Tackling pandemic-related health grand challenges: The role of organizational ambidexterity, social equality, and innovation performance

Abstract

The outbreak of COVID-19 has brought the world to a standstill, with severe consequences on economic and health systems, requiring the identification and implementation of innovative solutions. This study's aims are threefold: to examine the impact of balanced and combined dimensions of ambidexterity on for-profit organizations' innovation performance related to pandemics, to uncover whether and to what extent such innovation performance contributes to tackling global health grand challenges (i.e., mortality rate, risk of infection, and life expectancy) associated with pandemics, and to investigate the moderating role of social equality in health in the relationships between innovation performance and health-related outcomes associated with pandemics. To uncover how for-profit firms tackle the health-related consequences of pandemics, we examine whether they have introduced product innovations to the health sector, defined as the market introduction of a new or significantly improved good, that have helped address the health challenges associated with the COVID-19 pandemic. Using a panel dataset (1974–2020) with 15,062 firm–year observations from the US, we show that both the separate and the synchronous implementation of the balanced and combined dimensions of ambidexterity have strong positive effects on firms' innovation performance and, particularly, innovation initiatives related to the pandemic. In addition, innovation activities (i.e., granted patents and citations focused on COVID-19) negatively affect mortality rate and risk of infection, as well as the positive impact of innovation on increasing life expectancy, with social equality in health moderating this relationship. Taken together, we make novel contributions to the literature on how to tackle the health-related consequences of pandemics through innovation and provide actionable managerial guidelines on how firms can enhance innovation performance.

KEYWORDS: health care's grand challenge, COVID-19 pandemic, innovation, organizational ambidexterity.

1. INTRODUCTION

Humanity is undergoing dramatic transformations from various ongoing grand challenges (Arslan & Tarakci, 2022; Wickert et al., 2021). Such grand challenges include inequality (Berrone et al., 2016), climate change (Wright & Nyberg, 2017), the

refugee crisis (Guo et al., 2020a), poverty (Ferraro et al., 2015), sustainability (De Ruyter et al., 2022), and health crises (Howard-Grenville, 2021; Noble & Spanjol, 2020; Wickert et al., 2021). We focus on health grand challenges (Nilsson, 2017; Vakili & McGahan, 2016) associated with pandemics such as that triggered by SARS (Daszak, 2012) and COVID-19 (Howard-Grenville, 2021), which, unlike many prior crises limited to specific industries, geographic regions, or organizations, are truly global and pervasive challenges affecting everyone (Guderian et al., 2021). The COVID-19 pandemic, for instance, has resulted in more than 595 million cases and over 6.4 million deaths worldwide (Worldometer, 2022). Beyond its devastating population health consequences, COVID-19 had also substantially altered the economic landscape, with many firms failing and others struggling to survive (De Massis & Rondi, 2020; Ketchen & Craighead, 2020).

Organizations across the globe have been trying to tackle grand challenges (Ferraro et al., 2015; Markman et al., 2019), including health-related challenges necessary for human survival (Olsen et al., 2016). For example, pharmaceutical companies, non-profits, and the World Health Organization have launched efforts to contain the spread of the deadly COVID-19 virus (Von Krogh et al., 2020). However, tackling grand challenges is a difficult endeavor, given their magnitude and complexity (Ferraro et al., 2015), often radical changes to how activities are organized and implemented, and the need for new technologies and tools (George et al., 2016). Consequently, researchers have begun turning attention to the role of organizational innovation, or the process involving change through the exploitation of new opportunities to commercialize new products, processes, or business models (Chrisman et al., 2015; Rosenbusch et al., 2019). In this study, we limit our focus to innovation by for-profit organizations (Eggers & Kaul, 2018), which differ considerably in their technologies and innovativeness from their non-profit counterparts and are more likely to engage in radical innovations required for tackling grand challenges (Eggers & Kaul, 2018; Muñoz et al., 2020). Studies indicate that "wicked" problems or grand challenges can be tackled with organizational innovation (Bacq & Aguilera, 2022; Doh et al., 2019; George et al., 2016), and health concerns associated with pandemics are certainly one of those challenges (Bertello et al., 2022; Guerrero & Urbano, 2020; Wickert et al., 2021). However, while the recent COVID-19 pandemic has led to rapid increases in innovation across the globe, such as in new vaccine development (Leshem & Wilder-Smith, 2021; Liu et al., 2021), the role of organizational innovation has yet to be aggregately associated with general health challenges (Dahlander et al., 2021; Demircioglu & Vivona, 2021; Guerrero & Urbano, 2020), such as increased mortality, infection risk, and life expectancy from population exposure to pandemics (Aburto et al., 2022; Ren et al., 2021).

Innovation and pandemic-related health challenges are topics that have largely been studied in isolation and informed by different disciplines. While the former has mostly been examined in the fields of business economics and management (Demircioglu & Vivona, 2021), in relation to organizations (Davies et al., 2018), studies on the latter are mainly rooted in the fields of medicine, biology, virology, population economics, and epidemiology (Galanis & Hanieh, 2021; Lopez & Neely, 2021). Despite attempts to bridge organizational innovation and pandemic challenges (e.g., Bapuji et al., 2020; Sheng et al., 2021), studies have primarily addressed the consequences of pandemics for firms in terms of navigating the new normal (e.g., Hitt et al., 2021; Lorenzen et al., 2020; Verma & Gustafsson, 2020), providing little insight into how they can leverage organizational innovation during pandemics to help solve pressing health grand challenges (see Bertello et al., 2022; George et al., 2020; Guderian et al., 2021). Prior studies on health challenges have treated organizational innovation as a dependent variable, analyzing how pandemics and other health grand challenges affect innovation in organizations (e.g., Arslan & Tarakci, 2022; Guderian et al., 2021; Shoss et al., 2021; Zhong et al., 2022). Thus, research centered on the role of organizational innovation in tackling health grand challenges is scarce.

At the same time, knowledge on how organizations can reach an innovation performance threshold (through capabilities and mechanisms) to effectively tackle health grand challenges is also scarce (Ferraro et al., 2015; Hartmann et al., 2021; Roulet & Bothello, 2021; Sawyer & Clair, 2022). The capabilities of innovation and the way organizations use these capabilities to leverage their available resources are crucial to organizational innovation performance (Ayuso et al., 2016). In the health context, for instance, research underscores the relevance of organizational ambidexterity capability and the use of both exploration and exploitation activities to enhance innovation performance (Burgess et al., 2015). Still unclear, however, is how firms can tackle health grand challenges through innovation capabilities and their underlying mechanisms. Also of paramount importance to organizational innovation performance are state characteristics (Lopez-Vega & Lakemond, 2022; Luo & Wang, 2012). State characteristics such as market size and openness (Hermosilla & Wu, 2018; Xie & Li, 2018), a well-functioning patent system (Jaffe, 2000; Papageorgiadis et al., 2014), the level of social cohesion and trust (Shaner et al., 2016), and the presence or absence of social inequality (Karataş-Özkan & Chell, 2015) determine the effectiveness of innovation diffusion within a sector or economy (Da Silveira, 2001; Lee et al., 2003). Understanding conducive state conditions at the nexus between organizational innovation and health grand challenges can help shed light on how organizational innovations during pandemics can be effectively diffused to tackle health grand challenges.

Given this discussion, the aim of our study is threefold: (1) to examine the role of for-profit organizational innovation in tackling health grand challenges, (2) to examine the capabilities and mechanisms through which for-profit organizations innovate to tackle health grand challenges, and (3) to examine state characteristics that can increase the positive impact of organizational innovations on health challenges during pandemics. To address these aims, we use a US panel dataset (1974–2020) with 15,062 firm–year observations to examine the link between innovation and pandemics. We do so by drawing on different theoretical lenses. First, relying on organizational ambidexterity theory, which addresses the capability of an organization to engage in both exploratory and exploitative activities (Boumgarden et al., 2012; Cao et al., 2009; Smith & Beretta, 2021; Tushman & O'Reilly, 1996), we examine the impact of the balanced and combined dimensions of ambidexterity on the innovation performance of for-profit organizations, with a particular emphasis on innovation outcomes related to pandemics. Second, drawing on theory and evidence on the accelerated diffusion of innovations, we examine the role of organizational innovation in tackling three health-related outcomes from a pandemic grand challenge: mortality rate, risk of infection, and life expectancy. Health-related innovations in the context of a pandemic, which often appear in the form of breakthrough technology-based products such as vaccines, are commercialized with the intention to curb the pandemic spread and to significantly reduce the risk of critical hospitalization or death (Leshem & Wilder-Smith, 2021; Liu et al., 2021). Third, we draw on social equality, a state characteristic in which people in a society have the same rights and fair access to opportunities and material resources (Jackman, 1974; Kolodny, 2014), to examine whether social equality in health moderates the organizational innovation–pandemic health outcomes relationship. We use social equality as a moderator, as it is critical for innovation diffusion in a socioeconomic system (Gutin & Hummer, 2021; Korda et al., 2011) and in tackling health-related grand challenges (e.g., Chuang et al., 2013; Phelan et al., 2004). Our findings indicate that social equality can serve as a facilitator of the relationship between organizational innovation and population health gains during pandemics.

We show that both the separate and the synchronous implementation of the balanced and combined dimensions of ambidexterity have a strong positive effect on firms' innovation performance and, particularly, innovation initiatives related to the COVID-19 pandemic. Our results also reveal that innovation activities negatively affect the COVID-19 mortality rate and risk of infection but positively affect increased life expectancy. Furthermore, the results confirm the moderating role of social equality in health in these relationships. Taken together, our study makes novel contributions to the innovation literature by examining the ambidexterity mechanisms that drive innovation while coping with pandemic grand challenges. It also provides actionable managerial guidelines on how to enhance innovation performance to respond effectively to pandemic grand challenges.

This study extends the organizational innovation literature in four ways. First, by examining the impact of specific structural ambidexterity forms (balanced *or* combined) and their combination (balanced *and* combined) on organizational innovation performance and treating the latter as an antecedent to health grand challenges, we respond to recent calls for further research on the capabilities necessary for for-profit organizations to tackle grand challenges (Ferraro et al., 2015; Hartmann et al., 2021; Roulet & Bothello, 2021; Sawyer & Clair, 2022). Second, by including innovation performance as an independent variable, we pave the way for new theoretical linkages between organizational innovation and health grand challenges. We provide novel insights into the effect of organizational innovation performance on macro-specific health outcomes (i.e., reduced mortality rate, reduced risk of infection, and increased life expectancy). Third, our study provides evidence of the importance of social equality in health in enhancing the positive impact of for-profit organizations' innovation performance on population health gains during pandemics. To our knowledge, this study is the first to test the moderating role of social equality at the innovation–health grand challenges nexus, responding to calls for research to understand the state conditions that help firms effectively tackle grand challenges (Demircioglu & Vivona, 2021). Fourth, this study responds to calls to address the role of innovation context (Ernst et al., 2015), which lacks sufficient examination in relation to health or societal grand challenges (Liu et al., 2021; Shaheen et al., 2022). Our study shows that during pandemics, the more effectively organizations can commercialize new products, the more immediate the population health gains will be. Our study also has implications for practice, as it shows how for-profit organizations can tackle the severe health-related consequences of pandemics through innovation performance and work to increase social equality in health in this context.

2. BACKGROUND LITERATURE AND HYPOTHESES

We present our research framework in Figure 1. The framework examines the impact of organizational ambidexterity on innovation performance related to pandemics and the impact of organizational innovation performance on health grand challenges. Organizational ambidexterity is "an organization's ability to be aligned and efficient in its management of today's business demands while being adaptive to changes in the environment" (Raisch & Birkinshaw, 2008, p. 375). Ambidextrous organizations are, on the one hand, aligned and efficient in terms of exploiting existing competences and reusing routines to respond to market demands (Chang et al., 2009; Gupta et al., 2006; Mom et al., 2019). On the other hand, they are adaptive in that they can acquire new knowledge and shift to different technological trajectories to facilitate organizational change (Boumgarden et al., 2012; Gupta et al., 2006). Organizational ambidexterity therefore involves an organization's ability to engage in both exploratory and exploitative activities (Boumgarden et al., 2012; Chang et al., 2009; Luger et al., 2018). Exploration involves experimentation, discovery, and revolutionary change (Luger et al., 2018; March, 1991); it requires new or dynamic firm competences (Lanzolla et al., 2021; Volberda et al., 2001) to fundamentally change existing structures to safeguard organizational sustainability over time (Gibson & Birkinshaw, 2004; Koryak et al., 2018). Exploitation involves an organizational capacity to engage in evolutionary change (Gupta et al., 2006; Luger et al., 2018) and to increase the fit among strategy, structure, and culture (March, 1991; Tushman & O'Reilly, 1996). Central to the exploration–exploitation trade-off is the organizational ability to simultaneously pursue revolution and evolution or radical and incremental innovation (Lin et al., 2013; Raisch & Birkinshaw, 2008). Practically, this ability is well proved in organizations such as Hewlett-Packard and Johnson & Johnson that successfully compete in existing markets through incremental innovation, while pursuing new market creation or entry in nascent markets through radically new products (Tushman & O'Reilly, 1996).

"Insert Figure 1 about here"

March's (1991) landmark article on organizational ambidexterity indicates the necessity of firms to jointly engage in exploratory and exploitative activities to sustain competitive advantages. Earlier research largely viewed exploration and exploitation as discrete practices, arguing that firms should focus on one and not both (e.g., Hannan & Freeman, 1977; Miller & Friesen, 1986). Drawing on March's (1991) exploration–exploitation framework, Tushman and O'Reilly (1996) introduced the concept of organizational ambidexterity as an organizational ability to both explore and exploit. Since then, diverse streams in organizational literature have examined organizational ambidexterity (Raisch & Birkinshaw, 2008; Wu et al., 2020), including organizational learning (Gupta et al., 2006; Ossenbrink et al., 2019), strategic management (Tiwana, 2008; Zhao et al., 2017), organization science (Andriopoulos & Lewis, 2009), and technological innovation (Ko & Liu, 2019; Taylor & Helfat, 2009). These streams highlight the ability of many organizations to engage in both single- and double-loop learning (Lee et al., 2017), incremental and radical innovation (Lin et al., 2013), efficiency and effectiveness (Cao et al., 2013), and induced and autonomous strategic processes (Burgelman, 1991). Yet they all refer to the same ambidextrous ability to jointly explore and exploit (Raisch & Birkinshaw, 2008), viewing ambidexterity as a prerequisite of organizational survival and long-term performance (Raisch & Birkinshaw, 2008).

