Bottom-up solutions in a time of crisis: the case of Covid-19 in South Korea

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Innovation systems have seen diverse actors attempting to tame the Covid-19 crisis, under varying degrees of government direction. Largely neglected in scholarly and public attention, however, are ‘bottom-up’ solutions arising from the periphery of innovation systems. Drawing on inductive case research on a fringe doctor who invented the idea of the drive-through testing system, and two university student teams that developed coronavirus applications, this study examines how peripheral actors generate innovative, bottom-up solutions at speed in a time of crisis. Our findings reveal that, in a crisis situation, bottom-up solutions transpire on the basis of three innovation drivers: (a) peripheral status, expediting the commence of innovation activities; (b) interdisciplinary collaboration, enabling access to a greater spectrum of knowledge and perspectives; and (c) prior knowledge, prescribing the direction of solution generation. We also identify that system intermediaries support the innovation activities of peripheral actors, thereby helping bottom-up solutions to become more customer facing. Such functions of intermediaries include demand articulation, technical assistance, and promulgation of generated solutions. Our findings offer theoretical implications for the literature on innovation in a time of crisis and practical implications for governments and organizations preparing themselves for the potential second wave of coronavirus emergencies, or even a completely new form of future crisis.

1. Introduction

The outbreak of Covid-19 has provoked a health-care emergency, which demands the urgent delivery of effective, affordable, and customer-facing care to the public.¹ To cope with crisis situation, governments are rolling out innovative measures to curb the spread of contagion. Firms and universities are also attempting to tame the epidemics, either in isolation or in collaboration with governments. Largely neglected in scholarly and public conversations, however, are ‘bottom-up’ solutions arising from the periphery of innovation systems. For example, although it is not widely known, drive-through testing centers setup around the world were based on the idea thought up by a
fringe doctor in South Korea (Kwon et al., 2020). University students in several countries are voluntarily launching free applications that give information about the coronavirus (e.g., Griffin, 2020; Spitznagel, 2020). Considering the importance of system-wide responses to public health emergencies, an in-depth understanding of bottom-up innovation in the time of the Covid-19 epidemic is warranted.

Extant innovation studies, however, provide limited propositions for understanding the bottom-up solutions of peripheral actors in emergencies. The reason for this is that, first, the innovation literature has typically focused on somewhat central actors, such as firms, governments, and intermediaries, in innovation systems. For example, open innovation research has tended to take a ‘firm-centric perspective’ (Sims et al., 2019, p. 11), and the triple helix literature has been ‘high-tech focused’ (Höglund and Linton, 2018, p. 61). Studies on innovation in emergencies have mostly centered on the responses of firms, governments, and intergovernmental agencies (e.g., Shane et al., 2003; Hud and Hussinger, 2015; Nilsson, 2017). As such, we know little about how peripheral actors in innovation systems come up with innovative solutions, especially in crisis situations. Second, the body of innovation research has mostly looked into the settings in which innovation processes transpire over a relatively lengthy period of time. For example, innovation intermediation studies show that it takes months to years for intermediaries to create and deliver value for their clients (Howells, 2006; Tran et al., 2011). Organizations need years to enact open innovation, and an even longer period is required to embed an openness culture within the organizations (e.g., Di Minin et al., 2010; Enkel et al., 2020). However, the recent Covid-19 emergency has demanded immediate responses, which has received scant attention in the extant literature. This study attempts to fills these gaps by asking: How do peripheral actors in innovation systems generate innovative solutions at speed in a time of crisis?

To address this inquiry, we conduct inductive, multi-case research that traces the innovation activities of: (a) a doctor who invented the idea of the drive-through testing system; and (b) two university student teams that developed and launched applications providing the public with important coronavirus information. By so doing, this study generates several findings that make two important contributions to the studies on innovation in a crisis situation. First, our findings add to the literature by unraveling three drivers, precipitating the innovation activities of peripheral actors that have hitherto been marginalized in scholarly attention. In detail, the bottom-up innovation of peripheral actors hinges on three interdependent dimensions, namely: peripheral status, interdisciplinary collaboration, and prior knowledge. Second, we contribute to the innovation studies by detailing the role of intermediaries in guiding the bottom-up solutions to become more customer facing. Such functions of intermediaries entail demand articulation, technical assistance, and promulgation of generated solutions.

