Repurposing without purpose? Early innovation responses to the COVID-19 crisis: Evidence from clinical trials

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The novel coronavirus has created one of the biggest social and economic challenges in recent decades. Since a critical issue in overcoming a large-scale pandemic involves finding effective treatments for the disease, there is typically urgent pressure on the health-care sector to develop innovations to combat the pandemic. Recently, scholars have argued that repurposing – that is, reusing an existing innovation in a different context – allows for such rapid innovation responses and can reduce costs, as the groundwork has already been laid. In this paper, we compare these benefits with the considerable disadvantages associated with innovation repurposing, including lowered barriers to entry, which can lead to declining average quality and duplicate work. Using data on 2,456 COVID-19-related clinical trials initiated between December 2019 and July 2020, we find that merely one-third of the trials actually investigated drugs or vaccines, whereas the rest focused on diagnostics and crisis management issues. In the trials concerning drug testing, we find that drug repurposing is a predominant innovation strategy, but many trials tested the same (combination of) drugs. This indicates an inefficient use of resources and reductions in the average variety and novelty of clinical trials. Furthermore, the small percentage of biopharmaceutical firms involved in the search for COVID-19 treatments raises the question of whether firms may have insufficient incentives to redirect innovation efforts to respond to the pandemic. Our paper contributes to crisis management research, the nascent debate on COVID-19, and the emerging literature on innovation repurposing.

1. Introduction

The COVID-19 pandemic that started in early 2020 has created major social and economic problems as well as an urgent innovation challenge (Chesbrough, 2020; Wenzel et al., 2021). Due to protective measures imposed by governments around the world, many areas of public and economic life were severely restricted (Pereira et al., 2020). In doing so, most governments were striving to balance the threat of overburdening their health-care systems against the individual and economic freedoms they constrain. A critical part of overcoming the pandemic involves developing an effective drug or vaccine that cures or protects against COVID-19 (Dhama et al., 2020). This is reflected in high expectations on the
part of the health-care sector to quickly develop appropriate treatments (Baden and Rubin, 2020). From a managerial perspective, the COVID-19 pandemic represents a crucial innovation challenge for the health-care sector, which is called upon to respond to the crisis with effective, innovative solutions.

Despite the wealth of general literature on new product development and innovation management, we have surprisingly little insight into how organizations respond to extreme innovation demands, or ‘innovation crises,’ as in the case of a pandemic (Rao and Greve, 2018; George et al., 2020). Previous literature on crisis management has focused either on describing how firms can respond to organization-specific crises, such as corporate scandals (Chandler et al., 2020; König et al., 2020), or on macroeconomic challenges, such as economic downturns or terrorist attacks (e.g., Mainiero and Gibson, 2003; Williams et al., 2017). However, this stream of research has not considered how managers can respond to a specific, exogenously induced innovation crisis in which situational requirements demand a versatile organizational response with regard to the development of specific new products or services.

The COVID-19 pandemic offers a particularly intriguing context to further theoretical understanding on innovation crises for three specific reasons. First, the economic incentives for developing a treatment for COVID-19 are unusually high in view of the global need for an effective drug or vaccine. Without such treatment, it would be irresponsible to fully levy the social distancing measures in place (Cohen and Kupferschmidt, 2020; Hill et al., 2020). Second, there is an exceptional time pressure, which is amplified by the fact that the first effective treatment yields the highest economic benefits, while subsequent products are overshadowed by the first mover (Porath, 2018). Third, the otherwise high regulatory hurdles in the industry are minimized due to the public need for medication, which significantly reduces the otherwise lengthy and costly approval process (Rome and Avorn, 2020). Taken together, these factors result in an exacerbated competitive situation coupled with high economic incentives. Thus, COVID-19 represents a novel situation for innovation management that provides unique insights into the responsiveness and adaptability of R&D processes in organizations.

To shed light on how organizations respond to the innovation crisis posed by COVID-19, we draw on and integrate the previous literatures on crisis management (Bundy et al., 2017; Pereira et al., 2020) and innovation repurposing (Toney et al., 2009; Andriani et al., 2017; Neuberger et al., 2019) to argue that reusing existing innovations in a new context (repurposing) can be an effective means of accelerating responsiveness in a crisis. However, this strategy comes at the expense of inefficiency and coordination problems. More specifically, we propose that repurposing is associated with low barriers to entry. When combined with high economic incentives, these low barriers of entry lead to a multitude of uncoordinated actions that cause redundancies and inefficiencies as organizations seek low-hanging fruits and quick wins. As a result, public pressure to promptly innovate can provoke a bustle which, instead of increasing purposeful innovation, fosters mere quantity but deteriorates the average quality of results. Furthermore, the inherent focus of repurposing on application rather than basic research can also prove detrimental for scientific advances in the long run.

We explore innovators’ early crisis responses and the trade-offs they faced using a sample of 2,456 manually coded COVID-19 clinical trials that started between December 2019 and July 2020. Our analyses show that slightly above 30% of the clinical trials in our sample test drugs, while only a small fraction of around 2% tests vaccines. The remaining trials often focus on understanding the disease, finding diagnostic tools, or assessing the wider impact of the pandemic. Among the clinical trials related to drug testing, repurposing plays a prominent role and we find that the most frequently tested drugs have either been approved as treatments for other diseases or have been previously tested for other diseases. Repurposing strategies are mainly used in clinical trials that come from countries with lower GDP per capita, and that are sponsored by hospitals, governments, and device manufacturers as opposed to biopharmaceutical firms. An alarming finding from our study is that a large proportion of COVID-19 trials test the same treatments or drugs, creating a thicket of redundant, uncoordinated, and costly testing, while reducing the variety that would be required for an effective, broad-based repurposing strategy (Sleight and Barton, 2010; Allarakhia, 2013). Another consequence of the high proportion of repurposing trials is the scarcity of research in completely new treatments that could combat the virus in a more targeted and effective way.

Our paper contributes to the literatures on crisis management and innovation repurposing in three important ways. First, in terms of crisis management, we highlight that exceptional innovation pressures can distort incentives toward an unfocused actionism that creates costly redundancies and may reward small wins rather than effective problem solving (Williams et al., 2017). In relation, our paper could also be of interest in the debate on ‘grand societal challenges’ (Ferraro et al., 2015;
George et al., 2016) as it shows how a major societal challenge is tackled under enormous time pressure. In addition, we contribute to the emerging literature on innovation repurposing, which has received scarce attention in the management literature (Andriani et al., 2017; Kucukkekeles et al., 2019) and is in need of empirical evidence and theoretical development. From an empirical standpoint, we extend the prior focus on repurposing drugs for orphan diseases and accidental discoveries to the context of a large-scale pandemic in which repurposing is used as a purposeful strategy. From a theoretical point of view, our paper demonstrates the double-edged nature of innovation repurposing by highlighting the inherent trade-off between the speed and cost of innovation versus the loss of average variety and novelty. Finally, our findings also contribute to the ongoing public debate on COVID-19, and our analyses can provide decision makers with relevant insights for improving crisis management and creating appropriate economic incentives. In particular, we suggest that a better coordination among clinical trial sponsors could reduce costly duplicate efforts while a clearer prioritization of novel developments could promote more diversity in the types of treatments tested. This applies to testing drugs that have proven ineffective in various studies, such as hydroxychloroquine, but which have been further tested in various subsequent clinical trials with public funding.

