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Crisis-driven innovation and fundamental human needs: A typological framework of rapid-response COVID-19 innovations

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ABSTRACT

As a microcosm for future challenges, the COVID-19 pandemic exhibits increasingly transboundary dynamics, causing interconnected problems across multiple societal systems. To examine the role of innovations as a social mechanism to reconcile these arising challenges, we view the unfolding of the pandemic through the lens of a content analysis of 707 innovation projects that address the fundamental human needs of consumers and businesses. This study proposes a novel procedure to characterize large-scale innovative activities via text mining and employs a theoretical framework for identifying the pressing societal needs amidst crises. Our typology of rapid-response COVID-19 innovations exhibits a diverse set of domains ranging from technological innovations to what may be described as frugal and social innovations. We provide evidence for the growing prevalence of social needs beyond the basic notion of safety during the early months of the crisis. Our contributions show that a structural model of innovation activities and their latent drivers may help policy makers and innovators to move toward achieving a systemic reaction to such crises.

1. Introduction

As the worst pandemic in the age of globalization, COVID-19 has confronted our societies with unprecedented threats and challenges. The virus has taken many lives and destroyed livelihoods worldwide. The current pandemic has been described as a microcosm for future societal challenges (Engler et al., 2020). Soin (2009) argues that the shapes and impacts of modern crises generally extend over prolonged durations and exhibit increasingly transboundary dynamics, simultaneously impacting multiple life-sustaining systems, sectors, and social functions. In hindsight, global actors reacted hesitantly to the early signs of the COVID-19 pandemic. This may be indicative of societal systems not being prepared for (or not even being aware of) what—in the face of arising wicked problems (Rittel and Webber, 1973)—has been described as a growing systemic risk caused by increasingly frequent calamities (Norman et al., 2020). Although challenges such as climate change and other anthropogenic problems of our time may best be met by sustainable, long-term transitions within our society (Abson et al., 2017; Patterson et al., 2017; Schlaile and Urmetzer, 2021), it is also of paramount importance to not ignore short-term reactions to such events. The severity of immediate impacts may affect our economy by inducing lasting recessions (World Bank, 2020) and our environment by causing ecological rebound effects (Barreiro-Gen et al., 2020). Such impacts may even shape our societal perception of future crises and the reaction toward them.

In the short term, the interconnected effects of the COVID-19 pandemic are attacking physical health, societal institutions, and economic welfare at once—threatening how we live, work, and interact. Immediate responses to the crisis have been driven by top-down politics imposing contact regulations to reduce the number of newly infected people and the rate of COVID-19 hospitalizations. This, in turn, has caused a plethora of other social issues ranging from economic costs to the lack of childcare or psychological harm (Bavel et al., 2020). However, allowing economic recovery through loosening lockdown regulations comes at the risk of increased rates of infections. Recent social-scientific contributions have investigated the effects of the pandemic on changes in pronounced human needs during the crisis. For example, Matias et al. (2020) show that both the virus itself and the measures undertaken to fight its propagation may simultaneously...
affect—as intended effects or as unintended side-effects—the satisfaction of various fundamental human needs, ranging from the need for physical health to the need for a living social environment. Suh et al. (2020) show that fundamental human needs for health and protection have severely increased during the pandemic. They also find that other needs for self-actualization, cognitive fulfillment, or love and belonging have been more frequently expressed after lockdown regulations were imposed and as time went on, whereas other needs started to decline after an initial peak. These studies suggest that the dynamic monitoring of the expression of unfulfilled human needs is necessary to guide policies and relief efforts during the pandemic (Ryan et al., 2020; Suh et al., 2020). Identifying prevalent needs is necessary but not sufficient for supporting the fulfillment of these needs; however, these relatively descriptive population-scale studies do not offer an investigation into the concrete mechanisms of satisfaction for rising human needs.

To contribute a perspective on how rising needs are met by solutions, we propose to follow Max-Neef et al. (1989) in understanding market demands as expressions of these fundamental human needs and innovations as provisions for the satisfaction of these needs, which emerge on the side of both consumers and producers. Crisis-driven innovations may be understood as a crucial way of addressing these complex or even competing societal needs during times of dire straits (Bessant et al., 2015). This proposition naturally leads to considering the emerging stream of research focused on innovation activities during COVID-19. Recent contributions in innovation research focus on an organizational or a firm-level perspective to present a techno-economic interpretation of the innovation process, which mainly centers on a procedural and technical framing of innovation activities for and in times of need (Biron et al., 2020; Kraus et al., 2020; Kuckertz et al., 2020). They explain how firms cope to survive the economic fallout of the pandemic and how innovation processes are structured and conducted. These contributions show that firms respond to emerging challenges by accelerating digitization (Kraus et al., 2020; Wang et al., 2020), rethinking corporate practices (Biron et al., 2020; Juergensen et al., 2020; Wang et al., 2020), or developing frugal solutions (Cankurtaran and Beverland, 2020). Startups rely on a bricolage approach (Kuckertz et al., 2020) and outpace other actors in their responses to emerging challenges (Ebersberger and Kuckertz, 2021). Cheshbrough (2020) particularly highlights the importance of open innovation (Cheshbrough, 2003; Enkel et al., 2009): scientists, pharmaceuticals, governmental institutions, non-governmental organizations (NGO), communities, and individuals should join forces to mobilize knowledge, to speed up the creation, launch, and testing of possible solutions, and to eventually combat the pandemic. Similarly, Crick and Crick (2020) point out how cooperation—that is, strategic cooperation with competitors—can effectively contribute to the global effort to mitigate the impact of the pandemic through the sharing of resources and capabilities. Another relevant strand of literature highlights the importance of—and the opportunity for—more collaborative and prosocial action (Basc et al., 2020; Bouman et al., 2020; He and Harris, 2020). These studies suggest that crises may increase the needs of businesses and entrepreneurs for economic subsistence, collaboration, and creation activities; they also make substantial contributions to the understanding of firm-level innovation processes during crises. However, thus far, this strand of literature has been biased toward an organizational and techno-economic perspective. It is only implicitly acknowledged whether innovations respond to emerging human needs in society and are, therefore, actually useful in contributing solutions to crisis-induced problems. Some studies feature rather limited technological examples, such as the severe shortage of ventilators as an example for cross-industry cooperation to accelerate the provision of these desperately needed devices (Cheshbrough, 2020). Although the above-mentioned contributions help to understand how crisis-driven innovations are created, they tell us little about the breadth and dynamics of innovative solutions emerging across multiple actors or about the guiding motives initiating these responses within innovation systems. However, crises affect collectives and are to be collectively overcome (Engler et al., 2020; Hekkert et al., 2020). An insufficient systemic understanding of the emergence of novel solutions during this unprecedented crisis runs the risk of misconceiving the complexity of both the innovation process and the ramifications of the current pandemic.

Current social science population studies (Suh et al., 2020) identify human needs and the resulting societal problems during COVID-19 but have not investigated the solutions to these problems. In contrast, innovation research (Basc et al., 2020; Ebersberger and Kuckertz, 2021; Kraus et al., 2020; Kuckertz et al., 2020) has largely focused on the process of innovating during crises but not on the domains of innovations and whether they correspond to different and changing human needs. This is why our study aims to integrate the concepts of fundamental human needs and innovation to derive a typological framework of rapid-response COVID-19 innovations and their latent drivers. We contribute to both aforementioned streams of research by offering an exploration of the solution space, corresponding to the prevalent and dynamically changing human needs, which is emerging through a crisis-driven innovation system. This perspective contributes a better understanding of the collective response and of how the search for solutions is guided within crisis-driven innovation systems and may inform practical implications for consumers, practitioners, and policymakers as well as their responses to the current crisis. Finally, our analysis reveals the possibilities of embedding rapid-response innovations into a socio-ethically guided and dedicated innovation system attuned to future challenges (Ghazinoory et al., 2020; Hekkert et al., 2020; Pyka, 2017; Schlaile et al., 2017).

To examine the domains of rapid-response COVID-19 innovations and the human needs they correspond to, we adopt a two-stage approach. First, we identify the arising innovation trends during the first two months of the COVID-19 crisis utilizing machine learning to construct a topic model (Maier et al., 2018) based on web-scraped text data of 707 innovation projects related to the COVID-19 crisis (henceforth, COVID innovations). In doing so, we contribute a novel procedure for characterizing large-scale innovation activities by employing the text mining technique of topic modeling using text data of innovation projects. Subsequently, we estimate the time trend of the identified domains of innovations over the two-month observation span using simple regression analysis to identify the rising and falling dynamics of the rapid-response COVID innovations. Second, and based on the derived structural model of innovation activities, we connect the different identified domains of innovations to a more latent classification of fundamental human needs, which is based on the contribution of Max-Neef et al. (1989). Employing this two-stage approach, each crisis-driven domain of innovations is thematically characterized, and its occurrence is estimated over time. Each domain is also classified according to the needs it addresses on the side of the consumers and producers of the innovations. Our results show that this perspective may help to identify points of intervention to move toward achieving a systemic reaction to such crises.

This paper is structured as follows. Section 2 substantiates our theoretical underpinning by connecting crisis-driven innovations with the notion of fundamental human needs and a perspective on innovation systems. Section 3 presents our data and methodology, including our topic modeling process, the regressions to estimate time trends, and the classification scheme to map fundamental human needs to our sample of innovations. Section 4 presents a synthesis of the derived clusters of our topic model, describing the time trends as well as human needs addressed by various domains of innovations. Section 5 discusses our findings against the backdrop of the unfolding crisis and dedicated
innovation systems. Section 6 offers some concrete practical implications of our results. Finally, Section 7 concludes the study and presents some limitations and promising avenues for future research.

2. Theoretical considerations

The COVID-19 pandemic significantly differs from previous disasters such as the global financial crisis of 2008. From a mainstream economics perspective, the global financial crisis represented an exogenous shock predominantly affecting market dynamics through decreased demand. Direct effects on the supply side were mainly limited to the finance and banking sectors. Disruptions on the industry level occurred as a consequence of the gradually unfolding recession rather than as a consequence of the crisis itself (Mandel and Vostil, 2020). In this sense, the global financial crisis represented an economic shock that was to be absorbed by the economic system, which subsequently reverted to an old normal (for an analysis of the recovery pattern, see Reinhart and Rogoff, 2014). The COVID-19 pandemic, in contrast, has immediate effects on economic welfare but also on physical health and the entire socioeconomic system. Owing to highly interconnected societies, the virus is rapidly transcending geographical borders, distorting global markets, disrupting corporate and social networks, and ultimately threatening human lives and livelihoods worldwide (Norman et al., 2020). Such crises pose enormous pressure on—and can cause drastic changes in—socio-technical regimes, which may include "technology, user practices and application domains (markets), symbolic meaning of technology, infrastructure, industry structure, policy and techno-scientific knowledge" (Geels, 2002, p. 1262). They may also result in severe shortages of resources and, thus, fundamentally endanger the satisfaction of society’s demands and needs. Lockdown measures cause supply chains to collapse, rendering an interrupted provision of—in some cases lifesaving—goods and services impossible (at least through traditional ways). In this sense, both the virus itself and the lockdown measures installed to slow down its spread inhibit the satisfaction of fundamental human needs. At the beginning of the pandemic, the soaring fear of unfulfilled needs triggered largely irrational consumption decisions, leading to the stockpiling of durable goods, toilet paper, and other hygiene products (Garbe et al., 2020; He and Harris, 2020). Thus, identifying the system of human needs and integrating this perspective into response and decision-making strategies is crucial for preventing societal harm and instability during crises. Similarly, Ryan et al. (2020) remind us that considering human needs is an important approach to designing adequate crisis management policies.