In what follows, we first review the extant studies on innovation in normal and crisis times. This is followed by a description of the way in which our data are collected and analyzed. We then present our findings and discuss their implications. Finally, we close by offering a research agenda for the future.

2. Theoretical background

2.1. Innovation under normal conditions

Under normal conditions, innovation transpires as a result of active knowledge flows among actors in innovation systems (Nelson and Rosenberg, 1993). Viewed through this lens of the innovation system, three drivers of innovation come to the fore: (a) accumulated prior knowledge; (b) interorganizational collaboration; and (c) intermediary support.

First, in normal times, knowledge is circulated in innovation systems as actors (e.g., firms, universities, and governments) engage in learning by doing, learning by using, and learning by interacting (Lundvall, 2016). As such, innovation is characterized by cumulativeness and path-dependence, such that ‘the innovators of today were also innovators in the past’ (Archibugi et al., 2013, p. 304). Second, under normal conditions, system actors espouse diverse forms of collaboration because innovation processes are separated and distributed across innovation systems actors (Coombs et al., 2003; Boon et al., 2008). Such a collaborative approach is typically manifested through open innovation in which ‘organizations make use of internal and external resources to drive their innovation processes’ (Mortara and Minshall, 2011, p. 586); a triple helix model that elevates the trilateral collaboration between industry, university, and government (Miller et al., 2018); and interorganizational relationships driving ‘purposeful interorganizational sharing of research and development (R&D) knowledge and capability to support innovation development’ (Dooley et al., 2016, p. 228;
Dooley and Gubbins, 2019). Finally, in normal circumstances, innovation intermediaries play a significant role in facilitating knowledge fluidity in innovation systems (Howells, 2006). Intermediaries in innovation studies have been defined as agents that provide financial resources with system actors (Lew et al., 2018); that articulate a demand for innovation (Gassmann et al., 2011); that generate or transfer knowledge that is essential for organizations, even providing problem-solving and technical assistance services (Howells, 2006); and, finally, that engage in the procurement of innovation, resulting in ‘the formation of temporary niche markets’ for innovative technologies and solutions (Hekkert et al., 2007, p. 424).

In the health-care sector, the aforementioned drivers of innovation need to serve as a basis to produce products/services featuring three main characteristics. Specifically, innovative products/services in the health-care context should be characterized by effective care, affordable cost, and customer-facing value (Pinzone et al., 2015; Gastaldi et al., 2018; Foglia et al., 2019).

2.2. Innovation in a time of crisis

Extant studies have examined how innovation systems and their constituents tackle a crisis as it unfolds, resurrect from the aftermath of it and prevent it from happening again. Specifically, this body of literature has drawn attention to innovation issues vis-à-vis public health emergencies (e.g., Archibugi and Bizzarri, 2004; Moors and Faber, 2007) and global financial crises (e.g., Hud and Hussinger, 2015; Conti et al., 2019). Propositions developed from two lines of inquiry offer a departure point for understanding the drivers of innovation in a time of a crisis. First, in a crisis situation, governments enact a series of fiscal policies to minimize the repercussions resulting from a system-wide decline in innovation projects and investment (Paunov, 2012; Conti et al., 2019). Government subsidies often serve as an innovation driver, resulting in ‘a production, value added and employment effect that amounts to at least twice the initial financing’ (Brautzsch et al., 2015, p. 623; Ahn et al., 2020). Second, interorganizational collaboration plays an important role in driving innovation in response to emergencies, because multifaceted problems arising from crises go far beyond the capability of a single actor (Mowery et al., 2010; Nilsson, 2017). Indeed, firms in the face of a crisis often establish ‘an extensive network of relationships with leading firms, universities, and research centers with the aim of…cross-industry innovation processes’ (Di Minin et al., 2010, p. 136), and such openness ‘increase[s]…their resilience’ in a time of crisis (Ahn et al., 2018, p. 49). Finally, intermediation agencies aid organizations in coping with societal grand challenges. Facing deadly diseases, for example, intergovernmental agencies (e.g., Medicines Patent Pool established and funded by the WHO) define challenges, propose solutions, and create a collective vision (Nilsson, 2017). Similarly, in their study of an open-source software community developing medical-record-keeping software, Sims et al. (2019) observed that global health-care agencies help the community’s software to become socially recognized and desirable.