2. Innovation repurposing and crisis management

The traditional innovation management literature is primarily concerned with the question of how organizations can innovate to gain a sustainable competitive advantage (Tushman and Anderson, 1986; Lengnick-Hall, 1992). At its core, this literature deals with the emergence of innovation stemming from the purposeful recombination of existing and new elements (Henderson and Clark, 1990; Kaplan and Vakili, 2015) within and outside of an organization (March, 1991; Chesbrough, 2003) to address specific needs of individuals and organizations. A common assumption in this line of work is that the need for innovation primarily stems from competitive pressure and the need for organizations to grow and survive in the marketplace by reaping the benefits of temporary monopoly rents generated by innovations (Schumpeter, 1912).

Significantly less attention has been paid to situations where the pressure to innovate does not arise from an organization’s need for growth and profit, but from an exogenous crisis, such as a pandemic, that exacerbates specific innovation needs and imposes significant constraints in terms of timing and the direction of innovation. In the past, such ‘innovation crises’ have often arisen in times of war. For example, the Manhattan Project, which aimed to develop the first nuclear bomb, was born out of the Second World War (Lenfle, 2011). Other examples are the invention of radar technologies or the precursors of the computer (Rau, 2005). These situations are distinctive from regular innovation processes because they typically force high urgency; often allow access to lavish public funding; and bring together actors across institutional boundaries, such as academia, government, and industry. In turn, this constellation of necessity and the pressure to act, available resources, and recombination of knowledge hold the potential for groundbreaking discoveries.

One solution for responding to innovation needs under time and/or resource constraints lies in innovation repurposing, a phenomenon that has received increased attention in the innovation literature (Andriani et al., 2017; Kucukkekeles et al., 2019). Repurposing means that a known solution to a similar problem is transferred to a new context (Allarakhia, 2013). Repurposing has gained considerable traction in recent years, expressly in the context of biopharmaceutical innovation (Chong and Sullivan, 2007; Toney et al., 2009; Neuberger et al., 2019). In view of the considerable risks, time, and costs associated with drug development (DiMasi et al., 2016), biopharmaceutical firms are turning more to such ‘exaptations’ as a means of speeding up the development process, while simultaneously reducing associated costs and regulatory hurdles (Breckenridge and Jacob, 2019; Polamreddy and Gattu, 2019). A classic example is Sildenafil, originally intended for the treatment of angina pectoris (chest pain) but re-used as a therapy for erectile dysfunction (Viagra®) due to its side effect of prolonged erections (Simsek et al., 2018). Apart from these ‘accidental’ discoveries, repurposing can also be employed more strategically. For instance, repurposing has been hailed as a solution to urgent innovation needs, especially with regard to rare diseases that are historically underfunded due to the small market size and the resulting difficulty of covering the innovation costs (Muthyala, 2011).

In the context of biopharmaceutical innovation, repurposing an approved drug or vaccine for another disease has the definite advantage that the treatment’s tolerability has already been established.
in earlier tests, which allows investigators to focus clinical trials on the treatment’s efficacy for another disease (Pantziarika et al., 2018; Pushpakom et al., 2019). Thus, from a clinical vantage point, repurposed drugs or vaccines can leapfrog the first phase of clinical trials, in which the tolerability of the drug is assessed, and move directly to the second phase, in which the focus is on the efficacy of the drug (Oprea et al., 2011). Moreover, the confirmed efficacy of a treatment for a given disease often correlates with the successful treatment for a related disease (Boguski et al., 2009). For instance, it is likely that an antibacterial drug is effective against various bacterial infections.

Despite its advantages, repurposing has a considerable downside resulting from the inherent lack of novelty and focus. In particular, the risk of repurposing is that performance and fit for the problem may be lower because the original innovation was developed with a different objective in mind. There is also the peril that repurposing diverts resources toward incremental innovation at the expense of more novel and radical innovations (Banbury and Mitchell, 1995). Furthermore, repurposing is based on a broad trial and error approach in which a variety of existing solutions are applied to a new problem (Cheng et al., 2018). Thus, repurposing resembles the search for a needle in a haystack and may come at the expense of not developing a profound understanding of the underlying causal mechanisms. In addition, investing in repurposing may be less attractive than de novo drug development as repurposed drugs tend to have a shorter exclusivity period (e.g., three instead of 10 years in the United States) and lower profit margins due to the availability of generic drugs (Pushpakom et al., 2019). Finally, biologists and pharmacists may also be deprived of important insights from preclinical basic research, which can provide valuable information about the treatment’s underlying mechanisms and a better understanding of the nature of a disease (Oprea et al., 2011; Strittmatter, 2014; Kesselheim et al., 2015).

In assessing the trade-offs associated with repurposing, the scarcity of time and resources plays a crucial role. Particularly in the context of a major pandemic, such as COVID-19, a situation that requires a rapid response, we expect that investigators will weigh the upsides of repurposing more strongly than its potential downsides and will, therefore, resort to drug repurposing as opposed to de novo drug and vaccine discovery. In fact, experience shows that repurposing strategies have been deployed in previous epidemics, such as with Middle East Respiratory Syndrome (Dyall et al., 2014). Moreover, given the acute burden on the health-care system induced by COVID-19, we expect that a high number of nontraditional players, such as hospitals and government agencies (as opposed to biopharmaceutical firms and research institutes), will be involved in clinical trials because they are at the forefront of the pandemic. Those nontraditional players will be more likely to resort to repurposing strategies because they represent lower barriers to entry.

Moreover, we expect to see a concentration of clinical trials around the most promising available therapies based on the pathogenic similarities of COVID-19 to other diseases. This approach creates a thicket of partially redundant trials and reduces the average novelty and variety of trials given the inexperience of nontraditional sponsors in clinical trials and the lack of coordination between local actors charged with crisis management. In view of the scarcity of previous theoretical and empirical evidence on this phenomenon, we refrain from developing formal theory-driven hypotheses and instead opt for an explorative study design that focuses on empirical patterns and descriptive analyses.

3. Overview of data and study design

Our investigation of innovation responses to the COVID-19 crisis is based on a comprehensive dataset of clinical trials initiated between December 2019 and July 2020. We obtained the data via the Aggregate Analysis of ClinicalTrials.gov (AACT), provided by the Clinical Trial Transformation Initiative. AACT facilitates access to the protocol and outcome data of all clinical trials registered in the ClinicalTrials.gov database, the official and comprehensive registry of clinical trials maintained by the United States National Library of Medicine. ClinicalTrials.gov contains information on clinical trials conducted in the United States and more than 200 other countries and territories across all disease areas and clinical development stages. Haessler and Rake (2017) provide further details on the available information, the types of clinical trials registered, and the regulatory requirements related to trial registration in the ClinicalTrials.gov database.