2.1. Human needs and satisfiers

With regard to the notion of fundamental human needs, various disciplines and schools of thought offer quite different understandings, definitions, and approaches (Cruz et al., 2009; Doyal and Gough, 1984, 1991; Maslow, 1945; Max-Neef et al., 1989). The word “need” is used in many ways, and human needs are frequently confused with human “aims,” “goals,” or “wants” (Doyal and Gough, 1984, 1991). One of the most-cited approaches to structure human need systems is Maslow’s (1945) hierarchy of needs. In his theory of human motivation, Maslow identifies three different kinds of needs following a hierarchical structure: basic needs (entailing physiological and safety needs), followed by psychological needs (entailing belonging and love as well as esteem needs), and, on top, self-actualization needs. Criticizing Maslow, scholars such as Doyal and Gough (1984) argue against such a hierarchical presentation and state that, in fact, “human needs are systematic or interwoven like a web” (p. 11). In their theory of human needs, Doyal and Gough (1984, 1991) differentiate between individual needs—such as survival, health, autonomy, or learning—and societal needs, such as production, culture, and communication. Likewise, Max-Neef et al. (1989) reject the hierarchical structure of needs: “Human needs must be understood as a system: that is, all human needs are interrelated and interactive. With the sole exception of the need of subsistence, that is, to remain alive, no hierarchies exist within the system. On the contrary, simultaneities, complementarities and trade-offs are characteristics of the process of needs satisfaction” (p. 19). Max-Neef et al. (1989) present a matrix of needs and potential satisfiers. The nine axiological needs are subsistence (e.g., being healthy, having food and shelter, or acting in a social environment), protection (e.g., having social security and health systems), affection (e.g., having friends and expressing emotions), understanding (e.g., having teachers and learning materials and interacting in schools or universities), participation (e.g., interacting in churches and communities), leisure or idleness (e.g., having games or parties), creation (e.g., being able to work and invent), identity (e.g., having symbols and religion and interacting in everyday setting), and freedom (e.g., having equal rights or developing awareness for equality). This presentation of needs and their different categories is arguably one of the most comprehensive ones that considers not only different kinds of needs but also how these needs can be addressed or satisfied (Cruz et al., 2009).

Max-Neef et al. (1989) introduce five different types of satisfiers for human needs, based on their relation to the satisfaction of other needs (see also Cruz et al., 2009): violators or destroyers seem to satisfy one need, potentially linked to protection, but at the same time—and somewhat paradoxically—they make the satisfaction of this very same need and/or other needs impossible. Often, the employment of these types of satisfiers is motivated by fear and displays a dynamic of supposed short-term benefits being outweighed by longer term negative consequences (e.g., gun ownership contributing to an immediate sense of protection leading to an arms culture that impairs the fulfillment of the need for protection in the long run). Being slightly less detrimental, so-called inhibiting satisfiers do not render the fulfillment of other needs impossible, but they seriously inhibit their satisfaction. In general, inhibiting satisfiers are created when over-emphasized singular needs exert a crowding out effect on the potential to fulfill other needs. Pseudo-satisfiers pretend to satisfy a need, provide a false sense of satisfaction, and might, in the medium term, hamper the real satisfaction of the need they initially targeted. Returning to the example of gun ownership, one may argue that the possession of a firearm may actually increase the likelihood of harm while allowing a false perception of safety. Singular satisfiers address one single need and are neutral toward the satisfaction of other needs. Finally, synergistic satisfiers satisfy a given need and simultaneously support the satisfaction of other needs (for more explanation and examples see Max-Neef et al., 1989, pp. 34–37).

2.2. Three propositions on innovation in times of need

Based on the interpretation of different satisfiers offered by Max-Neef et al. (1989), the COVID-19 pandemic and the imposed lockdown measures act as inhibiting satisfiers for various needs of both consumers and businesses. Although these satisfiers clearly seek to fulfill the need for subsistence and/or protection of physical health, they simultaneously impair the common way of satisfying almost all other needs, ranging from affection, participation, and leisure to freedom. Beyond that, these satisfiers may even be violators in the sense that they address the need for physical subsistence but exert a negative effect on other dimensions of subsistence (e.g., mental health). Under these restrictions, the virus compels society to change the traditional ways of seeking to
satisfy needs for subsistence and protection and calls for innovative medical goods and services such as pharmaceuticals, vaccines, and medical devices. At the same time, lockdown regulations prioritize the satisfaction of the need for (physical) protection but render society’s old ways of fulfilling other cognitive, emotional, societal, and no less, economic needs infeasible (Matias et al., 2020; He and Harris, 2020). However, history has shown that if a crisis is pervasively endangering the fulfillment of human needs, human ingenuity finds new ways to reach satisfaction (Pyka et al., 2019). These new ways may come in the form of innovations that alleviate the pressure resulting from the threat, restrictions, and regulations (Mowery and Rosenberg, 1993). In their seminal paper, Mowery and Rosenberg thoroughly discuss research on the relationships between (user and producer) needs, demand, and innovation. They conclude that both producers’ and consumers’ needs simultaneously influence and guide the innovation process (in terms of supply push and demand pull). “[N]eeds manifest themselves through demand which, in turn, is determined by individual preferences for the goods produced. To include satisfiers within the framework of economic analysis involves vindicating the world of the ‘subjective’, over and above mere preferences for objects and artifacts” (Max-Neef et al., 1989, p. 27). According to Yu (2018), fundamental human needs always have the potential to engage, motivate, and mobilize people. A need always offers the potential for different satisfiers to emerge, creating the opportunity for actors in the system to provide a heterogeneous set of potential satisfiers (Cruz et al., 2009). In economic terms, the satisfaction of human needs creates value, whereas the probability of not satisfying these needs relates to risk. Thus, identifying and understanding fundamental human needs is essential for effectively managing innovations (Yu, 2018). As Hekkert et al. (2007) argue, preferences (as an expression of needs) may influence the direction of (technological) innovations if they are “strong and visible” (p. 423). In times of crises, the endeavor to identify needs may thus be of crucial importance to provide guidance of search to innovative and other endeavors seeking to alleviate the fallout of the pandemic. This leads us to our first proposition:

**Proposition 1.** (P1): Crisis-driven innovations address multi-dimensional human needs.

The pivotal role of innovations in times of crises has been extensively discussed against the backdrop of previous disasters (Archibugi et al., 2013; Bessant et al., 2012; Hausman and Johnston, 2014). Typically, fast-growing and highly innovative firms can effectively harness windows of opportunity to exploit unmet market needs (Giotopoulos et al., 2017). In particular, small companies and startups appear to be capable of rapidly responding to crises. They actively use their relational capabilities and creatively develop solutions using existing resources (Weick, 1993). Following Bessant et al. (2012) and their concept of crisis-driven innovations, these innovations often take the form of simplified, low-cost adaptations of existing solutions (which we may call frugal innovations; Weyrauch and Herstatt, 2017) and are characterized by creative recombinations stemming from very different, even unrelated, fields. Entrepreneurs, in particular, seem to act as brokers combining and assimilating knowledge (Bessant et al., 2012). Archibugi et al. (2013) argue that firms following a more explorative approach to the innovation system function that Bergek et al. (2008) and Hekkert et al. (2007) have called the direction or guidance of search (in the sense of incentives or selection pressures acting on the individuals and organizations within an innovation system). This is attributable to the potential cascading effects of the needs and their satisfaction on other actors (firms, consumers, etc.) within the system or—as Schumpeter puts it—the observation “that needs and their visible satisfaction immediately lead to a contagious effect on the economic agents in the vicinity” (Schumpeter, 2002, p. 104). Owing to the trans-boundary dynamics of the COVID-19 crisis and the imposed lockdown regulations, different pronounced human needs emerged in society, leading us to the proposition that we observe different domains of innovations emerging in a system of heterogeneous actors.

**Proposition 2.** (P2): Different pronounced human needs drive the emergence of different domains of innovations during crises.

Whereas fundamental human needs are universal, the satisfiers and the economic goods we use as satisfiers differ between cultures and change over time and owing to certain circumstances (Max-Neef et al., 1989). Ryan et al. (2020) note that individuals’ willingness to accept the cost for additional risk reduction during the COVID-19 pandemic is not static but changes over time. Based on a study of the U.S. population, Suh et al. (2020) show that the frequency of expressions of different human needs changes over time (from January to August 2020) owing to seasonal effects or to major events such as the current pandemic. Fundamental human needs seem to become more urgent when the crisis...
itself and the different measures undertaken to address it inhibit their satisfaction. More precisely, Suh et al. (2020) differentiate among the five hierarchical dimensions of needs according to Maslow and show that expressions of physiological needs peaked in early March 2020, and subsequently dropped and remained at an extremely heightened level. Expressions of safety needs exhibited a similar but lagged trajectory, with their peak in early April. The authors document expressions of cognitive needs to be highly pronounced from March to May but continuously decreasing subsequently, likely owing to the deescalating dynamic of the pandemic in the early summer months. Expressions of needs for love and belonging exhibit a steady climb until mid-April and remain on a slightly heightened level after that, compared with pre-crisis levels. Expressions of the need for self-actualization display a steep rise until April and remain on a comparatively high level but steadily decrease through the summer months. Based on these observations and our previous propositions, we further propose that the changing urgency of the different human needs expressed in society during the course of a crisis may also correspond with the changing trends for domains of innovations over time.

Proposition 3. (P3): Crisis-driven innovations respond to the changes in human needs over the course of a crisis.

3. Methods

To provide evidence for the three aforementioned propositions, we conduct a content analysis on text data describing 707 innovations during and for the COVID-19 pandemic with the aim of producing a typological framework of rapid-response COVID-19 innovations. Our methodology seeks to produce this framework through a modern interpretation of what Kraeauer (1952) describes as a valuable overlap between quantitative and qualitative techniques of content analyses. Aiming to investigate P2, we employ a machine learning algorithm designed for topic modeling. Topic modeling produces a quantitative and descriptive picture of the latent thematic structures in large amounts of text data (Maier et al., 2018). Our calculated topic model identifies unique domains of COVID innovations by grouping the 707 individual innovation projects based on the semantic (dis-)similarities of textual project descriptions. Each domain is characterized by a set of frequently occurring keywords, which helps us to develop an understanding of the types of innovations emerging in response to the first wave of COVID-19 infections. We can also measure the diversity of the domains of innovations using semantic distance scores. Finally, we confirm the quantitative characterization of the identified domains of innovations of our topic model through a qualitative assessment of the contents of the 10 most representative innovations for each of the 16 domains (160 innovations in total).

Although the identification of domains of innovations addresses our second proposition before the first one, we can work backward from this point to investigate P1. We integrate our derived structural model of innovation domains with an assessment of the human needs addressed by different domains of innovations. Accordingly, we apply a coding scheme (Krippendorff, 2004) to the contents of the identified 160 most representative innovation projects to differentiate between the 9 fundamental human needs based on the theoretical framework proposed by Max-Neef et al. (1989). This coding procedure helps to identify which types of innovations emerge as satisfiers for which types of latent fundamental human needs during the COVID-19 crisis. To address P3, we statistically test the occurrence of each of the 16 identified domains of innovations over time. This allows us to create a more dynamic picture of the trajectories of domains of innovations, which helps us to understand how market demands and innovative offerings have changed in response to emerging societal needs over the first two months (after lockdown measures had been widely introduced). The following sub-sections will expand on each step of the methodological procedure.

3.1. Data retrieval

In our analysis, we use data on the innovation level, thus following the object-oriented approach and presenting an alternative to the so-called subject-oriented approach, which, for example, analyzes firms on the micro level. Using the object-oriented approach, innovations can be identified in two different ways. First, innovations can be identified through expert assessments, by scrutinizing publications in trade journals, or through a combination of both. This approach has been used for building the Science Policy Research Unit (SPRU) innovation database (Pavitt et al., 1987, 1989; Townsend, 1981), the database of Finnish innovations (Patel et al., 2014), and the database of Swedish innovations (Sjö et al., 2014). Second, one can identify the sample of innovations through online sources, which is the approach we follow. In this study, the data originate from a joint initiative of the consumer foresight firm TrendWatching and the impact consulting firm Business of Purpose. The two providers have collaborated for crowdsourcing, curating, and publishing a collection of innovations induced by the COVID-19 pandemic and by the subsequent lockdown measures. We used the publicly available information on their joint web-platform COVID Innovations primarily for two reasons: First, the companies build their reporting activities on the framework of “purpose-driven innovation” (TrendWatching BV, 2021), which lends itself for the classification of human needs. Second, we found that their reporting on innovation projects related to COVID-19 was more exhaustive and reliable compared to the reporting of other market foresight companies. In the first two months, from March 22 to May 20 of 2020, we identified 707 unique crowdsourced innovations that build the body of our data set. The curated information provided on the platform contains a brief descriptive title of the innovation, a short text explaining the innovation, an industrial classification, the date the innovation was first introduced into the data set, and a link for further information linking to the innovation’s website. We extract all of these information from their joint web platform using automated web scraping and compile a dataset for further processing. We validate the extracted data by cleaning faulty entries, removing duplicates and checking for the relevance of each entry (i.e., checking the respective project websites for determining whether or not this innovation is directly related to COVID-19).

