Scheiner et al., 2015, p. 113). On the other side, general insights/approaches to be adopted to innovate under emergency situations are poor since innovation in time of crisis is an understudied topic in the wide stream of literature of innovation management (Chesbrough, 2020). Second, we contribute to the emerging literature stream of technological exaptation by highlighting and formally defining the concept of exaptive distance in technological space between source and destination domains (Andriani and Cattani, 2016). Moreover, we underline that the process of exaptation is nested in rich learning processes that support the evolution of technology from the initial domain to the space of adjacent possible, maybe following a trajectory that would have not been taken otherwise. Finally, we contribute to the literature on crisis management by considering wider health-based crisis and crisis models of innovation, which have been neglected by the prior literature on crisis management due to its prominent focus on risk prevention/assessment, the effect of crisis on business performance, financial-based crises, and crises mainly pertaining and addressed by a single organization (Mora Cortez and Johnston, 2020). This gains relevance when considering the increasing complexity and globalization of current organizational structures, technological systems, and societies, which enhance the susceptibility to crises and to the problems that crises generate (Rosenthal and Kouzmin, 1997). In this context, crisis management has been advocated as a mean to address crises (Pearson and Clair, 1998; James et al., 2011).

5.2. Managerial implications

From a managerial perspective, our study suggests that in crisis management, a first step before or while setting ex novo R&D projects can be devoting efforts to search, per analogy, for potential applications of existing innovations to the crisis-induced problems whatever the source domain of the existing solution could be. Still, efforts for sourcing solutions from domains with a longer exaptive distance than problem posed by the crisis may be preferred to generate innovation. This may be done, on the one hand, by stimulating/training people to think outside of the box and, on the other hand, through specific calls for creative ideas, funding opportunities, and/or the creation of platforms for idea-sharing. This study shows that in the presence of global COVID-19 pandemic crisis, organizational and managerial behavior can be more and more directed toward flexibility, focusing on aspects of agility to cope dynamically with turbulent (uncertainty and complexity) environments and consequential problems (Evans and Bahrami, 2020). Technological exaptation can be a main element of the agility in organization and governance of vital actors to adapt to unforeseen changes suggesting timely and rapid solutions to constrain negative effects of COVID-19 pandemic (Janssen and van der Voort, 2020). In short, agility of organizations can use technological exaptation as one of the main elements of flexibility to adapt to turbulence in order to cope with uncertain, new or relatively unexplored problems that continually emerge and have to solved in COVID-19 crisis with the speed and timing of decision-making (Janssen and van der Voort, 2020). Furthermore, we advise that exaptation comes with different, and maybe unexpected ways of learning opportunities. Still, the main mechanism of innovation model in crisis management, can be generalized with an approach of analogy aimed at pursuing a recombinant search approach. Analogies are a main cognitive mechanism that people and organizations may use for a variety of learning purposes, as in the case of unsolved problems in unrelated domains, in a context of crisis management.

6. Concluding remarks and limitations

Good ideas can come from anywhere, making technological exaptation relevant to cope with the COVID-19 pandemic. Searching for existing solutions, even
from distant domains, for which there may be a collateral application to manage this crisis will likely speed up finding further innovative solutions to the crisis-induced problems by allowing taking advantage of available and more established knowledge. In this perspective, time, costs, and unpredictability of innovation processes are likely to diminish, in turn favoring the adoption of a more effective crisis model of innovation for the COVID-19 pandemic. Still, we claim the proposed model may be generic in nature, thus, of interest for other crises, not necessarily health-based ones. Since crises are likely to become more prolific and severe over time, we eventually believe our findings constitute a relevant starting point for future crisis models of innovation in time of crisis.

Notwithstanding, we acknowledge these conclusions are tentative in that the COVID-19 pandemic is still ongoing. Accordingly, sources may be incomplete, or only capture certain aspects of the ongoing dynamics of technological innovation; there is need for much more research into the relations between patterns of innovations and situation of crisis management to explain the relationships underlying the evolution of technology over time and space. The narrative approach applied here for some critical innovations in the presence of COVID-19 outbreak has the purpose of creating new insights to be, however, further verified and compared with other settings for generalizability purposes. This study, therefore, develops specific concepts, such as exaptive distance to stimulate future research on explaining new relations supporting the evolution of technology based on exaptation in turbulent markets with crisis management. Finally, as Beltagui et al. (2020) highlight, the narrative method is, by its nature, interpretive in its approach and it may favor one interpretation while suppressing others. While acknowledging this limitation, we also underline that, in certain circumstances, as the case of real-time crisis, this one of the few ways to conduct research given the absence or integrity of secondary data and the difficulty to attain permission and access to people involved in the crisis management.

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Note

1Scientific specialty, within a discipline, includes a set of scientists that perform research along similar lines. In any specialty there will be a class of problems that is permissible to be solved with current theory and methods, and a much larger class that is impermissible.

Lorenzo Ardito is an Assistant Professor of Technology and Innovation Management at the Politecnico di Bari, also qualified to the position of Associate Professor according to the Italian Ministry of Education, Universities and Research. He is an External Fellow at the Mount Royal University and has been visiting PhD candidate at the WHU-Otto Beisheim School of Management. His main research interests concern innovation management, sustainable development, and digital transformation. His studies on these topics are made in collaboration with scholars worldwide and have been published in leading international journals – e.g., Journal of Product Innovation Management, Journal of Business Research, Technological Forecasting and Social Change, R&D Management, Technovation. He leads the CocciaLAB at the CNR to investigate, with interdisciplinary scientific approaches, the determinants of socioeconomic phenomena associated with economic growth and wellbeing of people. He has written extensively on Economics of Innovation, Long Waves, Management of Technology, R&D Management, History of Technology. His research publications include more than three hundred papers in several disciplines.

Mario Coccia is a social scientist at the National Research Council of Italy (CNR) and visiting scholar at YALE University School of medicine. He has been research fellow at the Max Planck Institute of Economics and visiting professor at the Polytechnics of Torino and University of Piemonte Orientale (Italy). He has conducted research work at the Georgia Institute of Technology, United Nations University-Maastricht Economic and Social Research Institute on Innovation and Technology (UNU-MERIT), RAND Corporation (Washington D.C.), University of Maryland (College Park), Bureau d’Économie Théorique et Appliquée (Strasbourg), Munk School of Global Affairs (University of Toronto), and Institute for Science and Technology Studies (University of Bielefeld). He leads the CocciaLAB at the CNR to investigate, with interdisciplinary scientific approaches, the determinants of socioeconomic phenomena associated with economic growth and wellbeing of people. He has written extensively on Economics of Innovation, Long Waves, Management of Technology, R&D Management, History of Technology. His research publications include more than three hundred papers in several disciplines.

Antonio Messeni Petruzzelli is Associate Professor of Innovation Management and founder of the Innovation-Management Group at the Politecnico di Bari. He currently serves also as visiting professor and member of the advisory board of the Digital Leadership Research Centre of Cass Business School. Prof. Messeni Petruzzelli is the author of more than 100 international publications and three international books on the topic of innovation management and technology strategy. His studies have been published in leading journals such as Research Policy, Entrepreneurship Theory & Practice, Academy of Management Perspectives, Journal of Management, International Journal of Management Reviews, Journal of World Business, and Long Range Planning. He belongs to the editorial team of Journal of Knowledge Management and Technological Forecasting and Social Change. Finally, his studies have been awarded the Nokia Siemens Network Award in Technology Management for Innovation into the Future.