In total, we identified 2,783 clinical trials related to COVID-19. The first clinical trials devoted to COVID-19 started on December 10, 2019, but we identified another 29 clinical trials that started before December 10, 2019, but were reclassified to COVID-19 after the outbreak of the pandemic. While we included these reclassified clinical trials in our sample, we excluded 327 clinical trials that reported an (expected) start date after the end of July 2020 or did not report any start data,
because we wanted to focus on the realized clinical trials rather than intended future trials. This leaves us with a sample of 2,456 COVID-19-related clinical trials.

Importantly, each clinical trial lists the sponsors associated with a given clinical trial. Sponsors are organizations (or individuals) that initiate, control, fund, or otherwise support the trial and are typically involved in both planning the trial and the analysis of the results. ClinicalTrials.gov provides only basic information about each clinical trial’s lead- and cosponsors, which are referred to as ‘collaborators’ in the database. To gain deeper insights into the type and provenance of the individuals and organizations involved, we manually classified (co-)sponsors into different finer-grained categories based on publicly available information, such as the sponsors’ websites. Specifically, for each of the 2,990 sponsors involved in the trials in our sample, we manually coded the sponsor’s country and the institutional type, which includes the categories of hospitals, biopharmaceutical firms, governments, academic institutions, device manufacturers, and others (e.g., individuals and insurance,). For a more granular analysis, we combined our manual coding with Pharm Exec’s Top 50 Companies 2019 to identify whether some of the world’s 50 largest biopharmaceutical firms were represented in our sample. Table 6 in the Online Appendix provides a detailed description of the different types of sponsors.

Similarly, we manually recoded the type of intervention or treatment based on the clinical trial descriptions to provide more detailed insights into the nature and purpose of the clinical trials, which are given in the full text descriptions at ClinicalTrials.gov. Table 7 in the Online Appendix lists the classifications we used and provides an explanation of the corresponding interventions or treatments. In addition, we consulted the Drugs@FDA database to obtain additional information about the drugs tested in COVID-19 trials, such as the approval status and the primary fields of application to identify repurposed drugs, a vaccine, and biological treatments. In addition, we used information on the number of COVID-19 cases and deaths at the country level provided by the Johns Hopkins University as well as information on GDP per capita and population sizes provided by the World Bank.

In the next section, we present descriptive analyses of clinical trial activities conducted in response to the COVID-19 pandemic. In addition, we employ social network analysis to map the relationship of different treatments (drugs) tested in the COVID-19 trials and present a map of sponsors’ geographical origins at the country level. To further explore the phenomenon of drug repurposing, we employ a probit regression comparing de novo drug development to repurposing strategies.

4. Analysis and key insights

4.1. Who is responding to the global need for action?

We begin our empirical analysis with an examination of the number of COVID-19-related clinical trials. The number of clinical trials initiated increased exponentially over the first months of the pandemic, as evidenced by a sharp increase in the cumulative number of COVID-19 trials shown in Figure 1. This growth pattern notably accelerated approximately 3 months after the start of the first clinical trial. The considerable growth in the number of COVID-19 trials indicates that clinical investigators are increasingly focusing their efforts on clinical trials related to COVID-19. However, in June and July, the growth rate of the newly initiated trials slowed, indicating that a saturation point had been reached.

To explain the growth pattern, the intriguing question arises as to who is reacting to the global pandemic. Figure 2 shows that COVID-19 trials are mainly (co-)sponsored by hospitals – including university clinics and academic institutions, such as universities or public and private research institutes. In contrast, only a minority of COVID-19 trials (approximately 12%) are sponsored by biotechnology or pharmaceutical firms. Of the trials sponsored by biotechnology or pharmaceutical firms, only a relatively small proportion (55 out of 293 trials or approximately 19%) is (co-)sponsored by 1 of the 50 largest biopharmaceutical firms worldwide.

We see several explanations for the prominent role of hospitals and academic institutions in COVID-19 clinical trials. One reason for the prevalence of hospitals as sponsors of clinical trial is that they represent a vital conduit through which patients can be recruited for trials. Through their direct contact with patients, hospitals can collect extensive clinical data in the course of their routine services without significant additional costs (Dugas et al., 2010). With the high number of COVID-19 patients being treated in hospitals worldwide, doctors and nurses are at the forefront of the pandemic and under pressure to find safe and effective ways to diagnose and treat the disease. In addition, the
crisis offers researchers the opportunity to learn more about the causes, mechanisms, and epidemiological consequences of the crisis, stimulated by a number of publicly supported research initiatives, which explains the prevalence of research institutes.

The comparatively modest involvement of biotechnology and pharmaceutical firms (especially the major players in the industry) as sponsors of COVID-19 trials seems especially surprising, as these firms are usually well-equipped financially and knowledge-wise to respond to emerging health-care needs. In particular, these firms have large portfolios of approved drugs and drugs under development that could potentially be repurposed to respond to the pandemic in a timely manner. Moreover, due to the global impact of COVID-19, biopharmaceutical firms can expect large demand, which is a major driver for the speed and direction of biopharmaceutical innovation (Rake, 2017).
potential explanation for the underrepresentation of biopharmaceutical firms is that repurposed drugs tend to have lower financial margins (Pushpakom et al., 2019) and that competition for bringing a treatment for COVID-19 onto the market is particularly high, both of which might discourage market entry. We provide further details on these possibilities in the discussion section.

In relation, we also explored the geographic provenance of sponsors involved in COVID-19 trials in Figure 3. Given the global scope of the pandemic, it is of little surprise that organizations and individuals from around the world sponsor clinical trials aiming to address the health crisis. However, two countries, the United States and France, figure particularly prominently among the sponsors. Taken together, sponsors from these two countries are involved in 41% of all clinical trials related to COVID-19. Figure 3 also shows that international cooperation of clinical trial sponsors through co-sponsoring is rather rare. In fact, only around 7% of the clinical trials in our sample are projects involving sponsors from different countries. The lack of international collaboration might explain the high number of similar clinical trials that test the same or similar interventions. Without international collaboration and exchange, the risk of information residing in isolated pockets increases considerably.

4.2. What kind of medical innovations are being developed to alleviate the pandemic?

In this section, we further examine the types of medical innovations that are being studied in clinical trials in the early stages of the global COVID-19 pandemic. Figure 4 reports the number of different intervention types relative to the cumulative number of trials over time. Overall, Figure 4 indicates that the distribution across different intervention types is stabilizing after some oscillation right after the beginning of the pandemic. The figure suggests that many COVID-19 trials test specific treatments, with the proportion of drug trials, which varies between slightly above 15% and around 30%, increasing over time to reach just over 30% of all clinical trials by the end of July 2020. The consistently high proportion of drug trials reflects the strong need for effective treatments to alleviate the viral symptoms and shorten hospitalization periods. Trials related to monitoring the spread of the disease and describing its symptoms continue to play a prominent role throughout the initial phase of clinical research on COVID-19. However, the share of this type of clinical trial decreases over time and reaches less than 15% of cumulative trials by the end of July 2020. Interestingly, more than 15% of the COVID-19 trials deal with secondary
indications, such as physical and mental health problems, resulting from pandemic-related socio-economic lockdowns, fears of infection, and prolonged hospitalization. While many policy makers and the public hope for the rapid development of an effective vaccine, our results show that by the end of July 2020, only around 2% of COVID-19 trials were testing vaccines. Although the number of clinical trials of vaccines has gradually increased with the progression of the pandemic, the number of such trials relative to the total number of trials remains rather low. This seems to suggest that vaccine development requires highly specialized competencies, which only a few players in the field possess.