2.3. Unpacking bottom-up innovation in a crisis

Since the outbreak of Covid-19 across the globe, we have witnessed the innovative solutions put forward by peripheral actors in systems of innovation. For example, college students, rather than governments or established high-tech firms, have voluntarily developed applications that predict the spread of coronavirus and trace the footprints of persons carrying the virus (see, e.g., Griffin, 2020; Spitznagel, 2020). These bottom-up solutions echo what Nelson and Winter (1982) label Schumpeter Mark I, which tends to transpire in economic turmoil and is characterized by a widening ‘innovative base, which is continuously enlarging through the entry of new innovators’ (Malerba and Orsenigo, 1996, p. 452).

The extant literature, however, may not provide a complete explanation of peripheral, bottom-up innovation during a crisis, for two main reasons. First, existing studies on innovation in both normal and catastrophic times have primarily focused on the innovation activities of actors at the core of systems (e.g., governments, established firms, and intermediaries), leaving the roles of peripheral actors understudied. Indeed, a ‘firm-centric perspective’ prevails in open innovation research (Sims et al., 2019, p. 11), and the existing triple helix model is typically ‘high-tech focused’ (Höglund and Linton, 2018, p. 61). Studies on innovation in economic crises and pandemics mostly revolve around the activities and responses of firms, governments, and intergovernmental agencies (e.g., Archibugi et al., 2013; Nilsson, 2017). Second, the extant research has mostly explored empirical settings in which innovation processes can span a relatively lengthy period of time. For example, the existing studies demonstrate that innovation intermediaries spend months to years creating and delivering value to their clients (Howells, 2006; Tran et
Moreover, open innovation facilitates successful innovation by ‘reducing time to market’ (Lazzarotti and Manzini, 2013, p. 30); yet, it has been found that organizations need, as a minimum, months to enact a certain form of open innovation, and an even longer period is required for organizations to create an openness culture that is engrained internally (Enkel et al., 2020).

Public health emergencies require a highly challenging task: the ‘urgent’ delivery of high-quality, affordable, and customer-facing solutions to the public. As we have all witnessed, this challenge is not easily achievable by governments or firms in isolation; rather, it can be fulfilled when innovative solutions are harmoniously produced from a wider innovation base, including not only central actors, but also peripheral actors in innovation systems. Against this backdrop, this study asks: How do peripheral actors in innovation systems generate innovative solutions at speed in a time of crisis?

3. Method

We used an inductive, multiple-case design because the extant literature presented insufficient footings for the deduction of hypotheses in relation to our research question (Bresman, 2013). Also, this inductively grounded approach fares better than a prestructured qualitative design when the phenomenon under study is unfamiliar and understudied (Miles et al., 2014).

3.1. Empirical setting and data collection

Our study focused on the Covid-19 pandemic in South Korea because it offers three advantages. First, South Korea was hit hard by the coronavirus earlier than other countries, meaning that this setting allows for a longer observation of the phenomenon under examination. Second, South Korea has successfully managed to tame the epidemic, as measured by the daily number of coronavirus cases and deaths. Finally, this country faced the outbreak of SARS in 2002–2003, whereby it had the opportunity to build certain capabilities that have been conducive to coping with the Covid-19 pandemic (Kuchler, 2020).

To select the representative cases of peripheral actors generating bottom-up solutions, we established three criteria: first, a case did not actively participate in the health-care innovation system under normal conditions; second, a case was socially considered to possess a peripheral status in the system; and, finally, a case generated solutions that were heavily used by the public and widely recognized by the local media. After collating local newspaper articles and interviewing two field experts (i.e., a health official and a pharmaceutical scientist), we purposefully sampled three nonmainstream actors: (a) Jinyong Kim, a physician who invented the idea of the drive-through coronavirus testing system; (b) a university student group that launched the Corona Doctor application, giving information about, for example, the location of regional test sites and paths of confirmed cases; and (c) a student team that developed the Mask-Nearby application, which notifies people about the availability of face masks for sale in nearby supermarkets. In early 2020, we conducted a total of nine semi-structured interviews with our informants. Data collection included several rounds of follow-up interviews that were exercised as emergent theoretical ideas producing a new set of inquiries. Each interview lasted 1 hour on average, and all interviews were digitally recorded and transcribed verbatim. The interview data were triangulated through 105 local newspaper articles. Table 1 outlines our data collection process.