3.2. Tracking domains of COVID-19 innovations

Topic modeling is a machine learning technique used to efficiently parse vast text data to obtain latent thematic structures. This technique is described as “an inductive approach with quantitative measurements, making it particularly suitable for exploratory and descriptive analyses” (Maier et al., 2018, p. 93) and starts with extensive data preprocessing. We use the text segments of the collected data described above and merge the title and description for each innovation entry. We transform all characters to lowercase and remove punctuation and special characters. We also remove the so-called stop words that are grammatical inflections. Next, we identify significant co-locations of words (terms closely co-occurring at high frequency) and compound these words into multi-word expressions (e.g., “face mask”). Finally, we remove outliers in the form of terms occurring in less than 0.1% of the documents and three terms most frequently occurring across all documents, not adding distinct meaning between documents (“COVID,” “launch,” and “people”).

Our topic modeling algorithm is based on the latent Dirichlet allocation (LDA) (Blei et al., 2003; Blei and Lafferty, 2007), which is an unsupervised machine learning procedure for parsing text data for co-occurrences of words and word patterns to derive latent structures. The algorithm delineates a distinct number of topics represented in our

\(^1\) See [https://www.COVIDInnovations.com](https://www.COVIDInnovations.com).
sample of innovation projects, which we call “domains of innovations.” Each domain is characterized by a list of frequently occurring keywords, and each of the 707 individual innovation projects receives posterior scores (from 0 to 1), indicating its coherence to the 16 identified domains (henceforth, coherence score) (Blei and Lafferty, 2009). Following Maier et al. (2018), we compute a number of different candidate models based on differing prior parameters defining the shape of the posterior distributions. Based on our data, we calculate the optimal number of topics considering the metrics proposed by Cao et al. (2009) and Griffiths and Steyvers (2004). We find that a final model with 16 topics optimally captures the heterogeneity of our text data using a prior alpha value of 0.25 to shape the posterior distribution. We run this final specification of our topic model for 10,000 iterations to ensure the reliability of our model results.

To assign a label to each domain, we consider the 10 most frequently occurring keywords that characterize a domain of innovations as well as the 10 most representative innovations featuring the highest coherence scores for a given domain. Although the number of unique domains of innovations (16) maximizes the thematic heterogeneity between domains and homogeneity within domains, we can further cluster these domains based on their similarity. The clustering simply helps to report our results in a coherent manner—that is, to report the results of domains that are similar to each other together. To aggregate the 16 domains into overarching clusters, we employ a hierarchical clustering algorithm (Miller and McCoy, 2017; Bui et al., 2016) using Hellinger distance, which is commonly applied to calculate the (dis-)similarity of topics in topic models (Beykikhoshk et al., 2018). The hierarchical clustering algorithm produces six overall clusters encompassing the 16 domains of innovations. Again, we assign general labels for the six overall clusters and use these as headings to lend structure to the presentation of results in the next section.

We intend to not only show a static picture of the topics related to the COVID-19–induced innovations but also analyze the dynamics of topic development over the two-month period of observation. For each of the 16 domains of innovations and for each of the 51 days in the observation period, we compute the average coherence score based on a 3-day rolling window. Like Antons et al. (2016), we estimate both a linear time trend and a quadratic time trend model for each topic. If the estimate of the quadratic time trend is significant, we base our analysis on the quadratic time trend model. If the estimate of the quadratic time trend is insignificant, the significant linear time trend estimation forms the basis of our discussion. Neither a significant linear nor a significant quadratic trend indicate a rather constant coverage of the topic across time as captured by the annual average coherence score. In this case, we check whether the mean coherence score is above or below the average.

### 3.3. Theoretical framework for coding human needs

For a deeper understanding of the different (domains of) innovations, we classify the top 10 innovations featuring the highest coherence scores (see a small selection of these innovations in Table A.5) for each of the 16 domains according to the fundamental human needs, which these innovations address. We differentiate between the needs of the users of the innovation and the needs of the innovators producing and offering the innovation. For the classification procedure, we return to our theoretical basis and follow the definition of the nine fundamental axiological human needs by Max-Neef et al. (1989) because their “schema proposed can be used for purposes of diagnosis, planning, assessment and evaluation” (p. 37). The schema presents a matrix of the nine axiological human needs (subsistence, protection, affection, understanding, participation, leisure, creation, identity, and freedom), which we use for our classification procedure. Max-Neef et al. (1989) also present specific examples for potential satisfiers belonging to each category, which provide guiding references for the classification of the sampled innovations.

| Sector                  | Percent | Sector (cont’d) | Percent |
|-------------------------|---------|-----------------|---------|
| Health & fitness        | 19.1    | Government      | 3.1     |
| Media & entertainment   | 16.0    | Marketing       | 2.7     |
| Food & beverage         | 15.3    | Consulting      | 2.4     |
| Information technology  | 14.4    | Materials & packaging | 2.4 |
| Retail                  | 9.9     | Financial services | 2.0 |
| Electronics & robotics  | 8.2     | Beauty & wellness | 1.6     |
| Non-profit              | 7.8     | Automotive      | 1.4     |
| Travel                  | 6.6     | Construction    | 1.4     |
| Apparel & fashion       | 5.7     | Real estate     | 1.3     |
| Education               | 5.7     | Architecture    | 1.0     |
| Transportation          | 5.5     | Energy & utilities | 0.7 |
| Home & garden           | 4.5     |                 |         |

Note: Each of the N = 707 observations is assigned to one or more industries.

For coding that is conducted by more than one expert, literature suggests ensuring that a sufficient coding quality and consistency is reached among the coders (O’Connor and Joffe, 2020). Therefore, coding needs to be performed by experts with a high level of expertise and common understanding of the subject (O’Connor and Joffe, 2020). Taking this into account, we choose four authors of this study with the highest expertise relevant for coding these particular features. This set of coders has extensive experience in working with (textual) data on innovation activities and is highly educated in firm-level innovation processes, as well as the socio-systemic perspective on innovation. The coding is based on the title and descriptions of the COVID innovations. Following O’Connor and Joffe (2020), our coding process follows a three-step procedure. First, before coding, all coders study the relevant literature on fundamental human needs and discuss their definitions and interpretations. This procedure is especially justified in our case, as coding latent features often leaves room for interpretation and as our coding frame calls for a high level of expertise and prior training (O’Connor and Joffe, 2020). To ensure that the training is successful and that all coders have the needed common understanding, we divide and code the data in a way that allows us to calculate the inter-rater reliability among the coders (Fleiss, 1971). We equally divide the sample between all coders such that every coder has their own sub-sample to code. The coded sample comprises the top 10 most representative innovations (highest coherence scores) of the 16 domains of innovations, leading to 160 innovations in total. In addition, and to be able to assess the inter-rater reliability later, we distribute a small amount of additional data to all coders to check whether they can code with consistency. There seems to be no consensus on the optimal amount of data needed for credibly assess the inter-rater reliability (Campbell et al., 2013), but 10% seem to be sufficient (O’Connor and Joffe, 2020). Therefore, we base our calculation on 10% of the shared data points coded by all coders. Before beginning the coding of the full sample, following the suggestions of O’Connor and Joffe (2020), we undertake a second step to ensure common understanding among all coders. In this step, all coders hold conceptual discussions, code a pre-defined test sample, and compare the results to develop a more aligned, common understanding of the subject (O’Connor and Joffe, 2020). Finally, all coders begin to code their sub-sample of 40 innovation projects as well as the additional data needed for calculating reliability measures. We calculate the reliability between coders using Fleiss’ kappa, which constitutes an appropriate measure considering that there are more than two coders and that categories are assigned based on latent characteristics, which are neither quantifiable and weighted nor ordered (Fleiss, 1971). For the final round of coding, we achieve a Fleiss’ kappa of 0.63, which can be interpreted as substantial agreement (Landis and Koch, 1977), showing our...
After coding the innovations, we calculate a final measure for the diversity of needs addressed by each domain with respect to consumers and producers. We use the Herfindahl–Hirschman index (HHI) as a concentration measure (Laine, 1995) to assess whether the needs addressed by a given domain of innovations concentrate around a few needs or cover a wide range of needs. Originally conceived for measuring market concentration, the HHI has no fixed thresholds for this purpose; thus, we only compare relatively low (low HHI) to relatively high concentration (high HHI) of needs.

4. Results

After extraction and cleaning of data, our final sample comprises 707 innovation projects related to COVID-19. The innovations originate in various industrial sectors, intuitively concentrating in sectors revolving around health and food provisions as well as media and information. The industry breakdown is shown in Table 1. Based on this data, our topic model identifies 16 distinct domains of innovations, covering a wide range of innovations from medical equipment to delivery services and solutions for stay-at-home parenting.

The hierarchical clustering reveals that these 16 domains are spread across 6 overarching clusters. Fig. 1 depicts all six clusters branching off into unique domains of innovations. The distance between domains of innovations is a measure for thematic (dis-)similarity. Cluster one (C1) is labeled Repurposing and encompasses the two domains of Medical Equipment (D7) and Protectives (D8). Cluster two (C2) is entitled Digital Innovations and comprises the domains of Contact Tracing (D6), Monitoring (D13), and High Technology (D14). Curing Cabin Fever constitutes cluster three (C3), entailing the domains of Hospitality (D5), Home Delivery (D12), and Gastro (D15). Cluster four (C4) is labeled Online Platforms and branches off into the domains of Virtual Space (D9), Information (D2), and Support Your Local (D11). Acts of Solidarity is the fifth cluster (C5) and includes the domains of Heroes (D16), Pro-Bono (D3), and Donations (D4). Cluster six (C6) is called Self-Sufficiency and covers the domains of DIY (D1) and Child Care (D10). Table 2 presents an overview of the 6 clusters and their respective 16 domains of innovations in addition to the 15 most frequently occurring terms per domain. For example, D8 (Protectives) belongs to C1 (Repurposing) and is represented by the following 15 most frequently occurring terms (in descending order of frequency):

- mask, make, hand, produce, face shield, company, plastic, face mask, hand sanitizer, filter, manufacture, face, protective, medical worker, and material.

Whereas these lists of keywords already give an initial impression of the kinds of innovations grouped into a domain of innovations, Table A.6 in the Appendix provides a condensed selection of the top five innovations per domain of innovations ordered by coherence scores. For each of these innovations, the table exhibits a descriptive title, the publication date, and the coherence score for the respective domain.