4.3. Is repurposing used as an innovation strategy to identify treatments?

We further investigated which drugs are being tested in COVID-19 trials. Table 1 provides information on the 11 most commonly tested drugs in our sample. As shown in the table, we find that many of the frequently tested drugs were approved more than a decade ago so that patent protection and market exclusivity should have expired, allowing for generic alternatives with much lower prices than the original drugs. Notably, the search for safe and effective COVID-19 treatments is not limited to antiviral drugs, and many of the drugs were originally developed for different indications, including parasitic and bacterial infections, hypertension, and cancer.

We also note that many commonly tested drugs are tested in combination with other drugs. To better illustrate this interesting observation, Figure 5 maps the co-occurrence of drugs or pharmaceutically active ingredients in COVID-19 clinical trials. Drugs that are not tested in combination with or compared to other drugs have not been included in the figure to improve readability. The size of the nodes in Figure 5 indicates how often a drug is used, while the position within the network indicates how often the drug is used in conjunction with other drugs. Remarkably, hydroxychloroquine is the most dominant drug in the figure and is used in a variety of combinations with other drugs. Other prominent drugs are azithromycin, ivermectin, favipiravir, and remdesivir, all of which are repurposed drugs.

Our results reveal that many clinical investigators are using repurposing as an innovation strategy in response to the COVID-19 pandemic. However, it remains to be seen whether repurposing will ultimately lead to successful innovations, that is, safe and effective medicines. We are concerned that the high concentration on a few drugs does not exhaust the full range of possibilities and that, despite the large number of clinical trials, the current landscape does not exhibit a sufficient level of breadth. In particular, the concentration on hydroxychloroquine, the most commonly used drug in COVID-19 drug trials, may not pay off. While scientific evidence is developing rapidly, trial results published since April 2020 have raised questions about the safety and efficacy of hydroxychloroquine (Scavone et al., 2020;
Wiersinga et al., 2020). In addition, the US Food & Drug Administration (2020b) issued a warning in June 2020 because it fears severe side effects from using hydroxychloroquine. Despite this academic evidence and the regulatory concerns, hydroxychloroquine remains the most widely tested medication for COVID-19 and is being tested in 83 additional new trials that started between May 2020 and the end of July 2020.

Notwithstanding the need for further research, some repurposed drugs are showing promising initial results as effective treatments for COVID-19. Remdesivir is a notable example. The drug has not shown clinical efficacy in trials against Ebola and the Marburg virus, but appears to be an effective treatment for COVID-19, at least for patients with severe symptoms (Rochwerg et al., 2020). In fact, shortly after receiving regulatory approval from the European Union on July 3, 2020, the European Commission signed a 63 million euro supply contract for the treatment of approximately 30,000 patients (European Commission, 2020). The United States followed suit and approved remdesivir as the first treatment for COVID-19 on October 22 (US Food & Drug Administration, 2020a). Based on current evidence, it seems that remdesivir is a successful case of drug repurposing.

To better understand when and why sponsors rely on drug repurposing, we conducted an exploratory probit regression analysis predicting the likelihood that a given clinical trial, studying a single drug or a combination of drugs, uses innovation repurposing. Our dependent variable equals one if a drug is repurposed, that is, the drug has been applied to treat a disease other than COVID-19 before, and zero otherwise (i.e., a de novo drug development). The information is based on our manual coding and matching information based on the Drugs@FDA database. We included various covariates as potential predictors, including the cumulative number of COVID-19 cases and COVID-19-related deaths per 100,000 inhabitants in the sponsor country, economic factors (GDP per capita), and indicators for different sponsor types. Table 2 provides a detailed description of the variables used in our probit regression.

Summary statistics and correlations are presented in Table 3, and the results of our regression analysis are presented in Table 4. The results of our probit regression suggest that drugs are repurposed in response to a high number of COVID-19-related deaths per 100,000 inhabitants in the sponsor country. Thus, as external pressure increases, repurposing is becoming more dominant as a crisis response. Moreover, the GDP per capita is negatively related

| Active ingredient or drug | Number of trials | Combinations with other drugs | Earliest FDA approval of drug used in COVID-19 trials | Main conditions treated with drug |
|---------------------------|------------------|-------------------------------|------------------------------------------------------|----------------------------------|
| Hydroxychloroquine        | 213              | 66                            | April 1955                                           | Malaria                          |
| Azithromycin              | 72               | 32                            | November 1991                                        | Bacterial infections             |
| Tocilizumab               | 43               | 32                            | January 2010                                         | Rheumatoid arthritis; systemic juvenile idiopathic arthritis |
| Lopinavir (Ritonavir)     | 42               | 41                            | September 2000                                       | HIV/AIDS                         |
| Ivermectin                | 33               | 16                            | November 1996                                        | Parasite infections              |
| ARB (angiotensin II receptor blocker) | 28 | 18 | April 1995 | Hypertension; congestive heart failure |
| Favipiravir               | 23               | 10                            | Not yet approved                                     | Influenza                        |
| Remdesivir                | 20               | 20                            | Not yet approved; since May 2020 emergency use authorization as COVID-19 treatment | Virus infections |
| ACE-I (angiotensin-converting enzyme inhibitors) | 18 | 2 | April 1981 | Hypertension; congestive heart failure |
| Nitazoxanide              | 18               | 8                             | November 2002                                        | Virus infections; parasite infections |
| Ruxolitinib               | 18               | 4                             | November 2011                                        | Myelofibrosis; polycythemia vera |

The numbers are based on 743 COVID-19-related trials testing 395 drugs initiated between December 2019 and the end of July 2020.
to the probability that a clinical trial tests a repurposed drug, which indicates that repurposing is a viable strategy for low-income countries where the financial resources for de novo drug development may not exist. We also see that the probability of de novo drug development increases if the sponsor is a biopharmaceutical firm, whereas device manufacturers, hospitals, or governments will more likely resort to drug repurposing. As drug repurposing presents lower barriers to entry, it invites more nontraditional sponsor types.

5. Discussion of results and policy implications

In this study, we set out to understand how organizations innovate in crisis situations, with a focus on the recent COVID-19 pandemic. Based on data from COVID-19-related clinical trials, we find that organizations are focusing on repurposing drugs as an immediate response to the health-care needs resulting from the viral pandemic. Despite the benefits of repurposing, we also see that many trials are testing the same drugs and pursuing similar strategies, indicating an inefficient use of resources and a duplication of efforts. The sheer mass of clinical trials also creates an impenetrable thicket and makes it difficult to identify truly novel and unique trials that follow high academic and clinical standards, especially since many trials are sponsored by nontraditional and potentially less experienced players. This can be problematic as it may inhibit policy makers from supporting the most promising approaches.