The literature also distinguishes between three types of organizational ambidexterity: simultaneous or structural, sequential, and contextual ambidexterity (Foss & Kirkegaard, 2020; O'Reilly & Tushman, 2013). Simultaneous or structural ambidexterity involves an organizational design that accounts for both adaptability-focused (i.e., exploratory) and alignment-focused (i.e., exploitative) activities, often through separated (but aligned) units or teams, competences, and processes for exploration and exploitation (Benner & Tushman, 2003; O'Reilly & Tushman, 2008; Ossenbrink et al., 2019). Sequential ambidexterity refers to the ability of firms to shift structures over time to alternate between exploration and exploitation, depending on their strategy (Duncan, 1976; O'Reilly & Tushman, 2013). Contextual ambidexterity involves a behavioral ability to judge how to divide time between alignment- and adaptability-focused activities (Gibson & Birkinshaw, 2004; Ko & Liu, 2019). In this study, we focus on simultaneous or structural ambidexterity, or how organizations organize their functions and processes to pursue both exploration and exploitation (Gibson & Birkinshaw, 2004; Junni et al., 2020).

The literature on simultaneous or structural organizational ambidexterity also distinguishes between a balanced and combined dimension of ambidexterity (Cao et al., 2009; He & Wong, 2004; Junni et al., 2013; Zhao et al., 2021). Balanced ambidexterity refers to the pursuit of exploration and exploitation in an equitable way (Venugopal et al., 2020), such that an ambidextrous organization puts the same emphasis on both exploration and exploitation (Jancenelle, 2020). Combined ambidexterity involves maximizing the magnitude of ambidexterity (Mehrabi et al., 2019) by pursuing high levels of both exploration and exploitation simultaneously (Cao et al., 2009; He & Wong, 2004; Venugopal et al., 2020). Both balanced and combined ambidexterity tackle structural aspects of organizational ambidexterity (Cao et al., 2009), pursuing explanations for the structural mechanisms that allow organizations to pursue both alignment and adaptability (Gibson & Birkinshaw, 2004; Ossenbrink et al., 2019; Sheremata, 2000); yet they are grounded in diverse theoretical foundations. Balanced ambidexterity stems theoretically from March's (1991) work, which acknowledges that trade-offs and competition between exploration and exploitation cannot be avoided and that ambidextrous organizations need to identify the appropriate balance between the two (Cao et al., 2009; Luger et al., 2018). Studies taking this view argue that a balance between exploration and exploitation is required and can be achieved by creating spatially (i.e., physically and culturally) separated business units (O'Reilly & Tushman, 2004) and designing different structures for each unit to engage separately in either exploration or exploitation (Raisch & Birkinshaw, 2008). For example, business units that deal with exploration are usually structured such that they can be kept small, are decentralized, and encompass loose processes, while units dealing with exploitation are larger, more decentralized, and characterized by tighter processes (Benner & Tushman, 2003).

On the other end, studies on combined ambidexterity stress the non-competitive or complementary relationship between exploration and exploitation (Gupta et al., 2006; Hahn et al., 2016). Combined ambidexterity is theoretically grounded in the concepts of orthogonality (Gupta et al., 2006; Junni et al., 2020; Katila & Ahuja, 2002) and supplementary fit (Gulati & Puranam, 2009) between exploratory and exploitative activities. Gupta et al. (2006) conceptualize exploration and exploitation as independent, non-competitive activities that are orthogonal to each other and thus simultaneously achievable. Gulati and Puranam (2009) emphasize the supplementary fit between contradictory activities that can be maximized through cross-fertilization. In this sense, combined ambidexterity represents the ability of organizations to develop and leverage organizational knowledge and resources that supplement each other and increase the combined magnitude of exploration and exploitation (Gibson & Birkinshaw, 2004; Voss & Voss, 2013). This can be achieved, for instance, by sustaining a primary organizational structure for routine tasks, adjustments, and efficiency and a complementary secondary structure for non-routine tasks and experimentation (Adler et al., 1999; Voss & Voss, 2013). Nonaka (1994) refers to "hypertext organizations" as those designed on the grounds of combined exploration and exploitation structures.

2.1. Organizational ambidexterity and innovation performance in the health sector

Companies often face difficulties in pursuing incremental and radical innovations at the same time (Lin & McDonough, 2014; Saemundsson & Candi, 2013). Yet certain companies with high levels of research-and-development (R&D) investment (Revilla & Rodríguez-Prado, 2018) are ambidextrous enough to manage this tension and exhibit higher innovation performance (Ko & Liu, 2019; Lin et al., 2013; Lubatkin et al., 2006). We adopt Rosenbusch et al.'s (2019, p. 205) definition of innovation performance as "the degree to which a firm's innovation process is successful in terms of producing outcomes that lead to new or significantly improved products or services, processes, new marketing methods, or new organizational methods in business practices." We focus on innovation performance related to the health sector and, specifically, product innovations that help tackle the health challenges associated with pandemics. Innovators include various types of companies, such as pharmaceuticals, biotechnology firms, research hospitals, and medical equipment suppliers, whose innovation performance is central to their functioning (Burgess et al., 2015; Sorescu et al., 2003). Yet, while the health sector represents a knowledge- and innovation-intensive industry, organizational ambidexterity in this sector has yet to be sufficiently addressed (Burgess et al., 2015), and organization ambidexterity and innovation performance in the context of pandemics are absent.

Prior research indicates a positive interaction between organizational ambidexterity and innovation performance (Atuahene-Gima, 2005; Guo et al., 2020b; Lichtenthaler & Lichtenthaler, 2009). Studies testing this relationship have shed light on the practices through which ambidextrous organizations achieve high innovation performance. Atuahene-Gima (2005, p. 61) explains that leading innovative organizations are effective in "exploiting existing product innovation competencies, while avoiding their dysfunctional rigidity effects by renewing and replacing them with entirely new competencies." Lichtenthaler and Lichtenthaler (2009) stress a type of ambidexterity that appears in the form of a dynamic capability to reconfigure and realign a firm's knowledge capacities, which is critical in managing internal and external knowledge in innovation. Xu et al. (2013) link innovation success to an organizational ability to balance internal technological strengths and external knowledge acquisition through competitor alliance participation.

Previous work highlights the merits of researching the balanced and combined dimensions of organizational ambidexterity to understand firm innovation performance (Geerts et al., 2018; Guo et al., 2020b). Organizational ambidexterity is increasingly considered a blend of these two dimensions (Cao et al., 2009; Foss & Kirkegaard, 2020), and therefore their joint consideration can provide a better understanding of the effect of ambidexterity on organizational performance outcomes (Cao et al., 2009; Zhao et al., 2021), including innovation (Guo et al., 2020b). While balancing or combining exploration and exploitation can affect firm performance with varying effects (Mehrabi et al., 2019; Venugopal et al., 2020), the conditions that enable innovative firms to benefit from one or both dimensions of ambidexterity are poorly understood. At the same time, understanding how for-profit organizations balance or combine exploration and exploitation in innovation initiatives related to pandemics can shed light on organizational ambidexterity in this context and therefore fill a research void.

We reason that a high level of balanced ambidexterity, which supports the spatial separation between exploratory and exploitative activities (Blindenbach-Driessen & Van den Ende, 2014; Crescenzi & Gagliardi, 2018; Gupta et al., 2006), contributes to improved innovation performance of for-profit organizations with regard to products that help overcome health-related consequences of pandemics. Designing an organizational structure in which incremental and radical innovations occur in spatially separated business units can help alleviate the tension and negative relationship between exploration and exploitation (Blindenbach-Driessen & Van den Ende, 2014; Geerts et al., 2018). A spatial separation of exploration and exploitation can reduce competition over organizational resources (Geerts et al., 2018) and enable managers to focus on the idiosyncrasies and requirements inherent in each type of innovation separately (Andriopoulos & Lewis, 2009). By contrast, having exploration and exploitation under the same roof may pose a threat to the ability to balance the two, which can lead to reduced innovation performance. Prior research shows that having a single operational environment for both exploration and exploitation can suffocate the former (Benner & Tushman, 2002, 2003) and weaken the firm's radical innovation performance. Under such circumstances, an overemphasis on exploitation will increase the risk of rigidity (Leonard-Barton, 1992) and obsolescence (Cao et al., 2009) in the firm's efforts to produce successful innovation outcomes in the long run. As the firm will concentrate its resources and managerial attention on exploiting and incrementally improving existing products in existing markets, it will eventually risk failure in its innovation attempts over time (Cao et al., 2009; Gupta et al., 2006). This occurs because the firm will focus primarily on existing knowledge and competences to innovate, failing to engage in transformational learning and the creation of new competences necessary for capitalizing on significant technological and market changes (Lanzolla et al., 2021; Volberda et al., 2001). Yet a threat can also emerge as part of the spatial separation between exploration and exploitation. While spatial separation can increase exploration, there is a risk of underemphasizing exploitation (Blindenbach-Driessen & Van den Ende, 2014). If a firm overlooks exploitation and focuses on exploration, it faces a high risk of failing to commercialize innovations and appropriate large returns (Mitchell & Singh, 1992). In the absence of exploitation, the firm will not have the infrastructure or financial capability to invest in costly R&D, which is required to implement radically new products (Geerts et al., 2018).

We argue that balanced ambidexterity, which involves a balance between exploration and exploitation, is central to the innovation performance of for-profit organizations in the context of pandemics. For-profit organizations in the health sector (e.g., pharmaceutical, biotechnology) engage in both exploration and exploitation to pursue incremental improvements to their existing offerings and radically new products (Balarezo & Nielsen, 2020; Winterhalter et al., 2016). The R&D unit of these companies, which mainly deals with radical innovations, is often spatially separated from other organizational units (Balarezo & Nielsen, 2020). We expect that a spatial separation, given that an organization can give equal attention to exploration and exploitation, can have a positive impact on the organization's innovation performance in the context of pandemics. For example, both Pfizer/BioNTech and Moderna developed the first-ever mRNA vaccines for COVID-19 and radically new technological know-how in vaccine development (Wouters et al., 2021). At the same time, these companies are exploiting this new knowledge and competences (through effective assimilation) to improve their product further (e.g., modifications of the vaccine to more effectively combat the new variants) and to pursue new mRNA-powered vaccines for other deceases such as HIV (Venkatesan, 2021). As such, we argue that the inability of for-profit organizations in the health sector to achieve a balance between exploration and exploitation can disrupt their innovation performance and render them unable to realize innovation outcomes. Thus:

Hypothesis 1 (H1): The balanced dimension of ambidexterity (for-profit organizations' balanced exploratory and exploitative activities through spatial separation) is positively associated with innovation performance related to pandemics.

Furthermore, we argue that a high level of combined ambidexterity (Gupta et al., 2006) contributes to for-profit organizations' improved innovation performance related to pandemics. When exploration and exploitation occur in complementary fields (e.g., markets, technologies) (Hahn et al., 2016) or when they are treated as orthogonal (non-competitive) (Gupta et al., 2006), organizations in the health sector can safeguard sufficient and timely resources to engage in both incremental and radical innovations. When exploration and exploitation are complementary, backed by long-term planning, knowledge development in such organizations can support the enhancement of both (Blindenbach-Driessen & Van den Ende, 2014; Zhou & Wu, 2010). Exploration can set the ground for the accumulation of organizational knowledge, which can then be exploited, while through exploitation organizations develop dynamic capabilities to engage in exploratory activities (Smith & Lewis, 2011). In addition, under a complementary logic, spatially separated exploration and exploitation units can generate spillovers, such as new knowledge, ideas, and opportunities for knowledge exchange, which can benefit both incremental and radical innovation processes (Geerts et al., 2018). Previous research highlights the positive relationship between exploration and exploitation, under a combined ambidexterity approach (e.g., Cao et al., 2009; Guo et al., 2020b; Junni et al., 2013). In the presence of high exploitation practices, a firm can become more aware of the boundaries of existing knowledge and develop capabilities for reconfiguring existing knowledge required for radical innovation (Cao et al., 2009; Fleming, 2001). Similarly, an increase in exploitation, which implies engaging in incremental innovations, can provide the financial capital required for exploration and, thus, engagement in costlier radical innovations (Geerts et al., 2018). On the other end, high investment in exploratory activities can benefit exploitation. A firm that engages in radical innovation in one market or business unit can generate new knowledge and competences that can enhance or make more efficient the exploitative activities in its other markets or units (Blindenbach-Driessen & Van den Ende, 2014).

This argument is particularly relevant for for-profit organizations in the health sector and their efforts to improve their sales and performance in the midst of a pandemic by giving high attention to both exploration and exploitation. We argue that pandemics offer a fertile ground for such companies not only to exploit their existing products but also to explore completely novel drugs. Given that existing products have already been developed, tested, and approved, launching them into the market takes less time and cost (Chong & Sullivan, 2007) and can offer a reliable intermediate solution while waiting for the development and approval of blockbuster drugs. Furthermore, the successful exploitation of existing products can inject the company with the financial resources necessary to boost exploration for novel medicines against pandemics.

In summary, we propose that complementarities between exploratory and exploitative knowledge, resources, and activities can enhance for-profit organizations' innovation performance (related to pandemics). Thus:

Hypothesis 2 (H2): The combined dimension of ambidexterity (for-profit organizations' combined exploratory and exploitative activities) is positively associated with innovation performance related to pandemics.