Table 3 is the contingency table for all domains of innovations across the nine dimensions of human needs (grouped by cluster) and differentiates between consumers’ and producers’ needs. Each domain has been evaluated based on its 10 most representative innovations (highest coherence scores) and the needs served by them. For individual domains, the share of the top 10 innovations addressing a specific need is indicated in-text as a fraction (x/10) or stated in percent when aggregating the frequency of addressed needs all domains of one cluster. In
Innovation Domains and Top 15 Associated Terms.

| Cluster ID | Cluster Label | Domain Label | Top 15 Associated Terms |
|------------|---------------|--------------|-------------------------|
| C1         | Repurposing   | Medical Equipment | hospital, ventilator, design, company, develop, startup, produce, supply, medical, government, facility, university, make, build, solution |
| C2         | Digital Innovations | Contact Tracing | safe, contact, distance, feature, device, track, data, date, close, develop, make, google, health, patient, provide, care, medical, information, doctor, covid patient, network, real-time, remote, professional, healthcare, organization, startup |
| C3         | Curing Cabin Fever | Hospitality | offer, service, room, germany, office, quarantine, hotel, restaurant, open, include, coffee, space, day, work, city |
| C4         | Online Platforms | Information | share, website, world, community, story, message, send, show, time, information, good, company, platform, whatsapp, isolation |
| D1         | Virtual Space | Online, virtual, video, live, enable, student, set, school, class, tour, meet, game, experience, event, zoom |
| D2         | Support Your Local | platform, connect, initiative, support, find, volunteer, offer, business, enable people, website, tech, local, business, time, non-profit, movement, support, donate, provide, project, create, relief, organization, fund, impact, work, artist, |
| D3         | Pro-Bono | house, community, initiative, worker company, free, business, service, provide, custom, employee, support, project, retail, product, transport, offer free, give, program, campaign, uk, hero, worker, start, esa, team, frontline, give, fight, covid, provide, million, donation, work, reach, create, home, design, brand, kit, include, travel, model, collection, fashion, studio, diy, designer, dutch, artist, quarantine, family, child, kid, online, book, creative, home, parent, create, idea, free, time, lockdown, activity |
| D4         | Donations | acts of solidarity |
| D5         | Child Care | Self-Sufficiency | C1 DIY |

Table 2 (continued)

Note: This table presents the resulting topic model of the latent Dirichlet allocation algorithm based on textual descriptions for all innovations. The domains of innovations are grouped by overarching clusters (as identified through hierarchical clustering) and presented with the 15 most frequently occurring terms for each domain of innovations.

In addition, we report the HHI, which measures the concentration of needs addressed by each domain, again differentiating between consumers' and producers' needs. The closer the HHI is to the value of 1, the more concentrated is the distribution of needs addressed by a given domain. Addressing P3, the estimated dynamics for each domain of innovations over time are presented in Table 4. Predicting the variance in average coherence scores per domain, the table reports the estimates for the independent time variables measured in days (and days squared) as well as the measures of fit (R²) and model significance (F). The last two columns indicate whether we interpret the model as linear or quadratic and how the trajectory (slope of regression line) may be described. In the following subsections, we briefly synthesize the contents for each cluster by providing examples of representative COVID innovations from each domain within a cluster. We also present our classification of human needs addressed by the top innovations representing distinct topics in a given cluster. To illustrate the dynamics over time, we provide a visual impression of the time dynamics through scatterplots with estimated regression lines for all 16 domains of innovations.

4.1. Cluster 1: Repurposing production capabilities

The first cluster (C1) encompasses the domains of Medical Equipment (D7) and Protectives (D8), with the former describing innovations for equipment used in hospitals, mainly centering around the production of ventilators for intensive care units. It includes companies from different industries dynamically repurposing their manufacturing capabilities to produce ventilators or startups developing new types of ventilators. The innovation with the highest coherence score describes a new design for a low-cost ventilator that is easily scalable in manufacturing processes. In a similar vein, D8 describes the production of protective gear such as face masks, hand sanitizers, and visors. The innovation with the highest coherence score describes the furniture manufacturer IKEA switching production to offer these types of protective medical workers free of charge.

In terms of classified needs, we find that both topics within this cluster mainly address consumer needs related to protection in the sense of preventing the spread of the disease to protect themselves, others, and...
### Table 3: Innovation Domains and Respective Classification of Consumers’ and Producers’ Needs.

| ID | Clusters & Domains | Consumers’ Needs | Producers’ Needs |
|----|---------------------|------------------|------------------|
|    | N Clusters | Subsistence | Protection | Affection | Understanding | Participation | Leisure | Creation | Identity | Freedom | HHI | N Clusters | Subsistence | Protection | Affection | Understanding | Participation | Leisure | Creation | Identity | Freedom | HHI |
| **C1** | Repurposing | 20 | 60% | 90% | 5% | 0% | 5% | 5% | 10% | 5% | 0% | 15% | 70% | 45% | 0% | 80% | 0% | 65% | 20% | 0% | 0.632 |
| D7 | Medical Equipment | 10 | 9 | 8 | 1 | 0 | 1 | 0 | 2 | 0 | 0 | 0.418 | 1 | 8 | 7 | 0 | 8 | 0 | 7 | 1 | 0 | 0.424 |
| D8 | Protective Innovations | 10 | 3 | 10 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0.307 | 2 | 6 | 2 | 0 | 8 | 0 | 6 | 3 | 0 | 0.424 |
| C2 | Digital Innovations | 30 | 40% | 77% | 7% | 43% | 7% | 10% | 10% | 0% | 0% | 17% | 77% | 27% | 10% | 57% | 0% | 47% | 13% | 0% | 0.385 |
| D6 | Contact Tracing | 10 | 2 | 7 | 2 | 1 | 2 | 3 | 0 | 0 | 0 | 0.197 | 1 | 5 | 5 | 1 | 5 | 0 | 5 | 1 | 0 | 0.285 |
| D13 | Monitoring | 10 | 6 | 6 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0.424 | 0 | 9 | 3 | 2 | 8 | 0 | 4 | 2 | 0 | 0.493 |
| D14 | High Technology | 10 | 4 | 10 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0.346 | 4 | 9 | 0 | 0 | 4 | 0 | 5 | 1 | 0 | 0.385 |
| C3 | Curing Cabin Fever | 30 | 50% | 33% | 7% | 0% | 30% | 30% | 10% | 7% | 0% | 47% | 27% | 40% | 0% | 57% | 0% | 37% | 27% | 0% | 0.294 |
| D5 | Hospitality | 10 | 4 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0.241 | 5 | 4 | 4 | 0 | 4 | 0 | 2 | 2 | 0 | 0.224 |
| D15 | Gastro | 10 | 4 | 2 | 1 | 0 | 5 | 4 | 2 | 1 | 0 | 0.186 | 3 | 4 | 5 | 0 | 7 | 0 | 5 | 3 | 0 | 0.368 |
| C4 | Online Platforms | 30 | 30% | 23% | 23% | 57% | 30% | 30% | 10% | 7% | 0% | 7% | 23% | 47% | 30% | 97% | 0% | 30% | 27% | 0% | 0.422 |
| D2 | Information | 10 | 1 | 2 | 4 | 8 | 0 | 4 | 1 | 2 | 1 | 0 | 0.296 | 0 | 2 | 5 | 6 | 10 | 0 | 5 | 2 | 0 | 0.537 |
| D9 | Virtual Space | 10 | 2 | 0 | 0 | 4 | 4 | 8 | 0 | 0 | 0 | 0.277 | 2 | 2 | 5 | 1 | 9 | 0 | 4 | 5 | 0 | 0.432 |
| D11 | Support Your Local | 10 | 6 | 5 | 3 | 5 | 1 | 0 | 1 | 1 | 0 | 0.271 | 0 | 3 | 4 | 2 | 10 | 0 | 0 | 1 | 0 | 0.360 |
| C5 | Acts of Solidarity | 30 | 30% | 33% | 37% | 23% | 37% | 13% | 13% | 20% | 0% | 7% | 40% | 67% | 10% | 83% | 0% | 23% | 37% | 0% | 0.330 |
| D4 | Donations | 10 | 4 | 4 | 4 | 1 | 5 | 1 | 1 | 1 | 0 | 0.213 | 0 | 4 | 6 | 1 | 8 | 0 | 1 | 1 | 0 | 0.330 |
| D3 | Pro-Bono | 10 | 4 | 4 | 0 | 5 | 4 | 1 | 3 | 1 | 0 | 0.233 | 1 | 5 | 5 | 2 | 8 | 0 | 2 | 6 | 0 | 0.440 |
| D16 | Heroes | 10 | 1 | 2 | 7 | 1 | 2 | 2 | 0 | 4 | 0 | 0.219 | 1 | 3 | 9 | 0 | 9 | 0 | 4 | 4 | 0 | 0.565 |
| C6 | Self-sufficiency | 20 | 5% | 15% | 25% | 20% | 25% | 65% | 25% | 20% | 0% | 5% | 15% | 35% | 5% | 85% | 0% | 65% | 35% | 0% | 0.565 |
| D1 | DIY | 10 | 1 | 2 | 2 | 0 | 3 | 6 | 3 | 2 | 0 | 0.186 | 1 | 2 | 0 | 0 | 8 | 0 | 8 | 4 | 0 | 0.413 |
| D10 | Child Care | 10 | 0 | 1 | 3 | 4 | 2 | 7 | 2 | 2 | 0 | 0.241 | 0 | 1 | 7 | 1 | 9 | 0 | 5 | 3 | 0 | 0.460 |

Note: This table presents the results of the qualitative classification of human needs, as proposed by Max-Neef et al. (1989), satisfied through the top 10 innovations representative for each innovation domain. Results are differentiated between consumers and producers. N is the number of innovations classified per innovation domain. The HHI reports concentration measures for addressed human needs by each domain of innovation, higher values indicate a more concentrated distribution of addressed needs.
the public health system itself (C1: 90%), with 9/10 innovations in D7 heavily satisfying the need for subsistence (e.g., physical health). Likewise, in terms of needs of the innovators offering these novel goods and services, we see a strong drive for protecting consumers and employees as well as supporting the public health system (C1: 70%). Moreover, for D7, our classification shows acts of affection connected to supplying not-for-profit devices (D7: 7/10). An omnipresent theme, which is true for almost all observed topics across clusters, is a documented innovation behavior strongly driven by the need for participation on the part of the innovators (80%). More precisely, innovators attempt to find ways of serving customers in a receding market under imposed restrictions, thus participating in the sense of offering solutions to the present crisis and, most strikingly, participating in terms of cooperating and engaging in co-creation activities even in collaboration with unlikely partners from other sectors. More than half of the classified innovations in this cluster (C1: 65%) exhibit an intrinsic need of the innovators for creation—that is, to be inventive and design novel solutions for reasons other than simply increasing sales or brand reputation. The calculated HHI for both domains exhibit relatively high values (0.418 for D7 and 0.307 for D8), underlining the focus of these innovations on subsistence and protection needs.

For both topics, we identify a significant and negative linear development over time (see Fig. 2, a–b), hinting that the demand for change was highest when hospitals, households, and producers of such equipment were blindsided by the early dynamics of the pandemic.

### 4.2. Cluster 2: Catalyzing digital innovations

The second cluster (C2) comprises three domains revolving around the use of digital technologies. The first domain addresses the issues connected to social distancing and describes the development of apps for Contact Tracing (D6). The innovation with the highest coherence score for this domain describes such an app developed by researchers at the Massachusetts Institute of Technology. The domain of Monitoring (D13) captures two types of innovations, providing information either to monitor the spread of the pandemic in a quantitative manner or to monitor individual health conditions of (potential) COVID-19 patients.