From a theoretical point of view, our study contributes to the emerging literature on innovation repurposing in management (Andriani et al., 2017; Kucukkeles et al., 2019). Although our empirical focus is on the health-care sector, the idea of repurposing could also be relevant in other contexts, including semiconductors (e.g., the use of Raspberry Pi computers in various environments), engineering (e.g., the use of drone technologies for passenger aviation), and software development (e.g., the redeployment of code) (also see Dew et al., 2004; Andriani and Carignani, 2014). Even in the context of biopharmaceutical innovation, our study is instructive because it shifts the focus in existing research on repurposing drugs for rare diseases and accidental discoveries toward the systematic use of repurposing strategies in response to a viral pandemic, thus providing an interesting contextualized comparison. More broadly speaking, understanding when and why organizations are innovating through repurposing can help to understand the dynamics of innovation and provide
a more holistic picture of the potential value of original innovations as they experience late cyclical revivals.

Our study also has important implications for the literature on crisis management (Bundy et al., 2017). Prior research has primarily focused on understanding crisis situations that emanate from specific organizational problems or macroeconomic factors (Mainiero and Gibson, 2003; Bundy et al., 2017). We expand this conception of a crisis by introducing the idea of ‘innovation crisis,’ which we understand as specific innovation demands that unexpectedly shift organizational attention to a new area. Such situations are particularly interesting because they show how organizations can adapt to unforeseen contingencies to effectuate immediate responses. We show that innovation repurposing is a dominant crisis response strategy and illuminate the value and dangers of applying old technologies in a new context.

A key finding of our study is that the (generally positive) activity level triggered by the crisis may have led to a lack of coordination and variety as evidenced by the large number of highly similar and potential redundant clinical trials. This is problematic because these duplicate clinical trials consume resources that could be better employed in different trials to increase variety and thus the likelihood of finding an effective treatment. A potential explanation for the lack of coordination could be that many clinical trials are confined to individual countries or conducted by a single institution, which may reduce information exchange between actors and explain the number of similar clinical trials. This problem could be spurred on by politically motivated and nationalist pressure from governments to give priority to local research and development. Moreover, as many organizations are working toward the same goal, the competitive landscape is becoming increasingly confusing, making it difficult for actors to keep track of new scientific evidence and promising avenues for future research.

In addition, the concentration on rapid success might also crowd out solutions that are more likely to be long-term oriented and create a ‘first-past-the-post’ mentality. In the end, this reduces economic incentives for developing truly novel innovations out of a fear of being too slow or having to compete

Table 2. Variable description

| Dependent variable | Description |
|--------------------|-------------|
| Repurposed drug | Binary variable equaling one if a drug is repurposed, that is, the drug has been applied to treat a disease other than COVID-19 before, and zero otherwise. |

| Independent variables | Description |
|-----------------------|-------------|
| COVID-19 cases per 100,000 population | Number of COVID-19 cases in a sponsor country per 100,000 inhabitants as of mid-August 2020. If multiple sponsor countries are involved, the variable represents the average of the corresponding countries. |
| COVID-19 deaths per 100,000 population | Number of COVID-19 deaths in a sponsor country per 100,000 inhabitants as of mid-August 2020. If multiple sponsor countries are involved, the variable represents the average of the corresponding countries. |
| Academic institutions | Binary variable equaling one if the trial is sponsored by an academic institution, and zero otherwise. |
| Biopharmaceutical firms | Binary variable equaling one if the trial is sponsored by a biopharmaceutical firm, and zero otherwise. |
| Device manufacturers | Binary variable equaling one if the trial is sponsored by a medical device manufacturer, and zero otherwise. |
| Hospitals | Binary variable equaling one if the trial is sponsored by a hospital, and zero otherwise. |
| Governments | Binary variable equaling one if the trial is sponsored by national, regional, or local governments, and zero otherwise. |
| GDP per capita | GDP per capita in 2019 in current US dollars. The variable enters the analysis in logarithmic form. If multiple sponsor countries are involved, the variable represents the average of the corresponding countries. |
| Days since first COVID-19 trial | Number of days from the first COVID-19 trial until the start of a trial. |
| Number of trial sites | Number of sites – such as hospitals or clinics – the trial is conducted in. |
| International trial | Binary variable equaling one if the trial is conducted in multiple countries, and zero otherwise. |
| Phase controls | A set of binary variables controlling for the phase of the clinical development process. |
against multiple alternative products. This would be the case, for example, if a sufficiently effective and inexpensive repurposed drug is brought to the market prior to the launch of a novel drug that takes much longer to develop and incurs higher costs. In this scenario, any follow-on product would have to compete and potentially share the market with the first mover, a prospect that reduces the *ex-ante* incentives to enter the market at all. An empirical indication for this problem could be the fact that biopharmaceutical firms, which traditionally introduce the majority of medical innovations, are woefully unrepresented in clinical trials related to COVID-19.

No study is without limitations and ours is no exception. The explorative approach of our study focuses on understanding how organizations respond to an unexpected crisis event that calls for rapid innovation. In view of the limited previous work in this field, we decided against testing a specific theory and instead focused on uncovering latent patterns in a descriptive way. This explorative approach naturally calls for future research to identify the causal factors influencing the pace and trajectory of COVID-19-related innovation.

### Table 3. Summary statistics and correlations

|                              | N  | Mean   | SD     | Min. | Max.   | (1)   |
|------------------------------|----|--------|--------|------|--------|-------|
| Repurposed drug              | 623| 0.8555 | 0.3518 | 0.1000 | 1.0000 |       |
| COVID-19 cases per 100,000 population | 623| 891.7808 | 679.2399 | 2.0000 | 4073.6323 | −0.1291** |
| COVID-19 deaths per 100,000 population | 623| 37.3321 | 21.6372 | 0.0000 | 86.5896 | −0.0305 |
| Academic institutions        | 623| 0.4366 | 0.4964 | 0.0000 | 1.0000 | 0.2329*** |
| Biopharmaceutical firms      | 623| 0.2681 | 0.4433 | 0.0000 | 1.0000 | −0.4729*** |
| Device manufacturers         | 623| 0.0128 | 0.1127 | 0.0000 | 1.0000 | 0.0469 |
| Governments                  | 623| 0.4205 | 0.4940 | 0.0000 | 1.0000 | 0.1928*** |
| GDP per capita               | 623| 10.1828 | 1.4845 | 2.0000 | 11.3144 | −0.1448*** |
| Days since first COVID-19 trial | 623| 148.1974 | 41.8130 | 0.0000 | 233.0000 | −0.1416*** |
| Number of trial sites        | 623| 5.7079 | 14.9859 | 1.0000 | 184.0000 | −0.0114 |
| International trial          | 623| 0.0562 | 0.2305 | 0.0000 | 1.0000 | −0.0782 |
| COVID-19 cases per 100,000 population | 1.0000 |       |       |       |       |       |
| COVID-19 deaths per 100,000 population | 0.5335*** | 1.0000 |       |       |       |       |
| Academic institutions        | −0.0541 | −0.0191 | 1.0000 |       |       |       |
| Biopharmaceutical firms      | 0.1368*** | 0.0661 | −0.3647*** | 1.0000 |       |       |
| Device manufacturers         | 0.0075 | −0.0380 | −0.0717 | −0.0368 | 1.0000 |       |
| Hospitals                    | −0.0523 | 0.0189 | −0.2058*** | −0.2733*** | 0.0761 | 1.0000 |
| Governments                  | −0.0954* | −0.0830* | 0.0839* | −0.0499 | −0.0233 | 0.0081 |
| GDP per capita               | 0.3966*** | 0.4157*** | −0.2039*** | 0.1998*** | −0.0401 | 0.1053*** |
| Days since first COVID-19 trial | 0.1886*** | 0.1355*** | −0.0433 | 0.2337*** | −0.0295 | −0.1398*** |
| Number of trial sites        | 0.0680 | 0.0542 | −0.1382*** | 0.2364*** | 0.1222*** | −0.0980* |
| International trial          | 0.0068 | 0.0196 | −0.0883* | 0.2300*** | 0.0341 | −0.1090** |
| Governments                  | 1.0000 |       |       |       |       |       |
| GDP per capita               | −0.0675 | 1.0000 |       |       |       |       |
| Days since first COVID-19 trial | −0.0129 | 0.0874* | 1.0000 |       |       |       |
| Number of trial sites        | −0.0501 | 0.1183** | −0.1056** | 1.0000 |       |       |
| International trial          | −0.0499 | 0.1021* | −0.0303 | 0.4843*** | 1.0000 |       |