Moreover, we expect an approach that facilitates the co-presence of high levels of balanced and combined ambidexterity (Cao et al., 2009; Wei et al., 2014) to have a positive effect on organizational innovation performance. Recent work shows that companies adopt multiple modes of ambidexterity at a given time and do not necessarily stick with a single mode or alternate between distinct ambidexterity approaches (Foss & Kirkegaard, 2020). While this work indicates that both balanced and combined organizational ambidexterity are important for firm performance and new product development (Cao et al., 2009; Mehrabi et al., 2019; Wei et al., 2014), the latter dimension creates a paradox through which the relationship between exploration and exploitation can be understood (Wei et al., 2014). Exploratory and exploitative activities can be competitive and interrelated or complementary at the same time. For example, Smith and Lewis (2011) suggest that a paradox view provides a more sufficient understanding of the way organizational ambidexterity unfolds and influences organizational outcomes. While exploration and exploitation strategies may compete for organizational resources, they can reinforce each other through iterative acquisition and assimilation of organizational knowledge (Andriopoulos & Lewis, 2009; Smith & Lewis, 2011). Cao et al. (2009) explain that when the balanced dimension synergistically co-exists with the combined dimension, this blended approach can maximize organizational outcomes, such as enhanced performance. Specifically, when a firm explores and exploits in a balanced manner (i.e., high balance), it will be in a position to acquire new knowledge (Gupta et al., 2006) and, at the same time, to effectively assimilate this new knowledge into its existing pool of competences (Cao et al., 2009). This will establish a "mutual leverage effect" (Cao et al., 2009, p. 785) between exploration and exploitation, which will lead to high levels of both exploratory and exploitative activities (i.e., high combined) and a strong positive effect on firm performance. By contrast, when exploration and exploitation are imbalanced (i.e., low balance), the mutual leverage effect between the two activities will be weaker, leading to a low combined dimension and an overall low positive effect on firm performance (Cao et al., 2009).

According to Wei et al. (2014), new product development relies on a synergistic approach that considers both balanced and combined aspects of exploration and exploitation. Establishing a satisfactory balance between exploration and exploitation can enable organizations to develop and exploit complementary knowledge between exploratory and exploitative efforts (Cao et al., 2009) and to align the complementarities between the two activities better, leading to high levels of both exploration and exploitation (Smith & Lewis, 2011; Wei et al., 2014). Yet organizational ambidexterity literature lacks evidence on how a synergistic approach that blends balanced and combined ambidexterity influences innovation performance outcomes.

We argue that for-profit organizations in the health sector that maintain high levels of both balanced and combined dimensions will exhibit high innovation performance related to pandemics. A pandemic prompts organizations in the health sector both to explore new solutions (e.g., vaccines) and to exploit existing products (e.g., existing medicines) (Saha et al., 2020). While such exploratory and exploitative activities are likely to occur in different units, they may compete for the same resources (e.g., financial, human capital) (Geerts et al., 2018).

Yet balancing exploration and exploitation can help these organizations establish a mutual leverage effect between the two through the simultaneous creation and assimilation of new knowledge (Cao et al., 2009). For example, a pharmaceutical company that explores new vaccines to combat COVID-19 is also acquiring new knowledge on the behavior of the virus (e.g., replication, immune-related biological processes, antibody responses). This knowledge, in turn, can help it improve strategies and processes to control and eradicate the virus and increase the effectiveness of both novel (e.g., vaccines) and existing medicines launched against the virus. Consequently, such practices are likely to enhance both exploration and exploitation of the firm.

In summary, we propose that a strategy that combines both a competitive approach (i.e., balanced ambidexterity) and a complementary approach (i.e., combined ambidexterity) of exploration and exploitation contributes to improved innovation performance of for-profit organizations in the health sector. This is because such as synergistic approach can enable the organizations to optimize the interrelationship between exploration and exploitation better in the innovation process. Thus:

Hypothesis 3 (H3): High levels of both balanced and combined dimensions of ambidexterity synergistically lead to better innovation performance related to pandemics.

2.2. Innovation performance and health grand challenges

Across the globe, countries and transnational organizations increasingly acknowledge that science, technology, and innovation can have a leading role in addressing grand challenges (Buckley et al., 2017; Nilsson, 2017). Grand challenges are "large, complex, unresolved societal problems, which are global in nature" (Berrone et al., 2016, p. 1941) but offer hopes of ultimately being tackled (George et al., 2016). While grand challenges occur in many social domains (Cai et al., 2019), such challenges are particularly prominent in the health sector. Health grand challenges include population growth and mortality issues (Chanda, 2015), antimicrobial resistance (Olsen et al., 2016), control of existing infectious diseases (e.g., malaria) and emerging diseases such as COVID-19 (George et al., 2020; Namazzi et al., 2013), and the treatment of uncurable diseases such as HIV/AIDS and access to medicines for them (Nilsson, 2017). The focus of the present study is on global pandemics, which pose a health grand challenge across the globe (Howard-Grenville, 2021). Pandemic diseases usually originate locally and then spread widely, becoming a menace for all (McDougall & McDavid, 2014). In the past two decades, humanity has confronted pandemics such as SARS (Daszak, 2012) and now COVID-19 (Howard-Grenville, 2021). In the face of such pandemics, the world has experienced new product innovations in the form of, for example, novel medicines and vaccines (Mullard, 2020), smart robots for distant communication between doctors and patients, new technologies for sanitation and disinfection (Cooper, 2021), and advancements in personal protective equipment (Brem et al., 2021).

Product innovations related to the health sector are instrumental in advancing health care systems and facilitating the protection of human health (Lehoux et al., 2014). Policy instruments have played a prominent role in establishing research infrastructures, building university–industry partnerships, and encouraging R&D for radically new products in the field of human health (Lehoux et al., 2014; Thune & Mina, 2016). Through conducive policy making, many organizations, such as pharmaceuticals, biotech firms, research hospitals, and medical equipment manufacturers, have emerged in the health sector in countries such as the US and Canada, yielding innovative products (Compagni et al., 2015). Most of these organizations are for-profit entities, whose success in developing and commercializing radical innovative products (e.g., cancer drugs, regenerative medicines, disease detection equipment, surgical robots) has led to substantial population health gains and drastic changes to the structure and provision of health services (Lehoux et al., 2014).

Prior research illustrates that product innovations do not immediately result in widespread gains, as they need time to be adopted (Fagerberg & Verspagen, 2002; Rogers, 2010). According to innovation diffusion theory, new products need time to build momentum and be diffused widely within a social system (Delre et al., 2010; Rogers, 2010), given the essential stages or processes that need to be accomplished hierarchically, such as the communication of innovations, the assessment of the advantages of innovations, and the decision to adopt (Choudhury & Karahanna, 2008; Rogers, 2010). Evidence indicates that it often takes 10 years or more for the diffusion of product innovations (Katz et al., 1963); yet certain conditions can accelerate this diffusion, and the time span to innovation adoption can be shortened dramatically (Kimberly, 1981; Meyer & Rowan, 1977). For example, in the presence of ambiguity, innovation adoption can materialize much faster because the time-consuming rational mechanisms involved in the assessment of innovation benefits are bypassed (Meyer & Rowan, 1977). For product innovations related to human health, several conditions have been linked to innovation diffusion speed, including the collective and coordinated actions by stakeholders in the health sector (Baptista, 2000; Clarysse et al., 2014), the development of new innovations based on strong scientific knowledge (Papazoglou & Spanos, 2018), the timely availability of strong evidence on the benefits of new innovations (Compagni et al., 2015), and the presence of open innovation models in inter-firm or multi-stakeholder partnerships (e.g., companies, governments, universities) (Papazoglou & Spanos, 2018; Salge et al., 2013). Pandemics present ambiguous circumstances suited to understanding the accelerated diffusion of new innovations. Evidence from the COVID-19 pandemic shows that product innovations, such as new medicines, vaccines, and protective equipment, can be widely diffused quickly for immediate population health gains (e.g., reduction of pandemic spread) (Liu et al., 2021). Studies have attributed innovation adoption speed during pandemics to the collective actions of diverse stakeholders (e.g., doctors, epidemiologists, hospitals, governments/states, medical device suppliers, supranational organizations) within the health care ecosystem (Liu et al., 2021).

We argue that the high innovation performance of for-profit organizations during pandemics can lead to greater health gains for the broader population. An organization's health-related innovation performance involves its effectiveness in producing new or significantly improved products, processes, or organizational methods (Rosenbusch et al., 2019) that help alleviate pandemic-related health problems. For example, the success of firms in commercializing new drugs or digital contact-tracing apps is widely acknowledged as critical to tackling the COVID-19 pandemic (Sharma et al., 2020). Essential population health gains include reducing mortality rates (Baud et al., 2020; Chanda, 2015), reducing infection risk (Ren et al., 2021; Sun & Zhai, 2020), and increasing life expectancy (Aburto et al., 2022). Drawing on theory and evidence linked to the accelerated diffusion of innovations (e.g., Kimberly, 1981; Meyer & Rowan, 1977), we argue that during pandemics, innovations such as vaccines are likely to be diffused quickly through the broader population due to the high ambiguity that exists, which makes people more willing to adopt early new innovations to avoid negative personal health outcomes. At the same time, we argue that the high coordinated efforts among firms and stakeholders to fight pandemic diseases (Liu et al., 2021) can speed up the diffusion of innovations to the broader society. In summary, we propose that the high innovation performance of for-profit organizations in the health sector during pandemics contributes to health gains for the broader population in the form of reduced mortality rates, reduced infection risk, and increased life expectancy. Thus:

Hypothesis 4a (H4a): For-profit organizations' innovation performance is positively associated with the reduction of mortality rates related to pandemics.

Hypothesis 4b (H4b): For-profit organizations' innovation performance is positively associated with the reduction of infection risk related to pandemics.

Hypothesis 4c (H4c): For-profit organizations' innovation performance is positively associated with the increase of life expectancy.

We argue that social equality in health positively moderates the positive relationship between for-profit organizations' innovation performance and population health gains during pandemics. Social equality refers to the view that all people in society should enjoy the same rights and fair access to opportunities and material resources, such as education, employment, health, and quality of life (Jackman, 1974; Kolodny, 2014). In the health context, social equality means fair access to health care for all citizens in a society (Abatemarco et al., 2020; Gulliford et al., 2002), such as access to quality treatment without discrimination (Culyer & Wagstaff, 1993).

Prior research highlights the importance of increased social equality for tackling health-related grand challenges and generating health gains for the wider population (e.g., Chuang et al., 2013; Phelan et al., 2004). Specifically, evidence positively links social equality in health with health gains such as reduced mortality rates, reduced infection risk, and increased life expectancy. Phelan et al. (2004) show that a reduction of social equality in health, with people having increasingly unequal access to health care, leads to increased mortality rates. In a pandemic context, reduced equality in health care is associated with higher mortality rates among specific populations (Phelan et al., 2004; Rozenfeld et al., 2020). For example, Rozenfeld et al. (2020) found racial disparities in mortality in the US during COVID-19 stemming from unequal access to health care for African Americans, immigrants, and Latinos. Studies also link fair access to health care with infection risk during pandemics. Rozenfeld et al. (2020) identify a higher risk of COVID-19 infection among African American and Latino populations in the US, who usually face limited access to health care. Bambra et al. (2020) show that COVID-19 infection in Spain was six to seven times higher in socially disadvantaged areas and marginalized communities, which have less access to the health care system than the least deprived. Furthermore, social equality and fair access to health care are positively associated with increased life expectancy (Asaria et al., 2019; Wahlbeck et al., 2011). While pandemics disrupt life expectancy (Omram, 2001; Woolf et al., 2021), research indicates that health disparities perpetuated by unequal health care access for specific sub-populations can accelerate the reduction of life expectancy in a society (Hirko et al., 2020; Woolf et al., 2021).

We argue that while higher innovation performance by for-profit organizations in the health sector can increase population gains, such benefits will be further enhanced in the presence of greater social equality. Studies on the diffusion of innovations (Delre et al., 2010; Rogers, 2010) show that the level of social equality influences the success and speed of innovation diffusion within a social system (Gutin & Hummer, 2021; Korda et al., 2011). The lesser the inequality in a social system, the wider, and thus more successful, is the diffusion of innovations (Korda et al., 2011; Rogers, 2010), as all members of a population will have equal and fair access to new innovations (Gutin & Hummer, 2021). In this sense, the innovations of organizations in the health sector can be more effectively diffused in a social system and materialize into wider health-related population gains in the presence of greater social equality. Therefore, we expect that under increasing social equality in health, for-profit organizations' innovation performance will lead to greater population health gains in the form of higher reduced mortality rates, higher reduced infection risk, and higher increase of life expectancy. By contrast, increased social inequality can have a negative impact on the diffusion of new innovations (Korda et al., 2011; Sirine, 2017). Studies indicate that social inequality can lead to the uneven diffusion of health-enhancing innovations in a population, which can limit access to health gains for some groups (Gutin & Hummer, 2021; Korda et al., 2011). Often, societal structures are such that successful innovations initially reach a few select and advantaged social groups before being diffused to the broader population (Korda et al., 2011). We therefore expect that in the presence of less social equality in health (i.e., greater inequality in access), for-profit organizations' innovation performance will decrease population health gains. Thus:

Hypothesis 5a (H5a): With increasing social equality in health, for-profit organizations' innovation performance will lead to a higher reduction of mortality rates related to pandemics.

Hypothesis 5b (H5b): With increasing social equality in health, for-profit organizations' innovation performance will lead to a higher reduction of infection risk related to pandemics.

Hypothesis 5c (H5c): With increasing social equality in health, for-profit organizations' innovation performance will lead to a higher increase of life expectancy.

3. METHODOLOGY

3.1. Data sources and sample

To investigate the research hypotheses, the empirical analysis is based on three datasets: innovation, firm, and state characteristics. The innovation data come from the US Patent and Trademark Office (USPTO) and, most specifically, from the *US Patent Application Publication*; the firm-level financial characteristics come from Compustat; and the state-level data (to capture regional heterogeneity) come from the US Census Bureau, the Bureau of Economic Analysis (BEA), and the Centers for Disease Control and Prevention (CDC). We collect data (address and company name) for each organization (assignee) first from the USPTO Patent Assignment Dataset Schema, which we subsequently allocate to innovation data (detailed patent title and description, application and grant date, and forward citations), and then from the *US Patent Application Publication* data, which classifies patents by their Cooperative Patent Classification. For our analysis, which is centered on the COVID-19 pandemic, we examined the patent description using the search criteria "sars cov," "coronavirus," "severe acute respiratory syndrome," "SARS-CoV-2," and "COVID-19." Following Bena et al. (2017) and Graham et al. (2018), we associate the strings assignee data from the USPTO with the company strings collected from Compustat, using fuzzy-string matching techniques based on the maximum likelihood n-gram method (Norvig, 2009). We verify the accuracy of the fuzzy-string approach by checking the global company key from the Global Corporate Patent Dataset (Bena et al., 2017). Finally, we incorporate state data from the US Census Bureau, the BEA, and the CDC using the zip-code and state information provided from Compustat. Our final sample includes 15,062 firm–year observations (baseline model for firms) over the period 1974–2020, which maximizes the available firm-time span.