### Statistical Tests for Linear or Quadratic Time Trends of Innovation Domains.

| Cluster | Domain | Days | Days^2 | Constant | R^2 | N | F | Mean | Interpretation | Dynamics |
|---------|--------|------|--------|----------|-----|---|---|-----|----------------|-----------|
| C1 D7   | -0.0013*** (-5.760) | 0.0980*** (-13.99) | 0.4038 | 51 | 33.182*** | linear | negative |
| C1 D8   | -0.0006* (-2.544) | 0.0782*** (-9.568) | 0.1167 | 51 | 6.474*** | linear | negative |
| C2 D6   | -0.0104*** (-3.145) | 0.0001* (-2.509) | 0.2262*** (-5.4) | 0.2231 | 51 | 6.891*** | quadratic | u-shape |
| C2 D1   | -0.0094 (-1.868) | 0.0714*** (-10.715) | 0.0665 | 51 | 3.491* | 0.000 | avg. |
| C2 D4   | -0.0051*** (-4.113) | 0.0001*** (-4.827) | 0.1114*** (-7.074) | 0.3641 | 51 | 13.742*** | quadratic | u-shape |
| C3 D5   | 0.0001 (-3.505) | 0.0499*** (-11.44) | 0.0052 | 51 | 0.255 | 0.052*** | below avg. |
| C3 D12  | 0.0030*** (-3.505) | -0.0001*** (-3.883) | 0.0371*** (-3.371) | 0.2487 | 51 | 7.944*** | quadratic | inverted u |
| C3 D15  | 0.0018* (-2.104) | -0.0000*** (-2.732) | 0.0572*** (-5.374) | 0.1929 | 51 | 5.735*** | quadratic | inverted u |
| C4 D2   | 0.0043*** (-4.71) | -0.0001*** (-3.725) | 0.0074 (-0.635) | 0.3975 | 51 | 15.84*** | quadratic | inverted u |
| C4 D9   | 0.0005* (-2.392) | 0.0462*** (-7.437) | 0.1045 | 51 | 5.721** | linear | positive |
| C4 D11  | 0.0007* (-2.173) | 0.0481*** (-4.93) | 0.0879 | 51 | 4.72** | linear | positive |
| C5 D3   | 0.0033*** (-5.713) | -0.0000*** (-10.715) | 0.0167*** (-22.68) | 0.4369 | 51 | 18.62*** | quadratic | inverted u |
| C5 D16  | 0.0033*** (-7.185) | -0.0001*** (-6.969) | 0.0163*** (-2.782) | 0.5182 | 51 | 25.82*** | quadratic | inverted u |
| C6 D1   | 0.0099*** (-5.012) | 0.0262*** (-4.539) | 0.3399 | 51 | 25.11*** | linear | positive |
| C6 D10  | 0.0002 (-1.588) | 0.0480*** (-10.703) | 0.049 | 51 | 2.523 | 0.054*** | below avg. |

Note: This table presents the results of the statistical model testing for linear and quadratic time trends in the occurrence of each innovation domain over the early months (51 days) of the pandemic. We measure occurrence over time using the average coherence scores (the average representation of a domain) for each domain per day. Significance levels are reported in the following order: *p < 0.10; **p < 0.05; ***p < 0.01.
a Brazilian foundation to monitor active COVID-19 cases across Brazilian regions. Finally, the domain High Technology (D14) describes innovations involving new and emerging technologies ranging from simple software systems to robots and artificial intelligence, mostly used for diagnosing COVID-19 infections but also for purposes of logistics and transportation or autonomous cleaning of facilities. The innovation with the highest coherence score describes Etihad Airways launching a self-service touchpoint with automatic symptom detection for pre-flight procedures at airports.

Comparing our analysis of addressed needs to C1, we see a slightly less pronounced prevalence of subsistence (C2: 40%) and protection needs (C2: 77%) that innovations across these three domains aim to satisfy for the users. In this aspect, C2 diverges when focusing on D13. Here, we document a strong focus on satisfying the need for understanding (D13: 9/10) the current situation in terms of dynamics of the pandemic and individual symptoms by offering analytical tools and making detailed information available for everyone to access via the internet. From the perspective of the innovators themselves, the needs landscape of C2 is similar to that of C1 but with an emphasized need for the protection of consumers and employees as well as for preventing the spread of the disease (C2: 77%). Likewise, we see the need for participation and cooperation strongly represented within this cluster (C2: 57%); we also see a stream of innovations satisfying creation needs on the part of the innovators (C2: 47%). Overall, the similarity between C1 and C2 is intuitive, as all domains in these two clusters center around technological innovations. Although the range of addressed needs is relatively concentrated for D13 and D14, a lower value of HHI for D6 (0.197) indicates the synergetic effects of solutions for contact tracing, which not only facilitate safety but also allow to return to having social interactions.

Within this cluster, whereas D13 exhibits no significant time trend and is constantly represented across time, D6 and D14 exhibit a u-shaped development in occurrences over the two-month observation period (see Fig. 3, a–c). A detailed investigation of the innovations within D14 shows an early first wave of innovations attributable to the development of portable testing equipment and a second, later wave of innovations that may have been caused by the reaction of airways and traveling companies introducing technological safety measures at the end of April and the beginning of May 2020 in their preparation for re-starting their businesses and in their attempt to highlight that airlines are part of the solution and not (only) part of the problem.
4.3. Cluster 3: Curing cabin fever

The third cluster (C3) encompasses the domains of Hospitality (D5), Home Delivery (D12), and Gastro (D15) and mainly describes services addressing issues of living in isolation within a household. For D5, we see a large stream of service innovations of hotels and hotel chains repurposing their resources to offer their rooms as isolated offices for people who cannot work from home, such as the Amsterdam-based hotel Zoku, or using the 24-hour room service as delivery service. Home delivery, however, is at the center of D12, mainly focusing on delivery services for groceries, such as the most representative innovation of Uber Eats partnering with Delivery Hero. Centering around the product of toilet paper, we see some innovations addressing the issue of responsible consumption and supply shortages, for example, by helping people assess a realistic amount of needed toilet paper per household. D15 describes food and beverage home deliveries through gastronomic establishments, sometimes with a little extra twinkle. The innovation with the highest coherence score describes employees of a public cafeteria cooking meals from home for a food assistance center.

For domains within C3, we see subsistence needs on the side of the consumers being served by half of the examined innovations (C3: 50%) and strongly emphasized by the domain of Home Delivery (D12: 7/10). The difference between C3 and previous clusters is that the innovations do not focus on curing or preventing illness but on enabling the satisfaction of basic needs such as having food and other groceries needed to sustain the basic standard of living in a situation of (perceived) supply shortages, lockdowns, and social distancing. Moreover, D5 and D15 point toward a societal need for participation (C3: 30%) and leisure activities (C3: 30%). Participation may involve adapting to the situation to continue having certain privileges and the possibility for interaction. Leisure may involve curing cabin fever by creating spaces for relaxation or participative interaction outside the own four walls in the form of hotel rooms being used as private rooms for families or small groups to enjoy a restaurant dinner together. On the side of the innovators, this cluster showcases subsistence needs driving innovation behavior, especially for the domains of Hospitality (D5: 6/10) and Home Delivery (D12: 5/10), signaling that businesses in these sectors are struggling to survive and are seeking ways to generate revenues. The HHI for these three domains of innovations are notably low (especially for D5 and D15), indicating a wide range of needs covered on both sides of market interactions.

Whereas D5 is constantly represented below average, D12 and D15 exhibit a significant quadratic time trend following an inverted u-shape (see Fig. 4, a-c). This may hint at a lagged reaction by gastronomic
4.4. Cluster 4: Online platforms help coping & connecting

The innovations found in the fourth cluster (C4) broadly revolve around the use of digital platform technology for supporting communication and interactions between individuals and communities affected by lockdowns. The cluster features the three domains of Virtual Space (D9), Information (D2), and Support Your Local (D11). Innovations strongly coherent with D9 center around bringing real-life interactions to the digital sphere, including sports tournaments, live events, or tutoring sessions. D2 encompasses endearing ventures of spreading positive news about/amidst the COVID-19 pandemic, such as the innovation “Something Positive” (highest coherence score). The domain also includes innovations offering outlets for people to share their struggles of coping with isolation and innovations countering negligence or misinformation (i.e., “fake news”) by educating society or condemning the spread of misinformation. Domain D11 centers around the idea of supporting local businesses by connecting them with local consumers or by offering them technical support to set up digital sales platforms.

Considering these examples, it becomes very plausible that this cluster also features the highest share of innovations addressing the need for understanding (C4: 57%) among all clusters. Here, understanding also relates to the nature of the crisis itself and how to best deal with it. Other consumer needs addressed by the innovations in this cluster are quite equally distributed. Strikingly, D9 heavily addresses the need for leisure (D9: 8/10), as real-world events from sports tournaments, parties, museums, or tourist attractions try to reach consumers through digital channels and virtual environments. Looking at the innovators’ needs, almost all innovations in this cluster satisfy the need for participation (C4: 97%), which may be explained by businesses actively engaging with communities and communal actors supporting each other. This is mirrored via the comparably high share of innovations serving the need for innovators to show affection toward the people and organizations in need of support (C4: 97%, second highest among all clusters). The HHI for all domains within this cluster indicate that consumers’ needs addressed are neither heavily concentrated nor highly diverse, whereas innovators’ needs seem to heavily concentrate on participation and affection.

Domains D9 and D11 exhibit a significant positive growth in representation within our sample over the time period of observation, documenting the realization of local communities and businesses to prepare...
for long-term solutions to deal with the new normal. Domain D2 exhibits a significant negative quadratic time trend, with a drop-off in innovations toward the very end of our period of observation (see Fig. 5, a–c).

4.5. Cluster 5: Acts of solidarity

The fifth cluster (C5) comprises the three domains of Heroes (D16), Pro-Bono (D3), and Donations (D4) and describes acts of solidarity and thankfulness to people hit hard during the crisis or helping to mount the immediate impacts of the pandemic. Domain D16 describes different types of campaigns ranging from collecting monetary donations to remembering and thanking the “frontline heroes” for the fight against COVID-19, which mainly include healthcare workers, supermarket clerks, and staff in public transport. Domain D3 describes the consultancies offering free services to suffering businesses to help guide their strategic decisions, human resource management, and efforts in pivoting business models and brand identity during COVID-19. The domain documents another phenomenon that occurred during the crisis: employee sharing of businesses otherwise unable to keep their staff employed with businesses (e.g., supermarkets) in need of helping hands. Domain D4 describes the companies collecting or donating money to artists, frontline workers, or small businesses that were hit hard during the crisis.

Consumers’ needs being addressed by the innovations in this cluster mainly revolve around subsistence or protection needs for the domains of Donations (D4: 4/10 for both needs) and Pro-Bono (D3: 4/10 for both needs), providing resources to those who need it. Domain D16 adds a less tangible notion of showing gratitude and affection to those on the frontlines of battling the pandemic (D16: 7/10). In terms of innovators’ needs, we see a prevalence of participation (C5: 83%) and showing affection (C5: 67%). The need for identity being served on the part of the innovators is slightly less pronounced over the whole cluster but is still the highest among all clusters (C5: 37%) and is especially represented in the domain of Pro-Bono (D3: 6/10). We find two possible explanations through our classification. First, doing good through non-profit innovations may help businesses to grow in terms of their self-perception and role in society. Second, although many represented innovations may rightfully be described as philanthropic acts, they may simultaneously (and for some innovations, purely) be motivated by improving brand image through differentiation. This is a theme we will return to for marketing innovations featured in cluster six. The HHI indicate that the needs addressed on both sides of interactions cover a medium range.

Our time trends show that D4 features a significant positive linear

![Fig. 6. Mean Coherence Scores in Cluster 5 (Acts of Solidarity).](image-url)
trend, highlighting the growing concern of helping those in grave needs (see Fig. 6, a). For D3 and D16, we estimate a significant negative quadratic time trend, resulting in a regression line that is inverted u-shaped; this documents a decline in the number of innovations centering around the notions of thankfulness and free offers (see Figs. 6, b–c). Speculating about this falling trajectory, it may be conceivable that fast, modern-day news cycles and short societal attention spans have resulted in societal fatigue for being receptive to these themes after being over-exposed to COVID-19 news.

4.6. Cluster 6: Self-sufficiency

The sixth cluster (C6) includes the domains of DIY (D1) and Child Care (D10). Domain D1 comprises businesses offering tools and instructions for “do it yourself” products and services, ranging from face masks and cooking tutorials to DIY haircuts. Domain D10 exhibits innovations addressing the need of families to care for and entertain their offspring sheltered at home. A high number of innovations encourage and support families to read to their children, with the innovation having the highest coherence score introducing a children’s book to help children understand the COVID-19 pandemic. Moreover, we see companies offering online tools for homeschooling, teaching chores in the household, or simply playing.

This cluster scores highest among all clusters in the dimensions of leisure (C6: 65%) and creation (C6: 25%) needs of consumers. For the former need, both domains offer solutions to keep individuals entertained; considering the domain of Child Care (D10: 7/10), the solutions keep children busy during lockdown-induced down times by offering games and, indirectly, some peace of mind for parents. The latter need is mainly addressed by DIY innovations. Considering the innovators’ needs, we see that subsistence (C6: 5%) and protection (C6: 15%) needs have the lowest values among all clusters. At the same time, the innovators’ needs for creation (C6: 65%) and identity (C6: 35%) are relatively pronounced. However, we see a clear divide between the two domains encompassed in this cluster. Although none of the top innovations in D1 can be connected to the innovators’ need to give affection or be affective, seven out of ten innovations take on this characteristic for D10. Considering the actual innovations across these two domains, this may lead to the conclusion that innovations for D1 are mainly marketing innovations and oftentimes gimmicky ways for businesses to showcase an awareness of the crisis by offering customers somewhat useful but ultimately non-essential tools to use at home. This may partly be true for innovations from D10, but the domain exhibits a wide range of innovations that effectively help families to connect, help children to develop an understanding for the current situation, and offer tools for parents to somewhat lighten the logistical burden of juggling a job and stay-at-home parenting. Both domains, however, entail innovations addressing issues that mainly need to be taken care of independently. The HHI reveal a disparity of needs covered by these innovations between consumers and producers. Although a wide range of consumers’ needs are addressed (especially for D1), the addressed needs on the side of producers are highly concentrated on the dimensions of participation and creation.