*P < 0.10, **P < 0.05, ***P < 0.01.
mechanism of repurposing in light of a specific theory (Hambrick, 2007). The literature on exaptation might be especially promising in this regard (Cattani, 2005; Andriani and Carignani, 2014). Follow-on studies could, for example, explore the role of firms’ experience, their internal resources and capabilities, network structures, and international collaborations as potential drivers of repurposing. Apart from studying organizational-level drivers, it might also be interesting to explore how different innovation demands can shape repurposing strategies. This could include factors, such as market pressure and the role of regulators in facilitating repurposing and fast-tracking this process. More specifically, it is likely that repurposing drugs to treat orphan or rare diseases (Kucukkele et al., 2019) is motivated by a strong cost-saving logic and, therefore, might differ fundamentally from repurposing strategies used in the context of a pandemic where speed is much more critical and potentially a major driver for the decision to rely on repurposing.

In addition, we have not investigated why organizations decide to participate in the search for COVID-19 treatments, which is another opportunity for further study. In particular, it would be interesting to investigate how firms balance the trade-off between public incentives to join the race for a drug or vaccine against the threat of high competition and the reduced financial margins for repurposed development versus the development of novel medicines. Understanding these considerations could help to identify the underlying incentives for firms to contribute toward solving a health-care crisis.

Finally, while we descriptively examine the value and caveats of innovation repurposing, a more in-depth analysis could show under which circumstances...
repurposing is more successful. In this regard, a comparison of repurposing efforts in different areas, such as rare diseases and COVID-19, could be particularly promising. It would also be interesting to see which organizations rely on repurposing strategies, whereas others prefer novel development. In untangling the causal mechanisms, organizational resources, and capabilities, as well as intellectual property rights, could play a central role. Therefore, we see our paper as an impetus to further explore the role of repurposing in innovation research.

Despite its limitations, our study carries some relevant implications for policy makers. In view of the relatively small number of biopharmaceutical firms involved in the search for COVID-19 treatments, the question arises as to whether firms have sufficient incentives to enter the market. There are two reasons that suggest this might not be the case. First, firms may not be able to patent a repurposed drug because the knowledge is already in the public domain. Therefore, profit margins are relatively low. Second, the 3-year exclusivity periods for repurposed drugs in the United States, the largest pharmaceutical market, may be too short to provide incentives for clinical trials of repurposed drugs, as firms still have to conduct expensive phase 3 clinical trials (Pushpakom et al., 2019). This suggests that policy makers should consider revising incentive schemes to provide motivations for firms to shift internal resources from alternative options to the development of treatments for an imminent pandemic. In view of the long drug development cycles (DiMasi et al., 2016), it seems to be of paramount importance to provide long-term incentives and public support to conduct continuous and large-scale research for treatments against viruses to be more reactive and more quickly react in the event of a crisis.

From a managerial perspective, our study has three important implications. First, the exponential growth rate and rapid development of clinical trials in a pandemic suggest that managers need to act quickly if they want to enter the market. For example, remdesivir was among the first clinical trials launched for COVID-19 and was the first to receive regulatory approval in the European Union. A late market entry could mean that competitors reap most of the benefits, although a follow-on product might later prove more effective. Second, managers must also be aware of the risks associated with rapid innovation in a health-care crisis. If a treatment shows unexpected side effects that only occur later, the legal and reputational damage could be irreparable. Third, there is, of course, a strong moral responsibility in responding to a pandemic. Although economic benefits play an important role when entering a market, a major crisis in the health-care sector may also require a strong commitment as part of a firm’s larger responsibility to society (Jones and Wicks, 1999). In recent years, people have become increasingly aware of how firms respond to a crisis, and the COVID-19 pandemic should be no exception (Wang et al., 2021).

Looking at the crisis situation as a whole, our study shows that innovation activities in a crisis situation follow fundamentally different dynamics than under normal circumstances. This has implications for the type of innovation (e.g., repurposing vs. de novo, short term vs. long term, incremental vs. radical), with repurposing being one of the key innovation strategies in a crisis. We show that repurposing is a double-edged sword that increases speed, but at the same time promotes a dynamic that creates inefficiencies and redundancies. The challenge for crisis management is to create selective incentives for innovation and at the same time improve coordination between actors to enable a broad search for repurposed innovation.

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References

Allarakhia, M. (2013) Open-source approaches for the repurposing of existing or failed candidate drugs: learning from and applying the lessons across diseases. Drug Design, Development and Therapy, 7, 753–766. Available from: https://doi.org/10.2147/DDDT.S46289.
Andrani, P., Ali, A., and Mastrogiorgio, M. (2017) Measuring exaptation and its impact on innovation, search, and problem solving. Organization Science, 28, 2, 320–338. Available from: https://doi.org/10.1287/orsc.2017.1116.
Andriani, P. and Carignani, G. (2014) Modular exaptation: a missing link in the synthesis of artificial form. Research Policy, 43, 9, 1608–1620. Available from: https://doi.org/10.1016/j.respol.2014.04.009.
Baden, L.R. and Rubin, E.J. (2020) Covid-19 – the search for effective therapy. New England Journal of Medicine, 382, 19, 1851–1852. Available from: https://doi.org/10.1056/NEJMe2005477.
Banbury, C.M. and Mitchell, W. (1995) The effect of introducing important incremental innovations on market share and business survival. Strategic Management Journal, 16, S1, 161–182. Available from: https://doi.org/10.1002/smj.4250160922.
Boguski, M.S., Mandl, K.D., and Sukhatme, V.P. (2009) Repurposing with a difference. Science, 324, 5933,
Repurposing without purpose? Early innovation responses to the COVID-19 crisis

1394–1395.Available from: https://doi.org/10.1126/science.1169920.