| Information of interest | Data sources | Use in analysis |
|-------------------------|--------------|----------------|
| Drive-through system    | Two interviews with Jinyong Kim, who invented the drive-through testing system; 19 local newspaper articles. | Coded to identify low-level concepts and second-order categories capturing interviewees’ activities and experience associated with the coronavirus pandemic. |
| Corona Doctor app       | Four interviews with the members of the application developing team; 12 local newspaper articles. | Used in the same manner as above. |
| Mask-Nearby app         | One interview with a programmer who offered technical assistance to the application developing team; 74 local newspaper articles. | Used in the same manner as above. |
| Background knowledge    | One interview with a health official and one interview with a pharmaceutical scientist. | Contributed to gaining an initial sense of the phenomenon under study. |
3.2. Data analysis

Drawing on common prescriptions for qualitative data analysis, we analyzed the data in three iterative steps. First, we collated the interview transcripts and newspaper articles to create a visual timeline illustrating sequential orders of micro-activities undertaken by each case. Second, the next step of analysis involved data reduction through qualitative coding that transformed the raw data into numerous low-level concepts representing the key activities and important actors in relation to our cases (Corbin and Strauss, 2015). Finally, we elevated the basic-level concepts toward the higher level of abstraction ‘by recognizing patterns of relationships among [concepts] within and across cases’, with the second and last authors playing devil’s advocate (Eisenhardt and Graebner, 2007, p. 25). In addition, to ensure that our findings were nested in theories, we consulted the literature on R&D team diversity, prior knowledge, and intermediaries. Put simply, as illustrated in Figure 1, our coding exercise iteratively produced: (a) first-order concepts encapsulating informant voices; (b) second-order categories identifying generalized patterns of activities and interactions undertaken by our cases; and (c) aggregate dimensions grouping the second-order categories in a manner that adds to the extant theoretical understanding. After completing data coding, we engaged in member checking, whereby the summary report of our findings was sent to three key informants, who, in turn, assessed whether our data interpretation fit the perspectives of the ‘groups from which data are solicited’ (Guba, 1981, p. 85).

![Figure 1. Data coding structure.](image-url)
4. Findings

4.1. Covid-19 outbreak in South Korea and innovative solutions

Coronavirus landed in South Korea on January 20th, when an infected foreigner arrived at the Korean airport tested positive. Since this first case of the new virus, the number of infections drastically increased to the point that, at the height of the outbreak on February 29th, 813 new cases were registered, bringing the country’s total caseload to 12,888. In response to this national crisis, South Korea rolled out a series of measures to curb the coronavirus pandemic, and, in March, the spread of the deadly disease began to taper off. The country finally seemed to flatten the first wave of the epidemic, with many other countries citing South Korea as a benchmark (Brazinsky, 2020; Fildes and Espinoza, 2020; Kuchler, 2020). The major reason for this success was the country’s massive testing campaign – indeed, after identification of the first case, local hospitals and municipal governments quickly ramped up testing, to the extent that nearly 400,000 people were diagnosed in less than 2 months (The Government of the Republic of Korea, 2020). Although the tremendous testing capacity of South Korea was derived from central actors in the national innovation system (e.g., the center for disease control, diagnostics manufacturers, and public health laboratories), there were equally important actors that received relatively scant attention. Our findings revealed that such ‘unsung heroes’ entail: (a) a doctor who invented a drive-through testing system, which contributed to the diagnosis of all suspected cases; and (b) college students who developed applications, which enabled individuals to understand if they might have been exposed to the coronavirus and to prepare themselves following the possible contact with infected people. In what follows, we demonstrate how these peripheral actors came up with the innovative solutions.

4.2. Innovative solution I: Drive-through coronavirus testing system

In late February, the coronavirus epidemic in South Korea entered a serious phase when the southern city of Daegu encountered a remarkable jump in the number of infections, having nearly 80% of confirmed cases at the height of the outbreak. On February 20th, the mayor of Daegu city made an urgent appeal for help to infectious disease doctors. Subsequently, Dr Jin Yong Kim endeavored to come up with a functioning solution to prevent hospitals from being overwhelmed by the explosion of cases. Dr Kim finally invented an idea that came to be known as the ‘drive-through testing system’ and, on February 21st, in the morning, he announced a PowerPoint document outlining this innovative solution to the relevant medical community. Two days later, a local hospital in the city of Daegu setup drive-through clinics for the very first time in the world. Later on, similar drive-through testing centers were opened up throughout South Korea.