Whereas D1 exhibits a significant positive linear time trend, indicating a growing need of households to perform certain tasks themselves and for businesses to acknowledge the current situation of consumers, innovations coherent to D10 are evenly represented across the two months and are constantly below the sample-wide average occurrence of a domain (see Figs. 7, a–b). This highlights the fact that child care has been a constant topic of conversation from the very start of the crisis to the end of our window of observation but that businesses may only have had limited interest or tools to help alleviate the arising issues of sheltering, schooling, and entertaining children at home.

5. Discussion

In line with Max-Neef et al. (1989) and Cruz et al. (2009), we have interpreted the imposed lockdown measures against the spread of COVID-19 as an inhibiting satisfier or even as a violator, securing physical health but impeding the fulfillment of various other fundamental human needs (from mental health to lack of social participation). Examining the evidence in support of our first proposition, which is that crisis-driven innovations address multi-dimensional human needs (P1), our analysis shows that innovations hold the potential of (counter-) acting as singular and even synergistic satisfiers during crises, facilitating the individual or simultaneous satisfaction of a wide range of fundamental human needs. For consumers, the needs addressed by innovations are relatively diverse. Whereas technological innovations seem to be more concentrated toward physiological subsistence and protection (see C1 and C2), we see diverse domains of innovations addressing various social needs (see, e.g., C3 and C6). On the side of the producers, the addressed needs are slightly more concentrated. We see
potential satisfiers for the needs of economic subsistence of businesses and protection of employees and customers (see C1–C3) as well as affection expressed through generous offers to individuals and organizations heavily affected by the crisis (see C4 and C5). We also document a pronounced satisfaction of the need for creation among producers of innovations (see, e.g., C1 and C6), even if this creation is not directly connected to the economic subsistence of the producer. Although society at large may have been shell shocked in the very early days of the crisis, the growing need for businesses and communities to participate in contributing to solutions and interact with each other becomes evident in our typology of innovation behavior (see C3–C6 for consumers and all clusters for producers). Akin to Kraus et al. (2020), we observe a large share of multi-directional solidarity between companies, communities, and consumers, often underlined by not-for-profit innovations. In line with Laperche et al. (2011), we witness otherwise unusual, but now valuable, collaborative strategies to innovate. We see private actors, partly spurred by financial restrictions, cooperating from the beginning of the crisis to share needed resources, often in the form of non-financial offerings by scrapping price tags off of new pro-bono (DI) services. The need for participation is also observed in more detailed examples of open innovation during crises (Chesbrough, 2009). These come in the form of (unlikely) alliances ranging from large-scale collaborations across industries (e.g., to build ventilators) to local businesses finding creative solutions (such as church services in drive-in cinemas) and business–community engagements (such as joggers delivering food from local restaurants to isolated people). Similarly, we observe collaborations among companies and even competitors, as well as other private, public, and communal (local) actors supporting each other. To varying degrees, these collaborations may prove beneficial in the future, and with participation shown to be a dominant driver (need) of innovation activities, the dire situation also presents a unique opportunity for companies to change toward more responsible behavior (in the sense of pseudo-satisfaction for the needs of participation, identity, and affection expressed through generous offers to individuals and organizations heavily affected by the crisis (see C4 and C5). We also document two domains of innovations specifying what previous studies have identified as having potential for increased prosocial collective actions (Bacq et al., 2020; Bouman et al., 2020; He and Harris, 2020). Especially against the backdrop of transmissive crises, the character of innovation as a collective action problem calling for transdisciplinary alliances becomes ever more palpable, as lucidly illustrated by Potts (2019): “The innovation problem is a knowledge problem of recombining distributed specialized knowledge in order to discover new opportunities and sources of value, including discovery of which bits of knowledge need to be combined” (Potts, 2019, pp. 47–48).

Across all domains of innovations as well as for most individual innovation projects, we identify at least two (and often more) needs addressed, both for consumers and producers. In line with Max-Neef et al. (1989), this points toward a possibility to interpret the observed innovative solutions as synergetic satisfiers, simultaneously fulfilling a set of needs during crises—as opposed to only singular needs. Surely, presenting entrepreneurs and companies as pure philanthropists is also a misguided notion. As described above, we find many examples that hint toward what Max-Neef et al. (1989) describe as the true development of businesses during the crisis (e.g., discovering and satisfying altruistic tendencies). However, on the business side of our observed innovations, the motivations behind producing these satisfiers are opaque, and we cannot make claims about it with certainty. For example, our results are in line with Naidoo (2010), as we find a large share of marketing innovations showing businesses re-framing the advertisement of their offerings to fit the situation. Whereas in some cases, these activities may genuinely address the need for identity, some other cases of opportunistic brand building activities may rather be described as pseudo-satisfaction for the needs of participation, identity, and affection. Max-Neef et al. (1989) precisely outline the examples of propaganda and advertisement as indicators for such behavior. Although the question of motivation is not easily answered, it is of tremendous importance to recognize that, regardless of the motivation behind it, we see businesses and other actors in the system largely dedicating and committing themselves to a social mission during the current crisis. The crisis thus presents an unprecedented window of opportunity to capture and foster this dedication by embedding initiatives in a more systemic fashion (Bogner et al., 2020).

We also see that different pronounced human needs drive the emergence of different domains of innovations during crises (P2). Hekkert et al. (2007) underline the function of guidance of search as a potent starting point for initiating virtuous cycles in innovation, requiring special scrutiny against the backdrop of a crisis such as the current pandemic. Human needs themselves can be considered as central functions relevant both on an individual level and a collective level (Cruz et al., 2009), thus also influencing the innovation system’s guidance of search function and therefore creating conditions conducive to the selection of appropriate solutions to be prioritized. This is only partly a technological argument and must also be regarded through a socio-cultural lens, bearing potential for various different satisfiers for various different needs. With regard to our second proposition, our analysis clearly provides evidence for the presence of heterogeneous entrepreneurial activity and innovators in various market segments. Heterogeneous actors engaging in novel forms of cooperation thus afford new and trans-disciplinary ways of fulfilling systemic functions by addressing or satisfying fundamental needs. Each collaborative endeavor by innovators—as reflected by the high relevance of participation needs for innovators in all observed clusters—expands the possibility space of potential satisfiers by providing new combinations of knowledge that enable new and previously unavailable evolutionary trajectories (Müller et al., 2020). Our analysis provides evidence for the aspects that Bessant et al. (2015) postulate as being characteristic of crisis-driven innovations, which are conceived under extreme conditions that cause shifts in focus within the search space for solutions. Our identification of diverse domains of innovations provide evidence for a high degree of entrepreneurial experimentation based on a user-centric perspective and a recombination of existing parts of previous solutions. Our findings are also in line with Kraus et al. (2020), as we see a rapid diffusion of digital technologies, such as online platforms to inform and connect people, or more advanced technologies, such as artificial intelligence software solutions to detect potentially infectious individuals. Our identified technological domains of innovations (see C1 and C2) partly represent the type of low-cost solutions that Cankurtaran and Beverland (2020) identify as emerging frugal innovations. We also observe the swift re-purposing of products or production processes not only within the pharmaceutical industry (Bryan et al., 2020) but also in other industries aiming to satisfy various needs beyond (but including) health. Notably, our domains of innovations specify what previous studies have identified as having potential for increased prosocial collective actions (Bacq et al., 2020; Bouman et al., 2020; He and Harris, 2020). We identify that these prosocial actions may come in the form of technological advances (see C1 and C2), business model innovations (see C3), provision of information and exchange platforms (see C4), and donations as direct acts of solidarity (see C5). We also find two domains of innovations contributing tools to support individuals in helping themselves (see C6), wherein direct interactions required to fulfill certain needs are impossible. We will revisit the question of the effectiveness of the offered satisfiers at the end of this section.

In investigating our third proposition, which is that crisis-driven innovations respond to the changes in human needs over the course of a crisis (P3), our analysis suggests that non-governmental innovators within our society such as companies, entrepreneurs, or citizen initiatives were able to quickly react to the early signs of the pandemic by providing communities and hospitals with clinical and community masks as well as protective visors in times the need for subsistence and protection could not yet be met by traditional actors in the market. This
observation serves as a reminder to avoid a purely bureaucratic perspective on managing crises. Instead, one might place trust and resources into non-governmental actors being part of a systemic effort to alleviate concerns during crises. After an early surge of innovations addressing these basic needs, we document a negative trend of technical solutions for protective measures over time (see D7 and D8), hinting at a quick innovation-driven satisfaction of the need for subsistence and protection. This finding is in line with the observations of Suh et al. (2020), documenting a quick decline after an initial peak for very similar need categories (physiological and safety needs). On the side of the producers, we witness a similar trajectory for the needs for subsistence and protection, which reach a peak amidst the periods of strict contact restrictions and subsequently decrease in occurrence. This is especially well-illustrated for the domains encompassed within C3, representing an industrial sector (gastronomy and hospitality) that was hit hard by the lockdown regulations. Presumably, the loosening of regulations during the early summer months offered opportunities for these businesses to resume their normal operations. Going beyond the need for protecting the physical health of individuals or economic subsistence of businesses, our results show that in the midst of a fearsome pandemic, subsistence and protection needs do not seem to be the sole concern of people. Societal acceptance of severe restrictions to “flatten the curve” was noticeably high early on, with people even self-regulating before restrictions were officially introduced. However, with passing time, an ever-increasing desire in society for relief could be witnessed, evidenced by frequent protests and a mounting pressure on political actors to reopen stores and bars and allow people to meet. To this point, we witness dedicated domains of innovations (e.g., D1, D2, and D9) meeting needs in the dimensions of understanding, leisure and creation, affec-
tion, understanding, participation, and leisure and identity. These human needs are present from the very beginning of our period of observation and exhibit a growing importance through the course of the crisis. This is in line with what Suh et al. (2020) have described as a surge of expressions for cognitive needs and self-actualization. Our analysis also features parallels to their evidence for a growing need for love and belonging (i.e., expressed through searches for digital communication platforms). On the side of consumers, our domains of innovations (e.g., D4, D9, and D11) represent the needs for affection and participation and exhibit positive trajectories over the first two months of the lockdown regulations, whereas the producers’ need for participation, in terms of collaboration and engaging with society, is highly pronounced for almost all domains of innovations.

We are able to neatly map the identification of the expressed needs of Suh et al. (2020) to potential innovative satisfiers represented in our domains of innovations. However, because our classification of needs is based on a more granular scheme and simultaneously considers respective satisfiers, we can contribute a more detailed picture of the needs addressed by different domains of innovations. In particular, the domain of Child Care presents a somewhat counterintuitive case. Our HHI indicates that this domain potentially covers a rather large range of needs for consumers; however, the respective occurrences of innovations belonging to this domain remain below average over the entire period of observation. Comparing this with our perception of what is actually a widespread societal issue for families, we are inclined to interpret this dynamic not as a lower urgency of this problem but rather as an inability of private actors within the innovation system to truly satisfy this deficient need. Fittingly, this domain of innovations displays a thematic closeness to the domain of DIY solutions.