3.2. Variable description

Our first objective is to examine whether and how the balanced and combined dimensions of ambidexterity drive innovation performance related to pandemics. Following the literature (Aghion & Jaravel, 2015; Cao et al., 2009;

Geerts et al., 2018; Kendall et al., 2010), we proxy innovation performance using the natural logarithm of the number of *granted patents* +1 (ln[patents+1]) for the coronavirus. In addition, for innovation quality we include *forward citations*, or the references received by other patents, reflecting the technological significance of subsequent technological developments (Trajtenberg, 1990). To test the robustness of our results further, we also include *patent applications* and the *grant lag*, which is the time difference between application and grant dates, indicating innovator beliefs about the value of the patent. According to Harhoff and Wagner (2009), well-documented patents are approved faster.

Organizational ambidexterity, which is the main variable of interest in the first stage of our analysis, consists of two distinct but related dimensions: *balanced dimension of ambidexterity*, which emphasizes the balance between exploration and exploitation and is measured using the absolute value of the difference between exploration and exploitation (Cao et al., 2009; He & Wong, 2004), and the *combined dimension of ambidexterity*, which considers a firm's combined magnitude of exploration and exploitation proxied using the interaction between exploration and exploitation (Cao et al., 2009; Gibson & Birkinshaw, 2004; He & Wong, 2004). To facilitate interpretation, in the regression models we rescale (reverse) the balanced dimension of ambidexterity (Cao et al., 2009), such that higher values indicate greater balance.

Research identifies four alternative approaches that measure *exploration and exploitation*: survey-based measures in a cross-sectional setting (Atuahene-Gima & Murray, 2007; Lin & McDonough 2014; Zi-Lin & Poh-Kam, 2004), accounting-based measures considering R&D expenditures (March, 1991), press-based measures using news documents (Rothaermel & Deeds, 2004; Uotila et al., 2009), and patent-based measures in a longitudinal setting (Ahuja & Lampert, 2001; Belderbos et al., 2010; Geerts et al., 2018; Leten et al., 2007). Our aim herein is to investigate the innovation dynamics of the firms in conjunction with a health grand challenge, which requires us to employ the patent-based approach with the longitudinal setting. In this context (Belderbos et al., 2010; Geerts et al., 2018), a firm's innovation activity is considered exploratory if it is established in a technology field that the firm had not patented in within the last five years (t – 5 to t – 1) (Ahuja & Lampert, 2001; Geerts et al., 2018; Leten et al., 2007). Using patent data from the USPTO, which is based on the Cooperative

Patent Classification system, we identified 93% of the total patents as exploitation and the remaining 7% as exploration.

Our control variables include a set of various firm-specific characteristics. According to Kleis et al. (2012), firms engage in innovation activities to build or maintain competitiveness; they achieve this through an increase in the productivity of value chain activities (process innovations) or the sale of new products or services (product innovation). The estimation models control for the *size of the firm* by considering both the natural logarithm of the company's revenue and the natural logarithm of total assets. Size is important because, in general, larger firms are better able to secure external finance for their projects (Chen et al., 2021; Li et al., 2019; Zhou et al., 2016). Furthermore, the *growth potential of the firm*, or the ratio of its intangible assets to total assets, controls for its speed of growth. Firms that exhibit strong growth rates cannot finance their growth with just internal funds but must also rely heavily on external finance (Stanworth & Curran, 1976). The reliance on external debt rises cost significantly, forcing firms to finance only high-yield projects and forgo projects low in profitability (Poutziouris et al., 2022). Therefore, high-growth firms have difficulty in securing additional funding, with detrimental effects on their innovation output.

In addition to these control variables, we include the *current ratio* (the ratio of current assets to current liabilities) in the estimation models. The current ratio calculates the firm's ability to repay its short-term obligations. A firm that lacks adequate collateral to secure favorable long-term finance may resort to trade credit to support its operations. This is particularly true for smaller firms (Abdulsaleh & Worthington, 2013). However, a firm lacking money will postpone payments (will operate trade credit) and, if trade credit is not enough to make it liquid, will pursue short-term loans at a high cost of capital (Kling et al., 2014). Relying on trade credit is therefore detrimental to a firm's ability to expand its production of innovating output, given the higher cost of financing it must incur. Furthermore, we include a *solvency ratio* as a control variable to capture the firm's ability to cover its long-term obligations with its assets. The general idea behind using this ratio is similar to that for the current ratio. In general, insolvent firms are less able to acquire cheap funding and therefore are less able to fund additional projects, including innovation initiatives.

According to Daskalakis and Psillaki (2008) and Psillaki and Daskalakis (2009), the *asset structure* of a firm (i.e., the ratio of its fixed assets to total assets) is an important determinant of external finance. This is because firms with high ratios can safeguard their lenders from adverse selection and moral hazard by providing collateral to secure more favorable loans (Kumar et al., 2017, Ramli et al., 2019). Firms with a high ratio of fixed assets to total assets will be able to secure cheaper finance to fund their projects, and because firms require a smaller return on investment to green-light the projects, patent output will increase. In addition, we include a *leverage ratio*, or the long-term debt to shareholder equity, as a control variable to capture the firm's ability to take on more debt. The higher this ratio, the more the firm's assets are financed by external funds and, thus, the less able the firm is to secure external finance. The additional cost of capital will force the firm to fund innovating projects that yield a high rate of return and thus dismiss low-yield projects, even if profitable, thereby reducing its patent output. Finally, prior research emphasizes the significant role of *R&D expenditure* in firms' ability to develop new knowledge, invent, and innovate (Alexy et al., 2013; Mudambi & Swift, 2014; Nicholls-Nixon & Woo, 2003). To control for the effect of R&D intensity on innovation, we include R&D expenditures divided by sales.

Research has also identified the effect of innovation on health outcomes (Cutler et al., 2006; Fuchs, 2010; Kramarow et al., 2007; Lichtenberg, 2013, 2014, 2016, 2017). In this context, we also aim to uncover the mechanism linking firms' innovation activities related to the coronavirus with regional and specifically state health outcomes obtained from the CDC. In particular, we examine whether and how firms' innovation initiatives (granted patents) have an impact on the *COVID-19 mortality rate* (i.e., the ratio of the number of deaths due to COVID-19 to the average total population in a specific year and area), *the COVID-19 infection risk* (reflecting the odds of being infected with COVID-19), and *regional life expectancy*. We explore this channel by also taking into account the presence of social inequality variables, including *income per capita (p.c)*, *unemployment*, *health expenditure p.c*, *health insurance coverage*, *percentage of college graduates*, and *urbanization*, all of which could potentially affect the access and use of innovative health technologies. Furthermore, following Grossman (1972), Shaw et al. (2005), and Kabir (2008), we control for a set of area characteristics, including *fraction of current smokers*, *fraction of those obese*, and *crime rate p.c*.

Any unobserved heterogeneity is captured by the year and state fixed effects, as well as industry fixed effects, based on the North American Industry Classification System. Table 1 provides summary statistics for all the variables included in the models, Table A1 in the Online Appendix (OA) a detailed description and source, and Table A2 a correlation analysis of the baseline variables.

"Insert Table 1 about here"

3.3. Data analysis methods

3.3.1. Ambidexterity and innovation performance related to pandemics

We identify whether and how the balanced and combined dimensions of ambidexterity drive innovation performance related to the COVID-19 pandemic in the context of a Poisson maximum likelihood regression. This regression is a typical methodological approach used in the literature specifically for count data with non-negative values and no inferences in distribution (Correia et al., 2019; Griliches, 1984; Santos & Tenreyro, 2006), ensuring consistent parameter estimates.

In line with the literature (Gouriéroux et al., 1984a, 1984b; Hausman et al., 1984, Licht, 1996; Wang, 1998; Wooldridge, 1997, 2002), we set $p_{i,t}$ as the innovation variable related to the coronavirus for firm i at time t, with mean $l_{i,t} > 0$, and define the Poisson model as

$$p_{i,t\backslash}x_{i,1,\cdots,}x_{i,T} \sim P(l_{i,t}) \qquad \forall i, t \qquad (1)$$

for the $x_{i,1,\cdots,}x_{i,T}$ set of regressors detailed in the previous section for firm i and time 1974–2020, including the balanced and combined dimensions of ambidexterity, along with additional controls (i.e., size, as measured by revenue and assets; growth; asset structure; current ratio; solvency ratio; leverage ratio; and R&D expenditure) and fixed effects. Therefore, the probability to observe $p_{i,t}$ patents or citations given the explanatory variables $x_{i,1,\cdots,}x_{i,T}$ is equal to

$$\Pr\,(p_{i,t\backslash x_{i,T}}) = \frac{\exp(-l_{i,t})l_{i,t}^{p_{i,t}}}{p_{i,t}!}. \qquad (2)$$

We implemented a series of misspecifications tests to ensure the statistical validity of our models, including the Hausman test for fixed or random effects, the Pesaran test for contemporaneous correlation and cross-sectional dependence, the Wald test for homoskedasticity, and stationarity tests for the presence of unit roots.

3.3.2. Innovation performance related to pandemics and regional health outcomes

To examine whether and how innovation initiatives in the health sector are related to regional (state) health outcomes, we consider a typical fixed effects panel:

$$\varphi_{it} = a_i + \beta' x_{it} + \varepsilon_{it}, \tag{3}$$

where the dependent variable φ_{it} is a scalar and measures regional (state) health outcomes, including the COVID-19 mortality rate, risk of infection, and life expectancy; x_{it} are the $k \times 1$ health outcome determinants, including social inequality variables (income p.c, unemployment, health expenditure p.c, health insurance coverage, percentage of college graduates, and urbanization) and other state-specific characteristics (fraction of current smokers, fraction of those obese, and crime rate p.c); β is a $k \times 1$ vector of unknown parameters; and ε_{it} is an i.i.d error term for state *i* = 1, 2, ..., *N*, where $t = 2000 - 2020$.

Following Hansen (1999, 2000, 2017), we also aim to uncover the effect of the social inequality variables on the relationship between innovation performance related to pandemics and regional health outcomes by estimating a panel threshold model, which generalizes the linear model in Eq. (3) by allowing for the presence of multiple social inequality regimes. That is,

$$\varphi_{it} = a_i + \beta' x_{it} + m_1' Innovation_{it} I(q_{it} \leq \gamma) + m_2' Innovation_{it} I(q_{it} > \gamma) + \varepsilon_{it}, \tag{4}$$

where $I(.)$ is the indicator function, q_{it} is the threshold/social inequality variable, γ is the scalar threshold parameter or sample split value, and (m_1', m_2') is the vector of the innovation coefficients in the low- and high-social-inequality regime, respectively. In other words, we estimate the effect of the innovation performance related to pandemics ($Innovation$) on health outcomes (φ_{it}) in different social inequality regimes, using low ($q_{it} \leq \gamma$) and high ($q_{it} > \gamma$) values of the social inequality variables. For example, what is the effect of the innovation performance related to pandemics ($Innovation$) on life expectancy (φ_{it}) in areas where education is high ($education > \gamma$)?

The estimation of the threshold parameter γ, which distinguishes the low- and high-social-inequality regimes, is important for policy makers in terms of making decisions about the social inequality variables to achieve a more positive effect of innovation performance on health outcomes. For example, which level of gross domestic product (GDP) innovation performance related to the pandemic negatively affects the COVID-19 mortality rate? We first test for the presence of a non-linear relationship between social inequality and health outcomes and then uncover the effect of innovation performance on health outcomes in different social inequality regimes by estimating the panel threshold model in Eq. (4).

4. RESULTS

Our first aim in this section is to identify whether and to what extent balanced and combined ambidexterity affect for-profit firms' innovation performance related to pandemics. We examine the hypotheses in the context of a count data model, the Poisson maximum likelihood regression, and present the results in Table 2. In the models, we consider the effects of exploration and exploitation, balanced and combined ambidexterity, and the interaction between balanced and combined ambidexterity. As the results show, exploration and exploitation are positive and statistically significant at the 1% level in all model variations, thus proving the importance of a firm's ambidextrous orientation. More important, both balanced and combined ambidexterity are positive and statistically significant at the 1% level for granted coronavirus patents in all specifications. In particular, in the full model (column 9), a one-point increase in balanced ambidexterity is associated with a 0.14 increase in granted patents, whereas a one-point increase in combined ambidexterity has a 0.22 increase in granted patents related to the coronavirus. The results reveal the significant role of both balanced and combined ambidexterity in innovation performance, thus confirming Hypotheses 1 and 2. Furthermore, the interaction between balanced and combined ambidexterity (column 9) is positive and statistically significant at the 1% level, as a one-point increase has a 0.23 increase in granted patents related to the pandemic. Thus, we find strong support of a synergistic effect of high levels of both balanced and combined ambidexterity on firm innovation performance, confirming Hypothesis 3.

"Insert Table 2 about here"

With regard to the control variables, size (measured using revenues and assets) has a positive impact on granted patents, reflecting firms' ability to secure external finance for their innovation initiatives (Chen et al., 2021; Li et al., 2019). By contrast, firm growth has a negative impact on innovation performance related to the pandemic, as the reliance on external finance increases the cost, resulting in a focus only on high-yield projects.