Brekenridge, A. and Jacob, R. (2019) Overcoming the legal and regulatory barriers to drug repurposing. Nature Reviews Drug Discovery, 18, 1, 1–2. Available from: https://doi.org/10.1038/nrd.2018.92.

Bundy, J., Pfarrer, M.D., Short, C.E., and Coombs, W.T. (2017) Crises and crisis management: integration, interpretation, and research development. Journal of Management, 43, 6, 1661–1692. Available from: https://doi.org/10.1177/0149206316680030.

Cattani, G. (2005) Preadaptation, firm heterogeneity, and technological performance: a study on the evolution of fiber optics. 1970–1995. Organization Science, 16, 6, 563–580. Available from: https://doi.org/10.1287/orsc.1050.0145.

Chandler, D., Poldorfo, F., and Yang, W. (2020) When is it good to be bad? Contrasting effects of multiple replications for bad behavior on media coverage of serious organizational errors. Academy of Management Journal, 63, 4, 1236–1265. Available from: https://doi.org/10.1016/j.ambj.2017.12.148.

Cheng, F., Desai, R.J., Handy, D.E., Wang, R., Schneeweiss, S., Barabási, A.-L., and Loscalzo, J. (2018) Network-based approach to prediction and population-based validation of in silico drug repurposing. Nature Communications, 9, 1, 1–12. Available from: https://doi.org/10.1038/s41467018-05116-5.

Chesbrough, H.W. (2003) Open Innovation: The New Imperative for Creating and Profiting from Technology. Boston, MA: Harvard Business Press.

Chesbrough, H. (2020) To recover faster from Covid-19, open up: managerial implications from an open innovation perspective. Industrial Marketing Management, 88, 410–413. Available from: https://doi.org/10.1016/j.indmar.2020.04.010.

Chong, C.R. and Sullivan, D.J. (2007) New uses for old drugs. Nature, 448, 7154, 645–646. Available from: https://doi.org/10.1038/448645a.

Cohen, J. and Kupferschmidt, K. (2020) Countries test tactics in ‘war’ against COVID-19. Science, 367, 6484, 1287–1288. Available from: https://doi.org/10.1126/science.367.6484.1287.

Dew, N., Sarasvathy, S.D., and Venkataraman, S. (2004) The economic implications of exaptation. Journal of Evolutionary Economics, 14, 1, 69–84. Available from: https://doi.org/10.1007/s10191-003-0180-x.

Dhama, K., Sharma, K., Tiwari, R., Dadar, M., Malik, Y.S., Singh, K.P. & Chieumupa, W. (2020) COVID-19, an emerging coronavirus infection: advances and prospects in designing and developing vaccines, immunotherapeutics, and therapeutics. Human Vaccines & Immunotherapeutics, 16, 6, 1232–1238. Available from: https://doi.org/10.1080/21655150.2020.1735227.

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. Available from: https://doi.org/10.1016/j.jhealeco.2016.01.012.

Dugas, M., Lange, M., Müller-Tidow, C., Kirchhof, P., and Prokosch, H.-U. (2010) Routine data from hospital information systems can support patient recruitment for clinical studies. Clinical Trials, 7(2), 183–189. Available from: https://doi.org/10.1177/1740774510363013.

Dyall, J., Coleman, C.M., Hart, B.J., Venkataraman, T., Holbrook, M.R., Kindrachuk, J., Johnson, R.F., Olinger, G.G., Jahrling, P.B., Laidlaw, M., Johansen, L.M., Lear-Rooney, C.M., Glass, P.J., Hensley, L.E., and Frieman, M.B. (2014) Repurposing of clinically developed drugs for treatment of middle east respiratory syndrome coronavirus infection. Antimicrobial Agents and Chemotherapy, 58(8), 4885–4893. Available from: https://doi.org/10.1128/AAC.03036-14.

European Commission. (2020) European Commission Secures EU Access to Remdesivir for Treatment of COVID-19. Available from: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1416 [Accessed 15 August 2020].

Ferraro, F., Etzion, D., and Gehman, J. (2015) Tackling grand challenges pragmatically: robust action revisited. Organization Studies, 36, 3, 363–390. Available from: https://doi.org/10.1177/0170840614563742.

George, G., Howard-Grenville, J., Joshi, A., and Tihanyi, L. (2016) Understanding and tackling societal grand challenges through management research. Academy of Management Journal, 59, 6, 1880–1895. Available from: https://doi.org/10.5465/amanj.2016.4007.

George, G., Lakhani, K.R., and Puranam, P. (2020) What has changed? The impact of Covid pandemic on the technology and innovation management research agenda. Journal of Management Studies, 57, 8, 1754–1758. Available from: https://doi.org/10.1111/joms.12634.

Haeussler, C. and Rake, B. (2017) The changing geography of clinical research: a critical analysis of its drivers. Industrial and Corporate Change, 26, 2, 285–310. Available from: https://doi.org/10.1093/icc/dtx002.

Hambrecht, D.C. (2007) The field of management’s devotion to theory: too much of a good thing? Academy of Management Journal, 50, 6, 1346–1352. Available from: https://doi.org/10.5465/amj.2007.28166119.

Henderson, R.M. and Clark, K.B. (1990) Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms. Administrative Science Quarterly, 35, 1, 9–30. Available from: https://doi.org/10.2307/2393549.

Hill, A., Wang, J., Levi, J., Heath, K., and Fortunak, J. (2020) Minimum costs to manufacture new treatments for COVID-19. Journal of Virus Eradication, 1, 6, 1–9.

Jones, T.M. and Wicks, A.C. (1999) Convergent stakeholder theory: too much of a good thing? Academy of Management Journal, 42, 2, 206–221. Available from: https://doi.org/10.5465/amj.1999.1893929.

Kaplan, S. and Vakili, K. (2015) The double-edged sword of recombination in breakthrough innovation. Strategic Management Journal, 36, 10, 1435–1457. Available from: https://doi.org/10.1002/smj.2294.