6. Practical implications

In our globalized world, natural or anthropogenic hazards and their resulting crises increasingly exhibit rapid and transsystemic diffusion processes. Thus, by understanding societal responses to crises as a systemic effort, we may be able to better leverage the abovementioned properties of crisis-driven innovations and find points of systemic

| Table 5 | Objectives and Actionable Measures for Relevant Actors in Crisis-Driven Innovation Systems. |
|---------|------------------------------------------------------------------------------------------|
| Objective | Actors                                      | Actionable Measures                                                                                                                                 |
| Expression of changing needs | Consumers                                  | Be aware of changed needs, reflect on changed needs during crises, and be aware that the satisfaction of one need might affect the satisfaction of other needs. |
|                                  | Businesses, organizations                   | Reflect on changed business needs, reflect on volatile regulations, be open toward changed needs of consumers, and employ new search strategies and horizon scanning. |
| Support the satisfaction of (changed) basic needs | Consumers                                  | Be aware of the dynamics of changed needs during crises. |
|                                  | Businesses, organizations                   | Recognize that consumers and businesses have multiple different basic needs. |
|                                  | Policy                                      | Observe changed needs reflected in changed demand pattern to observe the changed needs to attune policy measures. |
|                                  | Policy                                      | Recognize the systemic dynamics of changing needs during crises. |
|                                  | Policy                                      | Take new roles and responsibilities and contribute to the co-creation of solutions. |
|                                  | Policy                                      | Maintain openness toward different and novel approaches. |
|                                  | Policy                                      | Connect to local knowledge hubs. |
| Learn from the experience         | Consumers                                  | Consider consumers and policy as partners for the development of new product and service offerings addressing the changed needs. |
|                                  | Businesses, organizations                   | Implement open innovation practices to do so. |
|                                  | Policy                                      | Search for solutions and partners in unexpected places. |
|                                  | Policy                                      | Search for partners who can swiftly react to the changed environment. |
|                                  | Policy                                      | Align given resources with new objectives. |
|                                  | Policy                                      | Foster and support transdisciplinary collaboration within the innovation system. |
|                                  | Policy                                      | Support not only the “usual suspects.” Support startups and SMEs for the swift development and delivery of innovations. Support entrepreneurial projects with a collaborative angle. |
|                                  | Policy                                      | Design challenge-led innovation policy mixes (on the regional, national, and supranational level) to allocate resources to innovation projects beyond technology-driven ones. |
|                                  | Policy                                      | Augment subsidies for corporate survival with incentives to innovate. |
|                                  | Policy                                      | Reflect on the different changed needs and their satisfaction. |
|                                  | Policy                                      | Reflect on the behavioral changes triggered by the crises. |
|                                  | Policy                                      | Identify unexpected actors in the innovation system and build long-term relationships. |
|                                  | Policy                                      | Support unexpected and effective collaboration. |
|                                  | Policy                                      | Reflect on the new role of policy during the crises. |

(continued on next page)
has been at the center of the discourse around the potential reactions to infections and, at the same time, protecting socioeconomic institutions and subsequently providing relief in times of crises. Our observations an innovative way of conducting economic transactions that may for interconnected systems of needs during crises. Notably, the collective help us to understand these innovations as a mechanism of satisfaction communities collaborating to seize opportunities through innovating the crisis. Regulatory measures such as contact restrictions, calls for cross-sector partnerships (Lubberink et al., 2017).

multi-stakeholder idea generation, crowdsourcing, as well as strategic publishing (social or living) labs for community involvement and cross-fertilizing collaborations. Key activities for businesses and orga crisis-driven innovation endeavor during the pandemic and should even identified by Lubberink et al. (2017) may also hold in the context of the management of market needs or demands and the respective innovation innovations (Lubberink et al., 2017). Thus, we propose a careful assessment of market needs or demands and the respective innovation behavior as an expression of socio-psychological needs of consumers and producers of innovations. This contributes to the identification of emerging points of intervention among actors and to a move toward a new paradigm of innovation systems dedicated to a larger societal mission. Arguably, many of the concrete collaborative activities identified by Lubberink et al. (2017) may also hold in the context of the crisis-driven innovation endeavor during the pandemic and should even be expanded in the near future to other actors not (yet) engaged in such cross-fertilizing collaborations. Key activities for businesses and organizations include (but are not limited to) stakeholder mapping, establishing (social or living) labs for community involvement and multi-stakeholder idea generation, crowdsourcing, as well as strategic cross-sector partnerships (Lubberink et al., 2017).

The tension between preventing or slowing the rate of COVID-19 infections and, at the same time, protecting socioeconomic institutions has been at the center of the discourse around the potential reactions to the crisis. Regulatory measures such as contact restrictions, calls for sheltering at home, or lockdowns and curfews invoked to satisfy protection and subsistence needs consistently create interconnected problems for the satisfaction of other basic human needs. The examined COVID innovations in our sample showcase the enormous opportunity for innovators to create shared value in times of crises—as they may be uniquely qualified to navigate the aforementioned tensions by providing an innovative way of conducting economic transactions that may simultaneously fulfill the fundamental needs of consumers and businesses alike. Our findings also show the value of closely screening the observed changes in demand patterns as a kind of policy compass, which may be considered when directing relief measures toward societal groups heavily affected by the crisis: it is consumers rather than (a loud minority of) anti-corona protesters the socio-political discourse should be attuned to. Our analysis of crisis-driven innovations shows that innovation systems were able to quickly react to the shortage of technological equipment in the early weeks of the pandemic gaining momentum, whereas other societal issues such as child care could only be superficially addressed throughout the crisis. These observations show the necessity to closely monitor economic activity to provide solutions to societal problems and to support innovative activity. This is particularly relevant in domains that can effectively contribute to relief efforts while focusing governmental provision on issues that cannot be easily addressed through the market. Contrasting this insight with the observed political measures to foster innovation during the crisis, it becomes evident that such measures can be seen as slightly biased toward established actors such as multinational corporations. Although the European Union announced additional research and innovation grants to companies providing innovative solutions for the COVID-19 pandemic, these grants have been attributed to about 36 large companies (approx. 8.7 million per company on average) (European Commission, 2020) mainly focused on providing technological solutions connected to physical health. Nevertheless, our analysis suggests that governmental support may also be linked to a more systemic provision of resources in the sense of a challenge-led innovation policy (Raven and Walrave, 2020). The observed activities of increased cooperation (often at the local level) may be better fostered through more equally distributed crisis innovation funds, supporting a large number of entrepreneurial projects with small tranches of financial support while requiring a certain degree of cooperation for eligibility and the allocation of resources. Provided by a system of (local) actors, we argue that this may enable a more diverse set of responses to what we have shown to be a diverse set of societal needs inhibited or violated by lockdown regulations. More precisely, such challenge-led innovation policy mixes could combine particular interventions that simultaneously target central innovation system functions (e.g., guidance of search, market formation, and the creation of legitimacy) in response to the crisis (Raven and Walrave, 2020).

The current crisis offers abundant evidence for the fact that fundamental human needs can be neither straightforwardly identified owing to their complex and interconnected systemic nature—especially when assessing them for a large collective of actors—nor sufficiently addressed through individual efforts or purely by technological advancements. Our analysis shows that decentralized, crisis-driven innovation systems can react to need deficiencies during crises. Considering the recent shift toward normatively oriented innovation systems as a response to larger societal challenges (Ghazinoory et al., 2020; Hekkert et al., 2020; Pyka, 2017), we follow Schlaie et al. (2017) in arguing for increased attention to the question of social responsibility and how societal systems can move toward desirable outcomes in the face of complex normativity and wicked problems. It is argued that the disruptive nature of the COVID-19 pandemic offers opportunities to not only avoid recovery patterns that point toward an old normal but also motivate societal actors to retain their dedication to the collective problem solving of other societal issues beyond the crisis itself (Bogner et al., 2020; Wahl, 2020). Policy action could capture the heightened attention and willingness to (collectively) participate in solution processes of consumers and businesses to embed these actors in dedicated innovation systems. On that note, another policy implication stemming from such decentralized and collective action is to take up polycentric

| Objective | Actors | Actionable Measures |
|-----------|--------|---------------------|
| Research  | Explore new modes of polycentric governance for innovation commons. Include the theoretical developments triggered by and the empirical evidence collected during the crises into changed research programs. Let the new social and technical reality inspire new research questions and approaches. Support consumers, businesses, and policy by monitoring crisis-driven innovations utilizing the approach pioneered in this paper in combination with complementary methods as an early indicator for urgent societal needs and their changes. | |

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Table 5 (continued)
governance approaches (Carlisle and Gruby, 2019) for governing these innovation commons (Potts, 2019).

Finally, our article points to promising implications for researchers investigating crisis-driven innovation processes, which may support and affect the decisions of other innovation system actors (e.g., consumers, entrepreneurs, policy actors). First and foremost, the approach pioneered in this article provides a sound basis for future studies using topic modeling and the needs-based classification for investigating innovations. In this regard, follow-up work should also aim for a comparison of the changed dynamics of needs and innovations between the early phase of the pandemic and the so-called “second wave”. Our brief additional investigation into a later sample of innovation projects (October-November of 2020), which is not reported, showed that a large number of domains of innovation seem to have prevailed (e.g., Protectives, Virtual Space, Home Delivery) and that the distribution of addressed human needs seems to have remained largely unchanged. However, some new domains of innovations seem to have emerged due to seasonal effects (such as holidays and colder temperatures) and the importance of some needs seems to be more (e.g., leisure) or less (e.g., understanding) pronounced compared to the first wave. Moreover, concomitant psychological research is advised to better understand how (and in which ways) the innovations identified actually act as effective (or rather pseudo-) satisfiers for certain human needs.

Based on our previous discussions, Table 5 summarizes a selection of practical implications that can be drawn from our study. These practical implications are categorized according to three objectives (expression of changing needs, support the satisfaction of (changed) needs, and more generally learn from the experience), central sets of actors (consumers, businesses/organizations, policymakers, and researchers), and the concrete actionable measures. The entries in Table 5 should be read as important practical take-home messages, which should, however, not be regarded as exhaustive. After all, more longitudinal and comparative data would be required to provide more targeted recommendations to the sets of innovation system actors listed in Table 5.

7. Conclusions and future research

In a procedure novel to the realm of innovation studies, we have clustered emerging domains of crisis-driven innovations amidst the COVID-19 pandemic and classified the innovations within our sample among nine dimensions of fundamental human needs. We find a diverse set of domains of innovations ranging from technologically driven innovations to what may be described as frugal and social innovations. The documented innovation behavior exhibits accelerated diffusion processes of sophisticated (digital) technologies on the one hand and accelerated provision of necessary resources to combat the diverse effects of the COVID-19 pandemic on the other hand. To this point, we show that the needs of both consumers and innovators have to be understood as a more complex phenomenon during crises—as we witness the immediate surge of non-exclusive needs going beyond the mere notion of physical health (but emphasizing the need for affection, understanding, participation, and creation). We see this variety of needs not only expressed through market dynamics but also satisfied through a set of respective entrepreneurial reactions. From this perspective, we argue that a systemic societal response to the modern crises of our time may build around and contribute to inducing dedication into systemic innovation activities. The main limitation of this study is the source of data. Although we ensure consistency within our sample by focusing on the provision of data by a single website, we are subjected to the curation processes of the platform and can neither claim an exhaustive representation of innovation activities during COVID-19 nor compare the degree of activity to pre-crisis time periods. The study is further limited by the short observation period, which may be extended in future studies benefiting from greater temporal distance. Unfortunately, the developments regarding the pandemic have turned grim again during the winter months of 2020, and lockdown regulations are again in effect. We argue that the expression and satisfaction of needs is subjected to temporal changes owing to the unfolding events and adaption processes within society, therefore warranting another (comparative) investigation into the needs and innovative satisfiers during the second large wave of infections. This study opens up promising avenues for future research in showing the value of an automated content analysis of large-scale text data on innovation projects. More importantly, we show that a socio-psychological assessment of innovations as an expression of human needs may help us in better understanding the workings of innovation (systems) and our market-based society, especially in such dire times. Future studies may focus on refining the classification of innovation projects for fundamental human needs or scrutinizing the workings of dedicated innovation systems in times of crises.