Current ratio and solvency ratio, which represent the firm's ability to repay its financial obligations, are also statistically significant. The effect of current ratio is positive (at the 1% level), while that of solvency ratio is negative (at the 1% level). Finally, R&D, which is essential for firms to develop new knowledge, invent, and innovate (Alexy et al., 2013, Mudambi & Swift, 2014), positively affects granted patents (at the 1% level).[i]

Our second aim is to uncover whether and how innovation initiatives are related to health outcomes in the context of a fixed effects panel presented in Eq. (3). Table 3 includes the results of innovation performance, particularly granted patents related to the pandemic, on COVID-19 mortality rate, risk of infection, and life expectancy. According to the results, granted patents related to the coronavirus have a negative effect on the mortality rate at the 1% level. In particular, a one-point increase in innovation outcomes related to the pandemic has an 0.11 decrease on the COVID-19 mortality rate, confirming Hypothesis 4a. Confirming our predictions, regional income p.c, health expenditure p.c, and the percentage of college graduates negatively affect the COVID-19 mortality rate (1% or 5% level). By contrast, unemployment, fraction of current smokers, and fraction of those obese have a positive impact on mortality (at the 1% level). Similarly, innovation outcomes related to the coronavirus negatively affect the odds of being infected with COVID-19, confirming Hypothesis 4b, whereas the effect on life expectancy is positive, in support of Hypothesis 4c. A one-point increase in innovation outcomes reduces the odds of being infected by 0.10 but increases life expectancy by the same amount. Overall, Table 3 shows the importance of innovation initiatives related to the coronavirus in terms of not only tackling the negative consequences (mortality and infection) but also increasing longevity.

"Insert Table 3 about here"

A third important objective is to further investigate the moderating role of social inequality in the relationship between innovation outcomes and COVID-19 mortality rate, risk of infection, and life expectancy in the context of the panel threshold model presented in Eq. (4). The first step involves testing for the presence of a non-linear relationship between social inequality and health outcomes, and the second involves examining the effect of innovation performance on health outcomes in different(low-/high-) social-inequality regimes. Table 4 shows the results of the threshold test for health outcomes (COVID-19 mortality rate, risk of infection, and life expectancy) considering the presence of one threshold. The first column shows the threshold variables (social inequality variables), the corresponding p-value for the null hypothesis of a linear model against the alternative of a threshold, and the threshold estimate.

As the results show, the linear model null hypothesis is strongly rejected in the presence of one threshold/split for all social inequality variables. In addition, the threshold estimates are $33,312 for income p.c, 6% for unemployment, 71,938 for health expenditure p.c, 75% for health insurance coverage, 25% for college graduates, and 48% for urbanization. We also checked for the presence of a second threshold but found no evidence of such.

"Insert Tables 4 and 5 about here"

Table 5 presents the effect of granted patents related to the pandemic on COVID-19 mortality rate, risk of infection, and life expectancy, taking into consideration the moderating role of social inequality. As the results show, income p.c, health expenditure p.c, health insurance coverage, and the percentage of college graduates have a negative impact on the mortality rate and risk of infection, but the effect is positive on life expectancy. Furthermore, the unemployment rate has a positive effect on the mortality rate and risk of infection. As expected, the impact of the fraction of smokers and those obese on the mortality rate and risk of infection is positive and statistically significant at the 1% level, but the effect of the fraction of those obese on life expectancy is negative (significant at the 1% level).

Importantly, when we consider the presence of social inequality regimes (low and high), the effect of granted patents related to the pandemic on COVID-19 mortality rate, risk of infection, and life expectancy confirms the findings in Table 3. More specifically, the overall effect of innovation performance in both regimes is negative for the mortality rate and risk of infection but positive for life expectancy, again confirming Hypotheses 4a–4c. However, social inequality plays a moderating role in the innovation performance–health outcomes relationship, as the estimated coefficient/effect of innovation is significantly stronger in areas with high levels of income p.c (above 33,312), health expenditure p.c (above 71,938), health insurance coverage (above 75%), college graduates (above 25%), and urbanization (above 48%) and low levels of unemployment (below 6 %), confirming Hypotheses 5a–5c.

5. FURTHER ANALYSIS

In this section, we further investigate the robustness of our results using different model specifications and econometric techniques. First, we estimate Eq. (2) using three additional proxies of innovation: total citations, patent applications, and the grant lag. We also estimate Eqs. (3) and (4) using total citations as the innovation variable. Second, we examine more carefully the statistical adequacy of our estimated models by addressing concerns about endogeneity using instrumental variables in two-stage least squares (2SLS) estimation.

5.1. Alternative model specifications

Table A3 in the OA shows the estimated results based on Eq. (2) using total citations based on different model specifications. The empirical results verify the findings in our baseline model: exploration and exploitation have a positive impact on citations at the 1% level across all models. Furthermore, balanced and combined ambidexterity and their interaction have a positive and significant impact (mostly at the 1% level) on innovation in terms of citations, again confirming Hypotheses 1, 2, and 3.

Similarly, in Table A4, which considers patent applications related to pandemics, we identify strong positive impacts of exploration, exploitation, and balanced and combined ambidexterity mostly at the 1% level of significance. Finally, in the grant lag model in Table A5, the role of balanced and combined ambidexterity is also important, as it significantly reduces the time between patent application and grant date. Regarding the effect of the control variables, the results confirm the findings of our baseline model.

To examine the robustness of the baseline results presented in Tables 3, 4, and 5, we further test whether and how citations related to the COVID-19 pandemic affect health outcomes in the context of a fixed effects panel and a panel threshold model. Table A6 presents the results of innovation performance related to the pandemic on COVID-19 mortality rate, risk of infection, and life expectancy. Confirming the baseline results, citations related to the coronavirus negatively affect the COVID-19 mortality rate and the risk of infection but positively affect life expectancy at the 1% level.

For the estimation of the panel threshold model, the first step involves testing for the presence of a non-linear relationship between social inequality and health outcomes and the second step evaluating the effect of citations on health outcomes in (low-/high-) social-inequality regimes. Table A7 in the OA shows the results of the threshold test for health outcomes (COVID-19 mortality rate, risk of infection, and life expectancy) considering the presence of one threshold. As the findings show, the linear model null hypothesis is strongly rejected in the presence of one threshold/split for all health outcomes and social inequality variables with the same threshold estimates as in Table 4. Table A8 presents the results of innovation performance and specifically citations related to the pandemic on COVID-19 mortality rate, risk of infection, and life expectancy. Confirming the previous findings, the effect of citations related to the pandemic on COVID-19 mortality rate, risk of infection, and life expectancy is significantly stronger in areas with high levels of income p.c (above 33,312), health expenditure p.c (above 71,938), health insurance coverage (above 75%), college graduates (above 25%), and urbanization (above 48%) and low levels of unemployment (below 6%), confirming the baseline model and hypotheses 4–5.

5.2. Addressing endogeneity

To secure the statistical validity of our models, we implemented a set of misspecification tests addressing model specification (fixed vs. random effects), cross-sectional correlation, homoskedasticity, and stationarity. However, according to the literature (Wooldridge, 1997, 2002), there might be concerns about the presence of endogeneity related to reverse causality and about omitted variable bias affecting the estimated coefficients and standard errors, thus resulting in invalid inferences.

To address these concerns, we estimate our models using the instrumental variables in 2SLS estimation, in which the endogenous variables are instrumented using a variable exogenous to the error term (valid instrument) but are highly correlated with the endogenous variable (relevant instrument). Following Barro (2015) and Durlauf and colleagues (2010, 2013), we instrument the endogenous variables using five-year lag values of the regressors as instruments. Tables A9 and A10 in the OA present the 2SLS results for Eqs. (3) and (4), respectively. Confirming the results of Tables 3 and 5 and, consequently, Hypotheses 4–5, any innovation initiatives related to the pandemic negatively affect the COVID-19 mortality rate and risk of infection but positively affect life expectancy, a result that is moderated by low and high social inequalities across regimes. In the same context, we carried out the Cragg–Donald weak identification test and the Sargan overidentification test and confirmed the validity and relevance of our instruments.

6. DISCUSSION

Arguably, a firm's success is dependent on its organizational ambidexterity and particularly its ability to efficiently adapt to the challenging current environment (Duncan, 1976; Gibson & Birkinshaw, 2004). In this research, we investigated whether and to what extent the synchronous implementation of two dimensions of organizational ambidexterity (i.e., balanced and combined) affects firms' innovation performance in the health sector related to the COVID-19 pandemic. Given the detrimental economic and social effects of the pandemic, the exploration of channels, including the implementation of organizational ambidexterity, which can enhance firms' innovation initiatives, is a priority. In this context, using USPTO patent data related to pandemics over the period 1974–2020, we investigate whether and how the balanced and combined dimensions of ambidexterity, along with specific firm characteristics, affect the innovation performance related to the COVID-19 pandemic. The results reveal that the synchronous implementation of balanced and combined ambidexterity has a strong positive effect on firms' innovation performance. The interaction effect of balanced and combined ambidexterity also has a strong positive effect on firms' innovation performance related to the pandemic. Our results are robust to using a series of checks, including citations, patent applications, and the grant lag, as alternative measures of innovation activities related to the COVID-19 pandemic. In addition, we investigate whether and how innovation activities focused on COVID-19 affect certain regional health outcomes (mortality rate, risk of infection, and life expectancy), while considering the role of social inequality variables. The results confirm the important role of the innovation performance–health outcomes relationship, as the effect is heterogeneous in the social inequality setting.

Our study identifies ambidextrous capabilities, which allow organizations to balance or combine exploration and exploitation activities, as key mechanisms through which for-profit organizations can innovate to tackle health grand challenges. To perform at this level, organizations need to develop exploration capabilities, which can help them sense gaps during pandemics and quickly acquire, mobilize, and process unique resources (e.g., new knowledge, intellectual capital, new technologies) to develop and commercialize radical innovations. For example, many vaccines against previously uncured viruses are a manifestation of radical organizational innovations (Wouters et al., 2021) stemming from organizations' exploration capabilities during pandemics. Failure to develop radical innovations that solve health challenges during pandemics may result in a loss of competitive advantage or diminished financial position. On the other end, our study highlights the requirement for sustaining, in parallel, high levels of exploitation activities. For-profit organizations need to develop capabilities that enable assimilation of new knowledge from exploration to facilitate exploitation for improving radically new products further (e.g., strengthening the effect of vaccines, adapting them to fight new virus variants) or exploiting (through adaptation or repurposing) existing products in their portfolio (Hanisch & Rake, 2021) to treat pandemic-related health risks.

6.1. Theoretical contributions

This study extends the organizational innovation literature in four ways. First, it explains specific capabilities and their underlying mechanisms that can help for-profit organizations innovate at a level required to effectively tackle health grand challenges during pandemics. Our findings reveal the significance of structural ambidexterity (balanced and combined) on innovation performance, with combined ambidexterity having a positive effect on the reduction of pandemic-related health risks. In this way, we respond to recent calls for further research on the organizational capabilities desirable for tackling grand challenges and how they do so (Ferraro et al., 2015; Hartmann et al., 2021; Roulet & Bothello, 2021; Sawyer & Clair, 2022). Furthermore, although previous research offers evidence linking organizational ambidexterity with organizational innovation outcomes and innovation performance (Atuahene-Gima, 2005; Guo et al., 2020a; Lichtenthaler & Lichtenthaler, 2009), it (1) lacks insufficient understanding of the way balanced and combined organizational ambidexterity jointly or in isolation influence organizational innovation performance and (2) lacks clarity on the impact of organizational ambidexterity on innovation performance in the health sector, which is necessary to address grand challenges. This latter part is surprising, given that research on innovation in the health sector underscores the relevance of exploring and exploiting external and internal knowledge to innovate (Burgess et al., 2015). Instead, by focusing on the different permutations of balanced and combined ambidexterity, our study sheds more light on how for-profit organizations draw on organizational ambidexterity to innovate for minimizing population health-related risks associated with pandemics. Our study shows that during pandemics, organizational capabilities need to adjust to allow engagement in both exploration and exploitation. This adjustment can become a crucial mechanism that allows for-profit health organizations to reach an innovation performance threshold necessary for addressing population health challenges during pandemics. That is, this mechanism can help organizations more effectively optimize the interrelationships between exploration and exploitation in the innovation process to produce both incremental (adaptations) and radically new products for the health sector.

Second, by using organizational innovation performance as an independent variable, we provide new theoretical linkages between organizational innovation and health grand challenges. Studies on macroenvironmental adversities such as pandemics, which give rise to global health-related risks, have primarily treated organizational innovation performance as a dependent variable (e.g., Arslan & Tarakci, 2022; Sharma et al., 2021; Zhong et al., 2022). Consequently, current literature on health grand challenges lacks insight into the effect of organizational innovation performance on macro-specific health outcomes (i.e., population health gains or risks). We address this gap by showing that enhanced organizational innovation performance (as an independent variable at the micro–macro level nexus) during pandemics can lead to greater gains for the broader population (e.g., reduced mortality rate, reduced risk of infection, and increased life expectancy). This constitutes a theoretical contribution, offering knowledge on how organizational innovation performance influences society and, more specifically, adds value at the broader societal level.

Third, our study provides evidence for the importance of social equality in health in enhancing the positive impact of for-profit organizations' innovation performance on population health gains during pandemics. Social inequality has a negative effect on the diffusion of new innovations in the health sector (Gutin & Hummer, 2021; Korda et al., 2011). However, social (in)equality has not been researched at the innovation performance–health grand challenges nexus. Our study contributes to the organizational innovation literature by considering for the first time the moderating role of social equality in health in the relationship between innovation performance and health grand challenges. Given that our study treats organizational innovation as an independent variable, we respond to calls for additional research on understanding the macro-economic or state conditions that enable firms to effectively tackle grand challenges (e.g., Demircioglu & Vivona, 2021). Our findings suggest that in the presence of high social equality (i.e., equality in access), for-profit organizations' innovations will more effectively diffuse in a social system and materialize into greater population health gains.

Fourth, our study addresses calls to consider the role of innovation context (Ernst et al., 2015) to better grasp innovation practices in relation to health or societal grand challenges (Liu et al., 2021; Shaheen et al., 2022).

We contribute to organizational innovation literature through a context-specific understanding – shaped by pandemics – of the impact of for-profit organizations' innovation performance on health grand challenges. Previous research shows that though product innovations usually need time to diffuse within a socioeconomic system (Fagerberg & Verspagen, 2002; Rogers, 2010), in some cases, diffusion can be accelerated to quickly produce benefits for society (Kimberly, 1981; Meyer & Rowan, 1977). While prior studies highlight the relevance of pandemics as contexts through which to understand the accelerated diffusion of new products (Liu et al., 2021), they have not empirically addressed it. Our study argues that pandemics present ambiguous circumstances suitable for understanding the accelerated or immediate diffusion of new innovations to tackle health-related grand challenges. Our findings illustrate that the better organizations perform by commercializing new products to solve pandemic-related problems, the more immediate the health gains for the broader population will be.