Kesselheim, A.S., Tan, Y.T., and Avorn, J. (2015) The roles of academia, rare diseases, and repurposing in the development of the most transformative drugs. Health Affairs,
Marvin Hanisch and Bastian Rake

34, 2, 286–293. Available from: https://doi.org/10.1377/]
hlhaff.2014.1038.
König, A., Graf-Vlachy, L., Bundy, J., and Little, L.M. (2020) A blessing and a curse: how CEOs’ trait empathy affects their management of organizational crises. *Academy of Management Review*, 45, 1, 130–153. Available from: https://doi.org/10.5465/amr.2017.0387.
Kucukkeles, B., Ben-Menahem, S.M., and von Krogh, G. (2019) Small numbers, big concerns: practices and organizational arrangements in rare disease drug repurposing. *Academy of Management Discoveries*, 5, 4, 415–437. Available from: https://doi.org/10.5465/amd.2018.0183.
Lenfle, S. (2011) The strategy of parallel approaches in projects with unforeseeable uncertainty: the Manhattan case in retrospect. *International Journal of Project Management*, 29, 4, 359–373. Available from: https://doi.org/10.1016/j.ijproman.2011.02.001.
Lengnick-Hall, C.A. (1992) Innovation and competitive advantage: what we know and what we need to learn. *Journal of Management*, 18, 2, 399–429. Available from: https://doi.org/10.1177/01492063921800209.
Mainiero, L.A. and Gibson, D.E. (2003) Managing employee trauma: dealing with the emotional fallout from 9-11. *Academy of Management Perspectives*, 17, 3, 130–143. Available from: https://doi.org/10.5465/ame.2003.10954782.
March, J.G. (1991) Exploration and exploitation in organizational learning. *Organization Science*, 2, 1, 71–87. Available from: https://doi.org/10.1287/orsc.2.1.71.
Muthyalal, R. (2011) Orphan/rare drug discovery through drug repositioning. *Drug Discovery Today: Therapeutic Strategies*, 8, 3–4, 71–76. Available from: https://doi.org/10.1016/j.ddstr.2011.10.003.
Neuberger, A., Oraiopoulos, N., and Drakeman, D.L. (2019) Renovation as innovation: is repurposing the future of drug discovery research? *Drug Discovery Today*, 24, 1, 1–3. Available from: https://doi.org/10.1016/j.drudis.2018.06.012.
Oprea, T.I., Bauman, J.E., Bologa, C.G., Buranda, T., Chigaev, A., Edwards, B.S., Jarvik, J.W., Gresham, R., Hayes, M.K., Hjelle, B., Hromas, R., MacKenzie, D.A., Muller, C.Y., Oraiopoulos, N., Reed, J.C., Simons, H.D., Siemieniuk, R., Silvestre, M.A., Virtanen, P.O., Wax, S., Wu, Y., Young, S.M., Larson, R.S., Willman, C., and Konda, S., Kanda, S., Kawano-Dourado, L., Kurian, L., Kizer, A., Murthy, S., Qadir, N., Rau, E.P. (2005) Combat science: the emergence of operational research in World War II. *Endeavour*, 29, 4, 156–161. Available from: https://doi.org/10.1016/j.endeavour.2005.10.002.
Rochwerg, B., Agarwal, A., Zeng, L., Leo, Y.-S., Appiah, J.A., Agoritsas, T., Bartoszko, J., Brignardello-Petersen, R., Ergan, B., Gang, G., Geduld, H., Gershengorn, H.B., Manai, H., Huang, M., Lamontagne, F., Kanda, S., Kawano-Dourado, L., Kurian, L., Kizer, A., Murthy, S., Qadir, N., Siemieniuk, R., Silvestre, M.A., Virtanen, P.O., Ye, Z., Zeraatkar, D., and Guyatt, G. (2020) Remdesivir for severe Covid-19: a clinical practice guideline. *British Medical Journal*, 370, m2924, 1–10. Available from: https://doi.org/10.1136/bmj.m2924.
Rome, B.N. and Avorn, J. (2020) Drug evaluation during the Covid-19 pandemic. *New England Journal of Medicine*, 382, 24, 2282–2284. Available from: https://doi.org/10.1056/NEJMp2009457.
Simsek, M., Meijer, B., van Bodegraven, A.A., de Boer, N.K.H., and Mulder, C.J.J. (2018) Finding hidden treasures in old drugs: the challenges and importance of licensing generics. *Drug Discovery Today*, 23, 1, 17–21. Available from: https://doi.org/10.1016/j.drudis.2017.08.008.
Sleigh, S.H. and Barton, C.L. (2010) Repurposing strategies for therapeutics. *Pharmaceutical Medicine, 24*, 3, 151–159. Available from: https://doi.org/10.1007/BF03256811.

Strittmatter, S.M. (2014) Overcoming drug development bottlenecks with repurposing: old drugs learn new tricks. *Nature Medicine, 20*, 6, 590–591. Available from: https://doi.org/10.1038/nm.3595.

Toney, J.H., Fasick, J.I., Singh, S., Beyrer, C., and Sullivan, D.J. (2009) Purposeful learning with drug repurposing. *Science, 325*, 5946, 1339–1340. Available from: https://doi.org/10.1126/science.325_1339.

Tushman, M.L. and Anderson, P. (1986) Technological discontinuities and organizational environments. *Administrative Science Quarterly, 31*, 3, 439–465. Available from: https://doi.org/10.2307/2392832.

U.S. Food & Drug Administration. (2020a) FDA Approves First Treatment for COVID-19. Available from: https://www.fda.gov/news-events/press-announcements/fda-approves-firsttreatment-covid-19 [Accessed 12 November 2020].

U.S. Food & Drug Administration. (2020b) FDA Cautions Against Use of Hydroxychloroquine or Chloroquine for COVID-19 Outside of the Hospital Setting or a Clinical Trial Due to Risk of Heart Rhythm Problems: Does Not Affect FDA-Approved Uses for Malaria, Lupus, and Rheumatoid Arthritis. Available from: https://www.fda.gov/media/137250/download [Accessed 14 May 2020].

Wang, X., Reger, R.K., and Pfarrer, M. (2021) Faster, hotter, and more linked in: managing social disapproval in the social media era. *Academy of Management Review*. Available from: https://doi.org/10.5465/amr.2017.0375.

Wenzel, M., Stanske, S., and Lieberman, M.B. (2021) Strategic responses to crisis. *Strategic Management Journal, 42*, 2, V7–V18. Available from: https://doi.org/10.1002/smj.3161.

Wiersinga, W.J., Rhodes, A., Cheng, A.C., Peacock, S.J., and Prescott, H.C. (2020) Pathophysiology, transmission, diagnosis, and treatment of coronavirus disease 2019 (COVID-19): a review. *Journal of the American Medical Association, 324*, 8, 782–793. Available from: https://doi.org/10.1001/jama.2020.12839.

Williams, T.A., Graber, D.A., Sutcliffe, K.M., Shepherd, D.A., and Zhao, E.Y. (2017) Organizational response to adversity: fusing crisis management and resilience research streams. *Academy of Management Annals, 11*, 2, 733–769. Available from: https://doi.org/10.5465/annals.2015.0134.

**Notes**

1 https://aact.ctti-clinicaltrials.org/.

2 Every clinical trial in the database contains information about the disease or medical condition that is being studied. We use this information to identify all trials studying COVID-19 by searching for the term ‘COVID 19’ and its synonyms, such as ‘SARS-CoV-2,’ among the conditions addressed in the studies and in the titles of the clinical trials. A full list of synonyms used in this study is provided in Table 5 in the Online Appendix.

3 https://www.pharmexec.com/view/pharm-exec-top-50-companies-2019.

4 https://www.accessdata.fda.gov/scripts/cder/daf/.

5 https://coronavirus.jhu.edu/region.

6 https://databank.worldbank.org/home.aspx.

7 We focused our regression analysis on drug repurposing. In an unreported robustness check, we also included repurposed biologicals in the analysis. The results from this extended analysis are qualitatively consistent with the results presented in the Table 4.

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