Above all, our results remind us that instead of pardoning an ill-prepared system, we may be well advised to remember the value of innovative endeavors to provide immediate responses to the demands of a society in dire straits. The observed patterns in our sample of COVID innovations encourage us to understand these moments in history as unique opportunities to change the world for the better. We may do so by being conscious of our diverse societal needs, the broad range of possibilities to fulfill these needs and willing to engage in creative collaborations to turn over a new leaf. In times of crises, future societal responses may consider complementing regulatory measures through systemically supporting innovation activities in society. After all, acting in unison is more powerful than acting in isolation.

CRediT author statement

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Appendix A. Selected Innovations

Table A.6.
Table A.6
Top 5 Innovations by Domain Ranked by Coherence Score.

| ID | Title | Date       | Coherence Score |
|----|-------|------------|-----------------|
| C1/D7 | Medical Equipment | 22/04/20 | 0.792 |
| 41 | Vega Innovations develops new low-cost, easily scalable medical ventilator | 22/04/20 | 0.792 |
| 515 | Dyson designs new ventilator in only 10 days and will produce 15,000 units for UK hospitals | 30/03/20 | 0.750 |
| 381 | Italian startup Isinnova 3D prints copies of ventilator parts to help hospitals | 25/03/20 | 0.740 |
| 357 | LEO A DALY showcases Hotel2Hospital design concept to temporarily turn hotels into hospitals | 05/05/20 | 0.683 |
| 113 | UK based Nippy plans to use its Nippy 3+ sleep apnea device to make ventilators | 16/04/20 | 0.662 |
| C1/D8 | Protective | 16/04/20 | 0.662 |
| 418 | IKEA launches production of masks, visors, aprons and hand sanitizer for medical workers | 03/04/20 | 0.660 |
| 206 | SafeHandFish repurposes soy sauce containers for hand sanitizer | 30/04/20 | 0.661 |
| 575 | Colombian brand Manjii is selling fashionable protective clothing made from recycled plastic | 27/04/20 | 0.645 |
| 369 | Keep Your Distance app by Eventelist helps you and your loved ones keep the minimum distance | 09/04/20 | 0.679 |
| 186 | Singapore government launches community-driven contact tracing app Trace-Together | 10/04/20 | 0.640 |
| 485 | Fitness tracking app StepExitGo encourages users to walk indoors during quarantine | 06/04/20 | 0.613 |
| C2/D6 | Contact Tracing | 13/04/20 | 0.791 |
| 677 | App from MIT alerts you if you’ve crossed paths with someone who is infected | 22/03/20 | 0.712 |
| 703 | 1.5 - Social Distancing App helps people keep a safe social distance | 20/04/20 | 0.683 |
| 369 | Keep Your Distance app by Eventelist helps you and your loved ones keep the minimum distance | 09/04/20 | 0.679 |
| 186 | Singapore government launches community-driven contact tracing app Trace-Together | 10/04/20 | 0.640 |
| 485 | Fitness tracking app StepExitGo encourages users to walk indoors during quarantine | 06/04/20 | 0.613 |
| C2/D13 | Monitoring | 09/04/20 | 0.620 |
| 629 | Brazilian Foundation Luiz Eduards Magalhaes launches website with real-time information about COVID | 09/04/20 | 0.620 |
| 695 | Alphabet’s Verily launches COVID screening tool to automate health systems’ frontline response | 07/05/20 | 0.584 |
| 4 | Zelgift helps organizations monitor the health of their workforce with real-time COVID symptoms | 08/04/20 | 0.544 |
| 27 | Website ‘Helmet-Based Ventilation’ provides information about helmet use for ventilation systems | 19/04/20 | 0.483 |
| 391 | Israeli startup VOCals Health tries to identify COVID carriers using voice biometrics | 01/04/20 | 0.481 |
| C2/D14 | High Technology | 13/04/20 | 0.791 |
| 503 | Elithad Airways tests new airport technology to identify travelers with COVID symptoms | 13/04/20 | 0.791 |
| 530 | Drone company DJI equips public safety agencies across the US with drone technology to fight COVID | 09/04/20 | 0.726 |
| 630 | Brazilian company ‘Hi Technologies’ produces portable COVID test that returns results in 15 min | 09/04/20 | 0.645 |
| 694 | Alibaba develops new algorithm able to identify COVID infections with 96% accuracy | 03/04/20 | 0.635 |
| 342 | Low-cost airline Cebu Pacific introduces ‘contactless flights’ in Philippines | 11/05/20 | 0.631 |
| C3/D5 | Hospitality | 29/04/20 | 0.703 |
| 680 | Amsterdam-based hotel Zoku transforms its rooms into hideaway offices for at-home workers | 29/04/20 | 0.703 |
| 460 | German website ‘Home Office im Hotel’ shows hotels across Germany offering hotel rooms to work from | 10/04/20 | 0.641 |
| 140 | Swedish couple opens ‘Bord för En’, a COVID-safe outdoor restaurant for 1 person only | 05/05/20 | 0.576 |
| 531 | Drive-in cinema in Germany conducts unusual weddings amidst social distancing measures | 07/05/20 | 0.569 |
| 433 | Helsinki Hotel Kämp launches its 24-hour room service as takeaway or home delivery service | 22/04/20 | 0.569 |
| C3/D12 | Home Delivery | 06/04/20 | 0.664 |
| 116 | Uber Eats and Delivery Hero branch out to supply groceries to customers stuck at home | 06/04/20 | 0.664 |
| 333 | Malaysian low-cost airline AirAsia provides in-flight food to people’s doorstep through new delivery | 11/05/20 | 0.662 |
| 12 | Woolworths turns a further 100 supermarkets into delivery hubs, introduces basic groceries boxes | 25/04/20 | 0.631 |
| 97 | UK volunteers launch Runnerdeliveries.com to help elderly people with their grocery shopping | 23/04/20 | 0.602 |
| 207 | Russian supermarket Vkusvill wants to install vending machines in residential buildings | 13/04/20 | 0.568 |
| C3/D15 | Gastronomy | 16/04/20 | 0.681 |
| 596 | Chefs from UnitedHealth Group now cook from home for ‘Loaves And Fishes’ distribution site | 16/04/20 | 0.681 |
| 39 | Vermont Deli sells raw ingredients, mails gift packages and provides delivery services | 01/04/20 | 0.625 |
| 148 | Strippers from Lucky Devil Lounge Bar in Portland, Oregon will deliver food topless | 16/04/20 | 0.616 |
| 348 | London craft brewer The Five Points Brewing Co starts selling kegs of beer to create home pub experience | 11/05/20 | 0.576 |
| 356 | Leon restaurants in UK are transformed into mini-supermarkets to fix food shortages | 08/04/20 | 0.532 |
| C4/D2 | Information | 03/04/20 | 0.732 |
| 296 | New website ‘Something Positive’ spreads positive COVID-related news only | 03/04/20 | 0.732 |
| 561 | CoVibes by Helen Huang publishes positive stories and good news for an uplifting mindfulness break | 03/04/20 | 0.732 |
| 22 | Whatsapp fights COVID misinformation by limiting message forwarding to one person at a time | 08/04/20 | 0.693 |
| 149 | ‘Stories Of COVID’ documents the impact of COVID-19 on future generations through interviews | 26/04/20 | 0.635 |
| 578 | Collaborative platform Quarantine Stories collects stories of isolation from people around the world | 20/04/20 | 0.620 |
| C4/D9 | Virtual Space | 18/05/20 | 0.856 |
| 123 | Topgolf partners with LPGA Tour to launch online golf tournament ‘LPGA eTour Live’ | 18/05/20 | 0.856 |
| 489 | Finnish museums step up their online game with video art and VR guided tours | 29/04/20 | 0.726 |
| 591 | Chinese e-commerce platforms offer online tours to popular tourist sites and museums | 01/04/20 | 0.690 |
| 611 | Bosch, Enve, Martin, Carlsberg and Pernod Ricard launch partnership with JD for virtual clubbing | 01/04/20 | 0.690 |
| 238 | Prominent tennis players play Virtual Madrid Open on Playstation 4 | 06/05/20 | 0.645 |
| C4/D11 | Support your local | 14/04/20 | 0.650 |
| 17 | Wirecard launches ‘Innovation for Now’ platform where German merchants can find tech assistance | 14/04/20 | 0.650 |
| 385 | Italian initiative Torniamo Presto enables people to buy gift cards from their local businesses | 21/04/20 | 0.645 |
| 556 | Covid-19 Tech Support is a non-profit initiative launched by volunteers to give free tech support | 23/04/20 | 0.602 |
| 382 | Italian platform Uniti Posiamo connects local businesses with people living nearby | 15/04/20 | 0.557 |
| 384 | Italian local initiative ‘Spesa Sospesa’ connects people in need for support with those who can help | 16/04/20 | 0.544 |
| C5/D4 | Donations | 11/05/20 | 0.774 |
| 373 | Jiggy Puzzles launches auction puzzle pieces to support artists during COVID | 11/05/20 | 0.774 |
| 162 | Spotify launches COVID Music Relief project to support artists | 02/04/20 | 0.726 |
| 237 | Proof of Impact unites organizations and donors through community-based efforts to combat COVID-19 | 25/04/20 | 0.713 |
| 696 | Airbnb launches global initiative to provide housing to healthcare professionals and relief workers | 29/03/20 | 0.662 |
| 664 | Australian stage and festival builder Stagekings creates affordable work-from-home desks | 16/04/20 | 0.617 |
Table A.6 (continued)

| ID   | Title                          | Date       | Coherence Score |
|------|--------------------------------|------------|-----------------|
| C5/D3| Pro-bono                       | 06/05/20   | 0.703           |
| 309  | Nashville-based marketing agency Reed provides free COVID strategy hotline for businesses in need | 10/04/20 | 0.641 |
| 416  | In Brazil, Hyundai gives free rides to safely transport healthcare professionals and the elderly | 09/04/20 | 0.576 |
| 525  | Brazilian ride-hailing platform Meuca allows companies to temporarily exchange employees to avoid layoffs | 05/05/20 | 0.569 |
| 560  | COVID Canvas by LikeWise in Brazil offers free brand strategy resource to help businesses reinvent | 16/04/20 | 0.569 |
| C5/D16| Heroes                         | 29/04/20   | 0.779           |
| 32   | Viral running challenge raises $6 million for health-care workers in the UK | 23/04/20 | 0.631 |
| 628  | Brazilian non-profit ‘Bee Pro Go’ connects charity campaigns with football fans to raise money | 20/04/20 | 0.625 |
| 510  | Elle launches ‘The Other Front Line’ campaign to put other every woman into spotlight | 30/04/20 | 0.567 |
| 265  | Palma-based travel technology company Hotelbeds launches ‘Holidays for Heroes’ campaign | 11/05/20 | 0.569 |
| 105  | UK energy startup Lifesaver supplies power banks to healthcare workers on the frontlines | 08/05/20 | 0.525 |
| C6/D1| DIY                            | 11/05/20   | 0.680           |
| 444  | Grooming brands release easy-to-use trimmers and scissor kits for DIY home haircuts | 23/04/20 | 0.663 |
| 5    | Zara models photograph themselves at home to promote the Spanish company’s new collection | 19/05/20 | 0.625 |
| 120  | Trojan Brand Condoms company launches free-for-all e-cookbook including sensual bread recipes | 11/05/20 | 0.617 |
| 402  | Influential US streetwear brand Sprayground launches innovative collection with 3D computer animated | 11/05/20 | 0.617 |
| 5    | London-based designer Paul Cockedde creates ‘Here Comes the Sun’ social distancing picnic blanket | 08/05/20 | 0.525 |
| C6/D10| Child Care                     | 03/04/20   | 0.736           |
| 701  | ‘A Kids Book About COVID-19’ offers free online resources to help kids understand the global crisis | 03/04/20 | 0.736 |
| 81   | US celebrities read aloud to kids in quarantine on StorylineOnline’s YouTube channel | 03/04/20 | 0.688 |
| 105  | UK energy startup Lifesaver supplies power banks to healthcare workers on the frontlines | 15/04/20 | 0.680 |
| 314  | ‘Make Way For Books’ app encourages reading eBooks to children staying at home | 14/04/20 | 0.677 |
| 594  | Chicago-based SkyArt helps kids at home stay creative with creativity kits and online tutorials | 01/04/20 | 0.603 |

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