Although Dr Kim was an infectious disease specialist, he was not a mainstream doctor in the Korean health-care/medical system. In South Korea those who played central roles in the system were medical professors completing residency programs with prestigious medical schools, and, subsequently, working for major hospitals. For this reason, the local news articles described Dr Kim as a peripheral doctor whose voice had been not salient in the system under normal conditions. This peripheral status, however, encouraged him to collaborate often with experts and researchers in other domains (e.g., architectural engineering and bioterrorism), rather than interacting only with doctors. Such interdisciplinary collaboration served as the basis for the development of the drive-through testing system. Dr Kim remarks:

[The] mainstream route for doctors begins with an undergraduate education and postgraduate studies in medical school and ends with a medical professorship. I did not want to follow this conventional path… In genetic terms, in-and-in breeding is inferior. Hybrid is stronger… For example, I did a collaborative research project where there were architectural engineers, mathematicians and communication scientists… This four-year collaboration broadened my intellectual boundary, really… My paper on the drive-through system includes one of those architectural engineers who contributed to the ventilation and equipment of this solution. (Interview, May 12, 2020)

We also found that the idea of the drive-through testing system came from prior knowledge that Dr Kim acquired when treating the first coronavirus patient in South Korea. Dr Kim was able to treat the first infected patient because he worked for the medical center nearest to the airport where the foreign lady suspected of being infected was sent and tested positive. During treatment, Dr Kim discovered that the new virus differed markedly from severe acute respiratory syndrome (SARS) and Middle East respiratory syndrome coronavirus (MERS), which he examined when they broke out in early 2000 in Korea. While an asymptomatic patient could carry a large amount of the Covid-19 virus, the previous coronaviruses proliferated in human bodies in
parallel with serious symptoms. Therefore, early on he concluded that the central tenets of the coronavirus testing system should be: (a) diagnosing ‘anyone’ suspected of being infected; and (b) testing ‘outside’ hospitals to maximize ventilation. This insight was further developed into the idea of the drive-through testing system through knowledge gained from a past research project. The following quote is illustrative:

I engaged in a collaborative project on bioterrorism. Back then, one expert on counter terrorism showed me a YouTube video that plays an American bioterrorism drill. Health officials there were driving cars and distributing medicines to individuals... That video made me think outside the box and, obviously, inspired me to come up with the drive-through model. (Interview, May 25, 2020)

4.3. Innovative solution II: Application software

As the daily number of cases began to rise in South Korea, university students voluntarily formed teams to develop web or mobile applications (hereinafter, apps), allowing convenient access to coronavirus-related information. The Corona Doctor and Mask-Nearby apps were two cases in point. The Corona Doctor app, developed by three students of Inha University, enabled users to see the footprints of infected cases, the location of regional test sites and aggregate newspaper articles from multiple sources. The Mask-Nearby app, created by four students of Korea University, allowed users to check the on-shelf availability of face masks in nearby stores.

In line with the inventor of the drive-through testing idea, our findings reveal that the app-developing students were actors at the periphery of the IT system. These university students were not professional software developers; nor did they work for IT firms. This peripheral nature gave them the latitude to make the apps they wanted, rather than what others directed them to develop. Furthermore, interdisciplinary collaboration featured prominently in the work of these students. Indeed, the Corona Doctor team comprised members in the field of computer science and biotechnology. The Mask-Nearby team, likewise, was made up of students in the field of media studies, industrial design, and psychology. Finally, it took only 2 days for the Corona Doctor team to launch the app after deciding on its development. We observed that the prior knowledge of these students served as the impetus for the speedy app development. For example, one of the members of the Corona Doctor team explained:

[A few months before developing our app] we participated in a hackathon event together. Here we needed to develop a final, functioning program within a day or so. This experience prepared me to know how to swiftly make an app and how we can collaborate well. (Interview, May 27, 2020)

The hackathon events prepared the case students to gain skills in speedy app development; however, they did not require the students to produce apps tailored to health-care emergencies. In what follows, we explain how the students developed effective, affordable, and customer-facing apps without sufficient knowledge about what customers (or the public) need in a health-care crisis.