6.2. Managerial implications

Our findings also have important implications for for-profit organizations in the health sector and policy makers. First, our findings suggest that managers commercializing innovations in the health sector (e.g., pharmaceutical companies, biotechnology firms, medical equipment manufacturers) should be less concerned about the trade-offs between exploration and exploitation if they want to achieve or sustain high innovation performance during pandemics and other health-related crises. Through relevant training programs, virtual seminars, and workshops (Luthans et al., 2008), managers can enhance their knowledge and capabilities to make decisions and craft strategies for balanced or combined ambidexterity. Such programs can also teach managers how to adjust organizational capabilities during pandemics and other major crises to heighten engagement in both exploration and exploitation. For example, training should be directed to informing managers on how to sieze radical innovation opportunities during pandemics and how to acquire, mobilize, and process unique resources such as new knowledge, intellectual capital, and new technologies. At the same time, managers need to be equipped with the ability to use new knowledge from exploration to improve, adapt, or repurpose existing products to solve health grand challenges. In this way, managers can enhance their organizations' innovation performance related to pandemics by (1) making effective decisions based on the structural separation between exploration and exploitation, (2) establishing long-term plans encompassing procedures to alternate between exploration and exploitation, or (3) taking a holistic approach that adds flexibility and an optimization logic behind the joint consideration of exploration and exploitation practices.

Second, our results suggest that managers of for-profit organizations in the health sector should pursue inter-organizational collaborations to develop or commercialize new innovations, as these can help accelerate the diffusion of innovations in the sector. Accelerated diffusion is particularly relevant during pandemics, when the success of rapid diffusion can bring about broader population health gains. Thus, managers should consider innovation strategies that draw on open innovation models, as open innovation can provide a win-win scenario for both for-profit organizations and society as a whole.

Third, governments and policy makers need to establish structures for a speedier and wider diffusion of health innovations in their countries to deal effectively and proactively with pandemics and other health-related crises. A way to do this is by establishing new or enhancing existing regulations and monitoring mechanisms to ensure fairer access to health care for all citizens. By achieving a state of social equality, governments can also be more effective in crafting strategies to enhance innovation in the health sector in times of need. At the same time, social equality can help nations derive more benefits from organizational innovation in the health sector through the reduction of costs associated with increased mortality, increased risk of infection, and reduced life expectancy during pandemics.

6.3. Limitations and future research avenues

Our study is subject to five limitations that pave the way for future research. First, our study focuses on organizational innovation performance. Innovation is an essential facet of organizational ambidexterity, and a firm's long-term health and performance depend on its ability to balance or combine incremental and radical innovation processes. We suggest that future studies draw on the balanced and combined dimensions of organizational ambidexterity to investigate other practices in which organizational ambidexterity is critical to firm sustainability. For example, future work could focus on marketing or operations to investigate the extent to which our findings are replicable within these practices.

Second, our study tests relationships by drawing on innovation micro-data in the health sector from the USPTO. While our results indicate strong relationships between ambidexterity and performance and between performance and health gains, these may be dependent on the US context. Therefore, further research could test the hypothesized relationships over the same time span but in contexts other than the US, to determine whether our findings are replicable in other countries.

Third, our study focuses on two dimensions of organizational ambidexterity (i.e., balanced and combined), but there is a third type of non-structural ambidexterity—namely, contextual ambidexterity (Raisch & Birkinshaw, 2008)—that we did not examine. Future studies, in an effort to examine organizational ambidexterity more holistically, could focus on both structural and contextual ambidexterity. Alongside the balanced and combined dimensions of ambidexterity, researchers could assess how systems, processes, and values (i.e., the context) (Adler et al., 1999; Ghoshal & Bartlett, 1994) can facilitate managerial and employee responses to the demands for both exploration and exploitation in organizations (Gibson & Birkinshaw, 2004).

Fourth, our study also focuses on the role of social equality in health in the innovation performance–health outcomes relationship. Further research could examine how economic development, in terms of GDP or other socioeconomic variables, might affect our results based on the US compared with countries that are in the same situation (i.e., facing a pandemic) but with weaker economic power. For example, a population's income, statistics related to health factors (e.g., smoking, obesity), and social variables other than social equality in health (e.g., crime rates, urbanization) are all factors that might affect our results.

Fifth, following prior research, we draw on patent data to test and measure organizational innovation performance (Artz et al., 2010 Bianchi et al., 2016; Shu et al., 2015) and patent-based measures in a longitudinal setting to test and measure organizational ambidexterity (Ahuja & Lampert, 2001; Belderbos et al., 2010; Geerts et al., 2018; Leten et al., 2007). Yet patent data do not provide a clear picture of the innovation significance or radicality of new products. Some patented products may represent incremental or minor improvements, while others may reflect radical innovations. At the same time, patent indicators miss non-patented innovations, such as new services, processes, business models, and technological infrastructures, which account for a large proportion of innovations. Desrochers (1990) explains that many ground-breaking innovations are never submitted for patents because of excessive costs or long procedures or are kept as trade secrets. Griliches (1990) emphasizes the difficulties in identifying the source of invention at the firm level, due to the diversification of corporations or multiple mergers. Consequently, future studies could explore existing or new datasets that provide more holistic measures of innovation performance that account for the significance and/or impact of innovations beyond new products.

For organizational ambidexterity, the use of patents as a proxy variable may not be sufficient to fully capture the difference and interaction between exploration and exploitation. Instead, actual behaviors and strategic goals of organizations, as well as organizational practices and processes, may be a more direct expression of an ambidextrous posture. Consequently, future research should employ more fine-grained measures of ambidexterity when testing for innovation performance and in relation to grand challenges. Future research could also examine the impact of non-patent-based strategies and collaborative innovation behaviors to tackle grand challenges through ambidexterity at the global level. Indeed, the issue of open innovation is pressing in the context of a pandemic emergency (Bertello et al., 2022; McGahan et al., 2021).

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TABLE 1 Descriptive statistics

Variable	Mean	SD	Min	Max
Log-total health patents (granted)	0.0045	0.0637	0.0000	2.3026
Log-total citations	0.0169	0.1585	0.0000	4.2767
Log-total health patents (applications)	0.0049	0.0665	0.0000	2.3026
Grant lag	2.6610	1.8251	0.0000	9.5893
Balanced ambidexterity $\lvert exploration - exploitation \rvert$	42.33	191.14	0.0000	3511.00
Combined ambidexterity $exploration \times exploitation$	256.36	1416.48	0.0000	27207.0
Exploration	1.48	1.94	0.0000	9.00
Exploitation	43.54	192.18	0.0000	3518.0
Size (revenue)	4.6035	2.7889	-6.9078	12.5633
size (assets)	4.7925	2.6596	-6.9078	14.9357
Growth	0.1014	0.1577	0.0000	1.0000
Asset structure	0.3669	0.2273	-1.2017	1.0000
Current ratio	3.7757	20.7621	0.0000	4036.0
Solvency ratio	7.0034	146.5081	-0.5377	17689.3
Leverage	1.0096	41.4615	-3578.8670	3873.88
R&D expenditure	134.3263	745.5674	-0.5150	27573.0
Mortality rate	0.00851	0.00132	0.0037	0.0121
Risk of infection	16.0463	3.0370	4.3438	19.4175
Life expectancy	76.71359	2.2544	71.6	81.6
Income p.c	27171.12	14842.21	4887.00	79771.0
Unemployment	0.05	0.01	0.03	0.07
Health expenditure p.c	45541.17	175875.7	1023.00	2562824.0
Health insurance coverage (%)	87.19	5.03	73.70	97.10
Percentage college grads	18.86	5.04	11.55	32.06
Fraction of current smokers	0.27	0.03	0.19	0.36
Fraction of those obese	0.29	0.04	0.20	0.37
Crime rate p.c	0.01	0.00	0.00	0.01
Urbanization	71.56	14.08	32.20	95.00

Note: The financial data are presented before winsorization.

TABLE 2 Results of balanced and combined ambidexterity on innovation performance related to pandemics (granted patents)

Variable	***Log-total health patents (granted)***									
	(1)	***(2)***	***(3)***	***(4)***	***(5)***	***(6)***	***(7)***	***(8)***	***(9)***	***(10)***
	Coef.	***SE***	***Coef.***	***SE***	***Coef.***	***SE***	***Coef.***	***SE***	***Coef.***	***SE***
Exploration	0.1328***	(0.0353)	0.2676***	(0.0504)	0.1551***	(0.0369)	0.2794***	(0.0603)	0.2906***	(0.0504)
Exploitation	0.1042***	(0.0134)	0.1599***	(0.0200)	0.2426***	(0.0761)	0.1498***	(0.0199)	0.14778***	(0.0193)
Balanced ambidexterity (BD)			0.1599***	(0.0200)			0.1474***	(0.0199)	0.1454***	(0.0350)
Combined ambidexterity (CD)					0.2325**	(0.1079)	0.1323***	(0.0408)	0.2239***	(0.0429)
BD × CD									0.2309***	(0.0257)
Size (revenue)	0.3272***	(0.0585)	0.3256***	(0.0589)	0.3320***	(0.0598)	0.3305***	(0.0602)	0.3300***	(0.0598)
size (assets)	0.6176***	(0.0724)	0.6107***	(0.0732)	0.5947***	(0.0742)	0.5882***	(0.0751)	0.5879***	(0.0750)
Growth	-0.7989***	(0.0908)	-0.7917	(0.5104)	-0.6685	(0.4835)	-0.6631	(0.4854)	-0.6692	(0.4827)
Asset structure	0.5204	(0.4811)	0.5001	(0.4854)	0.4063	(0.4758)	0.3884	(0.4796)	0.3624	(0.4778)
Current ratio	0.0261	(0.0168)	0.0240	(0.0170)	0.0412**	(0.0180)	0.0390**	(0.0183)	0.0356**	(0.0181)
Solvency ratio	-0.0722***	(0.0262)	-0.0713***	(0.0261)	-0.0707***	(0.0260)	-0.0698***	(0.0258)	-0.0696***	(0.0259)
Leverage	-0.0312	(0.0566)	-0.0304	(0.0564)	-0.0275	(0.0590)	-0.0269	(0.0588)	-0.0254	(0.0586)
R&D expenditure	0.0105***	(0.0030)	0.0106***	(0.0031)	0.0105***	(0.0031)	0.0106***	(0.0031)	0.0103***	(0.0031)
Constant	0.0050	(0.2854)	0.9601	(0.2908)	0.9364***	(0.2876)	0.8939***	(0.2934)	0.8829***	(0.2933)
No. of obs.	*15,062*		*15,062*		*15,062*		*15,062*		*15,062*	
R^2	*0.4752*		*0.5722*		*0.4562*		*0.4622*		*0.5722*	
Adjusted R^2	*0.4492*		*0.5483*		*0.4229*		*0.4284*		*0.5029*	
Probability of Wald chi-square test	*0.0001*		*0.0000*		*0.0001*		*0.0000*		*0.0000*	
Year FE	*Yes*		*Yes*		*Yes*		*Yes*		*Yes*	
Industry FE	*Yes*		*Yes*		*Yes*		*Yes*		*Yes*	
State FE	*Yes*		*Yes*		*Yes*		*Yes*		*Yes*	

Note: Asterisks denote statistical significance at the 1% (***), 5% (**), and 10% (*) level. Robust standard errors are in parentheses. The probability of the Wald chi-square test examines the null hypothesis that all regression coefficients are equal to zero. FE = fixed effects.

TABLE 3 Results of innovation performance (granted patents) related to the COVID-19 pandemic on mortality rate, risk of infection, and life expectancy

Variable	*COVID-19 mortality rate*		*COVID-19 risk of infection*		*Life expectancy*	
	Coef.	*SE*	*Coef.*	*SE*	*Coef.*	*SE*
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Health patents (granted)	***-0.1114******	***(0.0340)***	***-0.1057******	***(0.0252)***	***0.1038******	***(0.0135)***
Social inequality variables						
Income p.c	-0.0693**	(0.0297)	-0.0294***	(0.0079)	0.0395***	(0.0114)
Unemployment	0.0593***	(0.0094)	0.0684*	(0.0395)	-0.2045	(0.1385)
Health expenditure p.c	-0.0805***	(0.0080)	-0.0609	(0.0446)	0.0689***	(0.0234)
Health insurance coverage (%)	-0.0125	(0.0794)	-0.0594***	(0.0114)	0.0940**	(0.0395)
Percentage college grads	*-0.0145******	*(0.0025)*	*-0.0396******	*(0.0115)*	*0.0505******	*(0.0175)*
Urbanization	0.0894*	(0.0524)	0.0010	(0.0356)	-0.0896***	(0.0304)
Other area characteristics						
Fraction of current smokers	0.0336***	(0.0040)	0.1845***	(0.0580)	-0.0859	(0.1075)
Fraction of those obese	0.0124***	(0.0039)	0.0938***	(0.0236)	-0.0948***	(0.0344)
Crime rate p.c	0.0587	(0.0944)	0.2945***	(0.0938)	-0.0944	(0.0859)
Constant	0.0485	(0.0345)	0.4846	(0.4844)	0.0250	(0.0263)
No. of obs.	*1118*		*1118*		*1118*	
R^2	*0.4958*		*0.4976*		*0.4756*	
Adjusted R^2	*0.4832*		*0.4692*		*0.4524*	
Probability of Wald chi-square test	*0.0000*		*0.0000*		*0.0000*	
Year FE	*Yes*		*Yes*		*Yes*	
State FE	*Yes*		*Yes*		*Yes*	

Note: Asterisks denote statistical significance at the 1% (***), 5% (**), and 10% (*) level. Robust standard errors are in parentheses. The probability of the Wald chi-square test examines the null hypothesis that all regression coefficients are equal to zero. FE = fixed effects.