4.4. Roles of intermediaries

Our data revealed the existence of intermediaries that supported the innovation process of the drive-through solution and coronavirus-related apps. First, as our interviewees commonly remarked, customer demand was clearly articulated through the services of information intermediaries during the coronavirus crisis. For example, to understand what individuals want to know about the coronavirus epidemic, the student app developers initially relied on Naver, a Korean web portal platform showing the latest hot searches on a real-time basis and aggregating newspaper articles with reader comments attached. One of the student developers put it as follows:

Initially, we looked around Naver’s real-time hot searches to understand the interest of people during the pandemic… And, as you know, news articles on Naver come with reader comments. These comments revealed what people really need. I think that web portal platforms played the role in enabling us to understand the demand of people. (Interview, May 24, 2020)

Second, intermediaries also played a role in promulgating the innovative solutions generated by peripheral actors. For example, after coming up with the idea of the drive-through testing solution on February 21st, Dr Kim immediately shared a PowerPoint document describing this novel testing system with the Korean surveillance system of emerging infectious diseases (KOEID). This information-sharing platform, made up of public health experts, then made the drive-through idea widely known to doctors so that, on February 23rd, a local hospital in the country’s virus hotspot was able to quickly setup the
world’s first drive-through centers. Similarly, right after the coronavirus apps had been launched, information intermediaries, such as the press and university public relations divisions, promoted the apps for social benefit.

Finally, intermediaries provided varying degrees of technical assistance with peripheral innovators. One educational organization, known as Soft Squared, voluntarily offered a series of marketing assistance for the Corona Doctor app to be widely used. Likewise, another educational organization, Like Lion, helped the Mask-Nearby team to deal with server-side issues of app programming, and even willingly paid the server cost for app hosting. The director of this educational organization put it like this:

I heard that the students started struggling with the app maintenance, as the number of users was explosively increasing. So, I wanted to help them handle such a technical problem… This was a rare opportunity for me to have a good influence for millions of people in this very short period. So, I was more than happy to help these students. The thing is we faced an enormous server cost because we rushed to make this app as soon as possible. I paid this without hesitation and no regrets. (Interview, May 13, 2020)

5. Discussion and implications
5.1. Mechanism of bottom-up solutions in a time of crisis

Our findings reveal that bottom-up solutions in a crisis situation transpire on the basis of three innovation drivers and three functions of intermediaries (see Figure 2). First, we find that innovation systems in emergencies experience the intake of new actors, which are located at the periphery, or even outside the systems, under normal conditions. These actors come up with innovative solutions, driven by their: (i) peripheral status; (ii) interdisciplinary collaboration; and (iii) prior knowledge.

Our analysis demonstrates that the inventor of the drive-through testing system and the student developers of the coronavirus apps are not categorized as actors who are considered to be central and influential in respective systems in normal times. Rather, they are peripheral actors with marginal power or influence. Such peripheral status in a time of crisis, paradoxically, serves as an advantage for commencing innovation activities. This is because peripheral groups are relatively free from institutionalized processes of innovation, compared to central actors (e.g., medical professors in major hospitals and large IT firms) that are captivated by established innovation processes and decision-making procedures (Leblebici et al., 1991; Salerno et al., 2015). Next, peripheral actors typically lack the essential resources for innovation activities, thereby exploring collaboration opportunities to overcome the resource constraints. In our cases, the drive-through testing idea was invented by a nonmainstream doctor, with the support of an architectural engineer. Likewise, the coronavirus apps were developed by students majoring in different subjects. Such diversity acts as a driver of bottom-up innovation because ‘teams with diverse backgrounds bring together a wider spectrum of task-relevant knowledge, experience and perspectives that are distinct and non-redundant [and] which can be combined in new ways’ (De Saá-Pérez et al., 2017; Martinez et al., 2017, p. 311). Another important driver is the prior knowledge of peripheral actors. The drive-through testing
solution, for example, might not have come into being if the inventor had not acquired knowledge about the new virus during his treatment of the first infected case, and the patients of previous coronaviruses (e.g., SARS). Moreover, the students were able to quickly develop coronavirus apps because they had acquired the relevant tacit knowledge from hackathon events. This echoes the literature suggesting that innovative ideas are accompanied by prior knowledge, which guides the direction of solution and enables innovators to understand the implications of the solution discovered (Dew, 2009; Kuo et al., 2019).

Second, we also identify that intermediaries directly and/or indirectly support the innovation activities of peripheral actors in three ways: (i) demand articulation; (ii) technical assistance; and (iii) promulgation of bottom-up solutions. In a time of crisis, what customers demand becomes transparently observable because of the demand articulation of information intermediaries (or infomediaries), which ‘gather and organize large amounts of information and act as an intermediary between those who want the information and those who supply the information’ (Muzellec et al., 2015, p. 140). Given that one of the most difficult parts of innovation is often referred to as the identification of customer needs (Callahan and Lasry, 2004; Schweitzer et al., 2018), the infomediaries’ demand articulation substantially lowers the barrier to undertaking innovation activities, in the eyes of peripheral actors. Next, intermediaries also provide varying degrees of technical assistance with the innovation activities of peripheral actors, in a manner that helps the bottom-up solutions to become more customer facing. Moreover, intermediaries promulgate the solutions of peripheral actors, which may otherwise remain largely unknown to those who need them.

5.2. Implications

This study contributes to the innovation studies by providing theoretical implications for understanding bottom-up solutions in crisis situations. The first implication concerns the innovation drivers that precipitate the innovation activities of peripheral actors that are, under normal conditions, located at the edge of the innovation landscape. Our findings confirm that several innovation drivers that are primary for formal organizations in normal times are also central to the innovation activities of peripheral actors in a time of crisis. These common drivers include accumulated knowledge, collaboration, and intermediary support. This study also reveals a unique innovation driver – peripheral status – that plays out, especially in an emergency. As we have intimated, actors possessing a peripheral status in innovation systems are not tightly tied to institutionalized innovation processes, thereby having greater leeway to invent or develop what they want, without the need to go through a complicated decision-making procedure. The second implication relates to the role of intermediaries in supporting the innovation activities of peripheral actors. In congruence with the extant literature, we identify that intermediaries’ functions of demand articulation, technical assistance, and promulgation are equally important in a time of crisis. Yet, unlike the existing research, our findings demonstrate that these services are offered on a voluntary or ad hoc basis by organizations, which may not provide such offerings at all in normal times.

Our findings also provide two sets of practical implications for governments preparing to cope with the potential second wave of Covid-19 epidemics. First, bottom-up solutions point to the importance of the human resource base in a country facing a catastrophic emergency. By implication, the greater the quality/variety of human resources possessed by a country, the more likely it is that they can tackle a catastrophic emergency, with both top-down and bottom-up solutions being simultaneously worked out. Indeed, innovation studies have confirmed that countries with larger stocks of high-quality human resources show greater persistence in their innovative activities during crises (Filippetti and Archibugi, 2011). Understood as such, (a) before a time of crisis, countries should attempt to expand their human resource bases to the extent that even large numbers of peripheral actors are equipped with certain degrees of technical capabilities and entrepreneurial mindsets; and (b) in a time of crisis, they must protect their human resources, both at the center and the periphery, in respective innovation systems. Second, peripheral actors encounter varying degrees of technical and financial issues when creating innovative solutions. This implies that governments have a role to play in promoting the innovation activities of peripheral actors in emergencies: they may introduce (a) funding programs that provide direct financial support for peripheral actors having difficulty managing their innovative solutions; and (b) incentive programs that encourage the innovative activities of individuals in a crisis situation. Our study shows that government R&D funds play a vital role in establishing vibrant innovation systems in normal condition. In the case of Korea, four among five health-care firms which developed a Covid-19 diagnostic testing kit have received government R&D funds over 5 years (The Government of the Republic of Korea, 2020). This suggests that government financial help and its
orchestration behind the scene can be an important element affecting reaction capability (and resilience) in a time of crisis.

5.3. Future research directions

The present study can be further developed through several lines of future research. First, our findings are derived from a single national context so that their generalizability is demarcated by a certain boundary condition. Building on the mechanism of bottom-up innovation identified in this study, future research may explore how bottom-up solutions are generated in other countries. Second, the student developers highlighted in this study represent digital entrepreneurship enacted by actors conventionally categorized as customers in ecosystems (Park et al., 2020). Future research could examine how and why customers engage in entrepreneurship in a time of crisis. Finally, the Schumpeter Mark I innovation predicts that the innovative base, in a time of upheaval, is 'enlarging through the entry of new innovators' (Malerba and Orsenigo, 1996, p. 452). Our findings suggest that peripheral actors in innovation systems represent one such new innovator. Future studies may explore other types of new actor, bringing with them innovative solutions in response to crises.

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**Notes**

1. In this work, the word ‘emergencies’ (or crisis situations, and similar) refers to health-care emergencies, unless otherwise noted.
2. The way in which we collected the newspaper articles is available upon request from the authors.
3. Dr Kim and his colleagues recently published a paper on the drive-through testing system (see Kwon et al., 2020).

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