TABLE 4 Threshold tests and threshold estimates (granted patents)

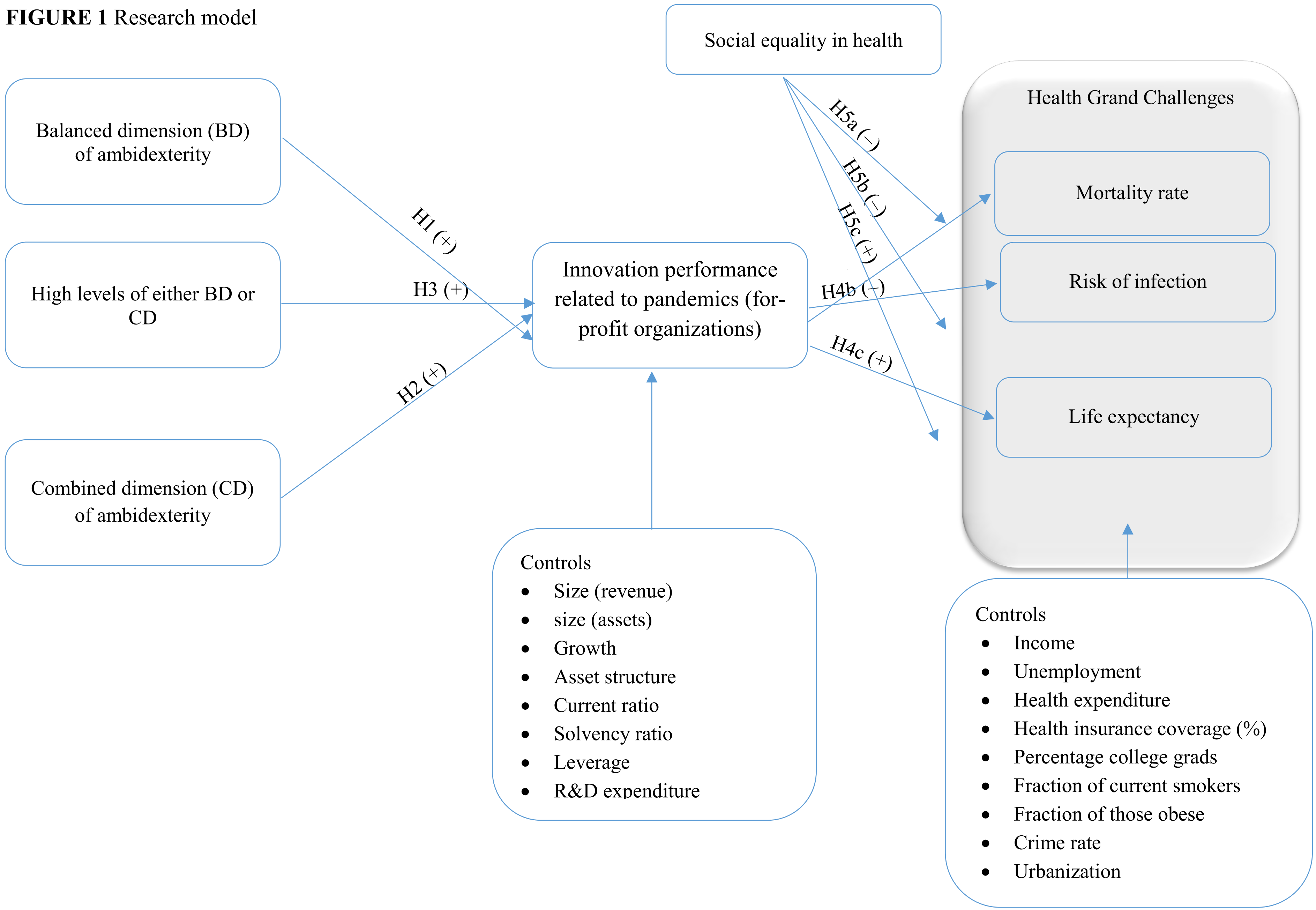
Threshold variable	***COVID-19 mortality rate***		***COVID-19 risk of infection***		***Life expectancy***	
	p-value	**Threshold estimate** γ	**p-value**	**Threshold estimate** γ	**p-value**	**Threshold estimate** γ
Income p.c	0.0001	33312	0.0000	33312	0.0035	33312
Unemployment	0.0023	0.06	0.0092	0.06	0.0000	0.06
Health expenditure p.c	0.0021	71938	0.0006	71938	0.0001	71938
Health insurance coverage (%)	0.0001	75	0.0002	75	0.0000	75
Percentage college grads	0.0005	25	0.0002	25	0.0007	25
Urbanization	0.0004	48	0.0000	48	0.0023	48

TABLE 5 Threshold results of innovation performance (granted patents) related to the COVID-19 pandemic on mortality rate, risk of infection, and life expectancy

Variable	*COVID-19 mortality rate*		*COVID-19 risk of infection*		*Life expectancy*	
	Coef.	*SE*	*Coef.*	*SE*	*Coef.*	*SE*
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Social inequality variables						
Income p.c	-0.0794***	(0.0096)	-0.0148*	(0.0085)	0.0957***	(0.0158)
Unemployment	0.0325***	(0.0112)	0.0951***	(0.0113)	-0.1496	(0.6462)
Health expenditure p.c	-0.0248***	(0.0078)	-0.0548*	(0.0332)	0.0299*	(0.0162)
Health insurance coverage (%)	-0.0326	(0.0428)	-0.0423**	(0.0213)	0.0787***	(0.0172)
Percentage college grads	*-0.0103****	*(0.0013)*	*-0.0668**	*(0.0346)*	*0.0531**	*(0.0279)*
Urbanization	0.0716	(0.0467)	0.0054	(0.0120)	-0.0674	(0.0969)
Health patents $I(Income\ p.c \leq 33312)$	-0.0239**	(0.0114)	-0.0193	(0.0214)	0.0572***	(0.0212)
Health patents I *(Unemployment* ≤ 0.06)	-0.1039***	(0.0276)	-0.0233**	(0.0112)	0.0230***	(0.0032)
Health patents I *(Health expenditure p.c* $\leq$ 71938)	-0.1032***	(0.0352)	-0.0241**	(0.0112)	0.0032	(0.2451)
Health patents I *(Health insurance coverage (%)*$\leq$ 75)	-0.0632**	(0.0248)	-0.0724	(0.0582)	0.0323**	(0.0131)
Health patents I (*Percentage college grads* $\leq$ 25)	-0.1692***	(0.0224)	-0.1032	(0.1842)	0.0241	(0.2941)
Health patents I *(Urbanization* $\leq$ 48)	-0.0294**	(0.0123)	-0.1294***	(0.0332)	0.1042	(0.1230)
Health patents $I(Income\ p.c > 33312)$	-0.1839***	(0.0294)	-0.1242***	(0.0482)	0.1924***	(0.0129)
Health patents I *(Unemployment* > 0.06)	-0.0482***	(0.0139)	-0.0114***	(0.0024)	0.0422	(0.2994)
Health patents I *(Health expenditure p.c* $>$ 71938)	-0.2284***	(0.0239)	-0.0472**	(0.0221)	0.4722***	(0.0420)
Health patents I *(Health insurance coverage (%)* $>$ 75)	-0.0932***	(0.0335)	-0.1930***	(0.0424)	0.1931***	(0.0321)
Health patents I (*Percentage college grads* $>$ 25)	-0.1834***	(0.0230)	-0.1328***	(0.0336)	0.1921*	(0.1103)
Health patents I *(Urbanization* $>$ 48)	-0.0257**	(0.0104)	-0.1596***	(0.0431)	0.1294***	(0.0230)
Other area characteristics						
Fraction of current smokers	0.0531***	(0.0094)	0.8551***	(0.0862)	-0.0862	(0.1957)
Fraction of those obese	0.0109***	(0.0011)	0.3058***	(0.0631)	-0.0859***	(0.0243)
Crime Rate p.c	0.0496	(0.1348)	0.4582	(0.2813)	-1.3338	(2.7954)
Constant	0.0099	(0.0080)	4.5391**	(2.0619)	0.0168	(0.1663)
No. of obs.	*1118*		*1118*		*1118*	
R^2	*0.4853*		*0.4724*		*0.6625*	
Adjusted R^2	*0.4693*		*0.4582*		*0.6353*	
Probability of Wald chi-square test	*0.0001*		*0.0002*		*0.0000*	
Year FE	*Yes*		*Yes*		*Yes*	
State FE	*Yes*		*Yes*		*Yes*	

Note: Asterisks denote statistical significance at the 1% (***), 5% (**), and 10% (*) level. Robust standard errors are in the parentheses. The probability of the Wald chi-square test examines the null hypothesis that all regression coefficients are equal to zero. FE = fixed effects.

FIGURE 1 Research model



ENDNOTES

[i] In the context of Eq. (2) and Table 2, we conducted two additional robustness tests. The first involved exluding exploration and exploitation from the model specifications, and in the second, we calculated exploration using a lag value of 4 or 6 (t – 4 to t or t –6 to t). In both cases, the results remained robust. The findings are available on request.

ONLINE APPENDIX

TABLE A1 Variable description and source

Variable	**Description**	**Source**
Log-total health patents (granted)	Natural logarithm of the number of granted patents +1 (ln[patents+1]) for the coronavirus based on the search criteria “sars cov,” “coronavirus,” “severe acute respiratory syndrome,” “SARS-CoV-2,” and “COVID-19”	USPTO
Log-total citations	Natural logarithm of the forward citations, or the references received by other patents	USPTO
Log-total health patent (applications)	Natural logarithm of the number of applications for patents +1 for the coronavirus based on the search criteria “sars cov,” “coronavirus,” “severe acute respiratory syndrome,” “SARS-CoV-2,” and “COVID-19”	USPTO
Grant lag	Time difference between application and grant dates	USPTO and author calculations
Balanced ambidexterity	Absolute value of the difference between exploration and exploitation. To facilitate interpretation, in the regression models we revise the variable such that higher values indicate greater balance.	USPTO and author calculations
Combined ambidexterity	Interaction between exploration and exploitation	USPTO and author calculations
Exploration	A firm’s innovation activity if it is established in a technology field that the firm had not patented in within the last five years (t – 5 to t – 1)	USPTO and author calculations
Exploitation	A firm’s innovation activity if it is established in a technology field that the firm had a patent in within the last five years (t – 5 to t – 1)	USPTO and author calculations
Size (revenue)	Natural logarithm of the company’s revenue	Compustat and author calculations
Size (assets)	Natural logarithm of the company’s total assets	Compustat and author calculations
Growth	Ratio of intangible assets to total assets	Compustat and author calculations
Asset structure	Ratio of fixed assets to total assets	Compustat and author calculations
Current ratio	Ratio of current assets to current liabilities	Compustat and author calculations
Solvency ratio	Ratio of long-term debt to long-term assets	Compustat and author calculations
Leverage	Ratio of long-term debt to shareholder equity	Compustat and author calculations
R&D expenditure	Ratio of R&D expenditures to sales	Compustat and author calculations
Mortality rate	Ratio of the number of deaths due to COVID-19 to the average total population in a specific year and area	CDC
Risk of infection	The odds of being infected with COVID-19	CDC
Life expectancy	Regional life expectancy	CDC
Income p.c	Income per capita per state	BEA
Unemployment	Unemployment rate per state	BEA
Health expenditure p.c	Health expenditure per capita per state	CDC
Health insurance coverage (%)	Percentage of citizens with public insurance per state	CDC
Percentage college grads	Percentage of college graduates per state	BEA
Fraction of current smokers	Percentage of smokers per state	BEA
Fraction of those obese	Percentage of obese per state	BEA
Crime rate p.c	Crime rate per capita per state	BEA
Urbanization	Urbanization rate per state	US Census Bureau

Note: USPTO = US Patent and Trademark Office; CDC = Centers for Disease Control and Prevention; BEA = Bureau of Economic Analysis.

TABLE A2 Correlation matrix

Panel A: Firm analysis

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	*Health patents (granted)*	1.000												
2	*Exploration*	0.6950	1.0000											
3	*Exploitation*	0.7649	0.5166	1.0000										
4	*Balance ambidexterity*	0.7444	0.5093	0.6532	1.0000									
5	*Combined ambidexterity*	0.7377	0.4899	0.7849	0.6851	1.0000								
6	*Size (revenue)*	0.6747	0.5607	0.3416	0.3373	0.3119	1.0000							
7	*size (assets)*	0.6901	0.5888	0.3726	0.3681	0.3387	0.7224	1.0000						
8	*Growth*	-0.5520	-0.3582	-0.1054	-0.2460	-0.2086	-0.2343	-0.2621	1.0000					
9	*Asset structure*	0.3196	0.2021	0.1451	0.1434	0.0340	0.3652	0.3668	0.4915	1.0000				
10	*Current ratio*	0.5002	0.1454	0.0670	0.1660	-0.0631	0.1762	-0.1413	-0.0395	-0.0951	1.0000			
11	*Solvency ratio*	-0.5416	-0.0258	-0.1085	-0.0830	-0.1690	-0.0618	-0.0614	-0.0246	-0.0525	-0.2233	1.0000		
12	*Leverage*	-0.2245	-0.3103	-0.1053	-0.0052	-0.2051	0.0135	0.0145	0.1060	0.1670	-0.1016	0.1209	1.0000	
13	*R&D expenditure*	0.6610	0.4329	0.6021	0.6008	0.5835	0.3533	0.3916	0.2814	0.0726	-0.0454	-0.1640	0.1056	1.0000

Panel B: State analysis

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	*COVID-19 mortality rate*	1.0000												
2	*COVID-19 risk of infection*	0.7630	1.0000											
3	*Life expectancy*	-0.5822	-0.5178	1.0000										
4	*Health patents (granted)*	-0.7838	-0.8392	0.8420	1.0000									
5	*Income p.c*	-0.7890	-0.6666	0.8188	0.7565	1.0000								
6	*Unemployment*	0.7298	0.7038	-0.1988	-0.6354	-0.4903	1.0000							
7	*Health expenditure p.c*	-0.6820	-0.6850	0.6221	0.6238	0.5161	-0.0772	1.0000						
8	*Health insurance coverage (%)*	-0.4478	-0.6504	0.6991	0.6417	0.6477	-0.2472	0.5449	1.0000					
9	*Percentage college grads*	-0.6916	-0.6236	0.6541	0.6354	0.4825	-0.5428	0.0629	0.3889	1.0000				
10	*Urbanization*	0.3652	0.1781	-0.3415	0.5697	0.4052	0.0362	0.0878	0.1705	0.4094	1.0000			
11	*Fraction of current smokers*	0.6446	0.7098	-0.3728	-0.1571	-0.0987	0.3727	-0.0636	-0.0858	-0.2723	0.3355	1.0000		
12	*Fraction of those obese*	0.6843	0.6673	-0.6728	-0.1017	0.4482	0.3447	0.1247	-0.1207	-0.6727	0.2751	0.2431	1.0000	
13	*Crime rate p.c*	0.1315	0.1119	-0.1023	-0.1181	0.1942	0.3622	0.0209	-0.0562	0.0873	0.3496	-0.0546	0.0145	1.0000

TABLE A3: Results of balanced and combined ambidexterity on innovation performance (total citations) related to pandemics

Variable	***Log-total citations***									
	(1)	***(2)***	***(3)***	***(4)***	***(5)***	***(6)***	***(7)***	***(8)***	***(9)***	***(10)***
	Coef.	***SE***	***Coef.***	***SE***	***Coef.***	***SE***	***Coef.***	***SE***	***Coef.***	***SE***
Exploration	0.1697***	(0.0251)	0.1840***	(0.0191)	0.1869***	(0.0265)	0.2561***	(0.0570)	0.2733***	(0.0371)
Exploitation	0.1210***	(0.0193)	0.2553***	(0.1286)	0.2245***	(0.0559)	0.2466***	(0.0678)	0.2436***	(0.0369)
Balance ambidexterity (BD)			0.2551***	(0.1086)			0.2441***	(0.0298)	0.2413***	(0.0368)
Combined ambidexterity (CD)					0.2303**	(0.1079)	0.3007***	(0.0792)	0.1208**	(0.0535)
BD × CD									0.1319***	(0.0190)
Size (revenue)	0.1525***	(0.0510)	0.1495***	(0.0515)	0.1520***	(0.0520)	0.1492***	(0.0525)	0.1476***	(0.0523)
size (assets)	0.3156***	(0.0591)	0.3038***	(0.0598)	0.2906***	(0.0606)	0.2792***	(0.0612)	0.2778***	(0.0612)
Growth	-0.6512**	(0.3287)	-0.6288*	(0.3308)	-0.6056*	(0.3167)	-0.5860*	(0.3186)	-0.6181*	(0.3172)
Asset structure	0.4291	(0.3277)	0.4719	(0.3316)	0.4514	(0.3243)	0.4910	(0.3278)	0.5013	(0.3254)
Current ratio	0.0100	(0.0168)	0.0999	(0.1691)	0.0134	(0.0182)	0.0134	(0.0183)	0.0122	(0.0180)
Solvency ratio	-0.0263	(0.0305)	-0.0253	(0.0302)	-0.0248	(0.0298)	-0.0239	(0.0296)	-0.0236	(0.0296)
Leverage	-0.0623	(0.0612)	-0.0605	(0.0606)	-0.0609	(0.0628)	-0.0592	(0.0622)	-0.0577***	(0.0062)
R&D expenditure	0.0183***	(0.0023)	0.0304	(0.0227)	0.0317	(0.0229)	0.0339	(0.0229)	0.0275	(0.0234)
Constant	0.8883***	(0.2140)	0.8213***	(0.2168)	0.7985***	(0.2152)	0.7331***	(0.2182)	0.7223***	(0.2182)
No. of obs.	*15,062*		*15,062*		*15,062*		*15,062*		*15,062*	
R^2	*0.4485*		*0.4773*		*0.4959*		*0.4403*		*0.5406*	
Adjusted R^2	*0.4294*		*0.4583*		*0.4825*		*0.4103*		*0.5184*	
Probability of Wald chi-square test	*0.0002*		*0.0000*		*0.0001*		*0.0000*		*0.0001*	
Year FE	*Yes*		*Yes*		*Yes*		*Yes*		*Yes*	
Industry FE	*Yes*		*Yes*		*Yes*		*Yes*		*Yes*	
State FE	*Yes*		*Yes*		*Yes*		*Yes*		*Yes*	

Note: Asterisks denote statistical significance at the 1% (***), 5% (**), and 10% (*) level. Robust standard errors are in the parentheses. The probability of the Wald chi-square test examines the null hypothesis that all regression coefficients are equal to zero. FE = fixed effects.

TABLE A4 Results of balanced and combined ambidexterity on innovation performance (patent applications) related to pandemics

Variable	*Log-total health patents (applications)*									
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*
	Coef.	*SE*	*Coef.*	*SE*	*Coef.*	*SE*	*Coef.*	*SE*	*Coef.*	*SE*
Exploration	0.1183***	(0.0317)	0.1539***	(0.0494)	0.1428***	(0.0334)	0.1981***	(0.0494)	0.1439***	(0.0494)
Exploitation	0.1747***	(0.0219)	0.1750***	(0.0491)	0.1225**	(0.0528)	0.1673***	(0.0491)	0.1643***	(0.0491)
Balance ambidexterity (BD)			0.1749***	(0.0492)			0.1651***	(0.0492)	0.1622***	(0.0491)
Combined ambidexterity (CD)					0.1296***	(0.0204)	0.2930***	(0.0805)	0.1839***	(0.0507)
BD × CD									0.2399***	(0.0265)
Size (revenue)	0.3667***	(0.0443)	0.3600***	(0.0448)	0.3711***	(0.0449)	0.3644***	(0.0454)	0.3642***	(0.0451)
size (assets)	0.6441***	(0.0608)	0.6171***	(0.0623)	0.6207***	(0.0621)	0.5932***	(0.0637)	0.5936***	(0.0638)
Growth	-0.8245*	(0.4849)	-0.8182***	(0.0790)	-0.7113	(0.4623)	-0.7068	(0.4672)	-0.7265	(0.4649)
Asset structure	0.0167	(0.0423)	0.9683**	(0.4328)	0.9078**	(0.4117)	0.8605**	(0.4209)	0.8326**	(0.4164)
Current ratio	0.0199	(0.0134)	0.0201	(0.0137)	0.0213	(0.0140)	0.0215	(0.0143)	0.0209	(0.0141)
Solvency ratio	-0.0717***	(0.0257)	-0.0685***	(0.0256)	-0.0701***	(0.0257)	-0.0668***	(0.0257)	-0.0665***	(0.0257)
Leverage	-0.0981**	(0.0462)	-0.0688	(0.0453)	-0.0634	(0.0478)	-0.0357	(0.0468)	-0.0122	(0.0464)
R&D expenditure	0.0136	(0.0321)	0.0142***	(0.0032)	0.0135	(0.0322)	0.0142	(0.0324)	0.0135	(0.0330)
Constant	0.5465**	(0.2666)	0.3836	(0.2724)	0.4868*	(0.2685)	0.3207	(0.2744)	0.3085	(0.2751)
No. of obs.	*15,062*		*15,062*		*15,062*		*15,062*		*15,062*	
R^2	*0.4484*		*0.5439*		*0.4494*		*0.4493*		*0.5492*	
Adjusted R^2	*0.4194*		*0.5024*		*0.4024*		*0.4146*		*0.5028*	
Probability of Wald chi-square test	*0.0002*		*0.0003*		*0.0000*		*0.0000*		*0.0001*	
Year FE	*Yes*		*Yes*		*Yes*		*Yes*		*Yes*	
Industry FE	*Yes*		*Yes*		*Yes*		*Yes*		*Yes*	
State FE	*Yes*		*Yes*		*Yes*		*Yes*		*Yes*	

Note: Asterisks denote statistical significance at the 1% (***), 5% (**), and 10% (*) level. Robust standard errors are in the parentheses. The probability of the Wald chi-square test examines the null hypothesis that all regression coefficients are equal to zero. FE = fixed effects.

TABLE A5 Results of balanced and combined ambidexterity on innovation performance (grant lag) related to pandemics

Variable	***Grant lag***									
	(1)	***(2)***	***(3)***	***(4)***	***(5)***	***(6)***	***(7)***	***(8)***	***(9)***	***(10)***
	Coef.	***SE***	***Coef.***	***SE***	***Coef.***	***SE***	***Coef.***	***SE***	***Coef.***	***SE***
Exploration	-0.1067***	(0.0190)	-0.1336***	(0.0132)	-0.1107***	(0.0187)	-0.1612*	(0.0928)	-0.1619*	(0.0929)
Exploitation	-0.1770***	(0.0805)	-0.1096***	(0.0092)	-0.1298*	(0.0671)	-0.1073***	(0.0091)	-0.1073***	(0.0091)
Balance ambidexterity (BD)			-0.1075***	(0.0091)			-0.1060***	(0.0092)	-0.1060***	(0.0092)
Combined ambidexterity (CD)					-0.1652**	(0.0710)	-0.0002***	(0.0000)	-0.1643***	(0.0605)
BD × CD									-0.1254***	(0.0171)
Size (revenue)	-0.0465***	(0.0078)	-0.0439**	(0.0179)	-0.0449***	(0.0038)	-0.0424***	(0.0038)	-0.0424***	(0.0038)
size (assets)	-0.1438***	(0.0471)	-0.1377***	(0.0147)	-0.1333***	(0.0467)	-0.1274***	(0.0046)	-0.1274***	(0.0046)
Growth	0.0230	(0.0259)	0.0278	(0.0258)	0.0319	(0.0245)	0.0361	(0.0243)	0.0363	(0.0243)
Asset structure	-0.1686***	(0.0241)	-0.1544***	(0.0239)	-0.1612***	(0.0230)	-0.1478***	(0.0229)	-0.1478***	(0.0229)
Current ratio	-0.0500***	(0.0102)	-0.0476***	(0.0101)	-0.0536***	(0.0102)	-0.0513***	(0.0101)	-0.0513***	(0.0101)
Solvency ratio	0.0113	(0.0372)	0.0110	(0.0350)	0.0111	(0.0321)	0.0108	(0.0301)	0.0108	(0.9373)
Leverage	0.0858	(0.0580)	0.0108	(0.0584)	0.0266	(0.0574)	0.0203	(0.0578)	0.2030***	(0.0578)
R&D expenditure	-0.0324	(0.0263)	-0.0316	(0.0260)	-0.0303	(0.0239)	-0.0294**	(0.0134)	-0.0294	(0.0238)
Constant	0.3521***	(0.1360)	0.3746***	(0.1371)	0.3805***	(0.0135)	0.4022***	(0.1354)	0.4020***	(0.1350)
No. of obs.	*15,062*		*15,062*		*15,062*		*15,062*		*15,062*	
R^2	*0.4484*		*0.5283*		*0.5494*		*0.5322*		*0.5593*	
Adjusted R^2	*0.4294*		*0.4925*		*0.5025*		*0.4987*		*0.5193*	
Probability of Wald chi-square test	*0.0000*		*0.0000*		*0.0002*		*0.0002*		*0.0001*	
Year FE	*Yes*		*Yes*		*Yes*		*Yes*		*Yes*	
Industry FE	*Yes*		*Yes*		*Yes*		*Yes*		*Yes*	
State FE	*Yes*		*Yes*		*Yes*		*Yes*		*Yes*	

Note: Asterisks denote statistical significance at the 1% (***), 5% (**), and 10% (*) level. Robust standard errors are in the parentheses. The probability of the Wald chi-square test examines the null hypothesis that all regression coefficients are equal to zero. FE = fixed effects.

TABLE A6 Results of innovation performance (citations) related to the COVID-19 pandemic on mortality rate, risk of infection, and life expectancy

Variable	***COVID-19 mortality rate***		***COVID-19 risk of infection***		***Life expectancy***	
	Coef.	***SE***	***Coef.***	***SE***	***Coef.***	***SE***
	(1)	***(2)***	***(3)***	***(4)***	**(5)**	**(6)**
Citations	***-0.0103****	***(0.003)***	***-0.0123****	***(0.003)***	***0.0103****	***(0.004)***
Social inequality variables						
Income p.c	-0.1284***	(0.0283)	-0.0284***	(0.0102)	0.0593***	(0.0224)
Unemployment	0.0245**	(0.0102)	0.0649***	(0.0224)	-0.0930	(0.0643)
Health expenditure p.c	-0.0448**	(0.0198)	-0.0493***	(0.0119)	0.0493**	(0.0194)
Health insurance coverage (%)	-0.1029	(0.1193)	-0.0593***	(0.0124)	0.0483**	(0.0223)
Percentage college grads	-0.0329	(0.0839)	-0.0893***	(0.0248)	0.0896*	(0.0478)
Urbanization	0.0583	(0.0493)	0.0395**	(0.0195)	-0.0837**	(0.0344)
Other area characteristics						
Fraction of current smokers	0.1248	(0.0850)	0.2994**	(0.1345)	-0.0839	(0.0532)
Fraction of those obese	0.1503	(0.1294)	0.0939	(0.0694)	-0.0593**	(0.0293)
Crime rate p.c	0.0569	(0.0495)	0.0425**	(0.0193)	-0.0525**	(0.0230)
Constant	0.2354	(0.3456)	0.9455***	(0.2838)	0.7393	(0.6443)
No. of obs.	*1118*		*1118*		*1118*	
R^2	*0.5632*		*0.5832*		*0.4528*	
Adjusted R^2	*0.5035*		*0.5295*		*0.4149*	
Probability of Wald chi-square test	*0.0000*		*0.0003*		*0.0001*	
Year FE	*Yes*		*Yes*		*Yes*	
State FE	*Yes*		*Yes*		*Yes*	

Note: Asterisks denote statistical significance at the 1% (***), 5% (**), and 10% (*) level. Robust standard errors are in the parentheses. The probability of the Wald chi-square test examines the null hypothesis that all regression coefficients are equal to zero. FE = fixed effects.

TABLE A7 Threshold tests and threshold estimates(citations)

Threshold variable	***COVID-19 mortality rate***		***COVID-19 risk of infection***		***Life expectancy***	
	p-value	**Threshold estimate γ**	**p-value**	**Threshold estimate γ**	**p-value**	**Threshold estimate γ**
Income p.c	0.0000	33312	0.0000	33312	0.0000	33312
Unemployment	0.0000	0.06	0.0000	0.06	0.0000	0.06
Health expenditure p.c	0.0001	71938	0.0075	71938	0.0025	71938
Health insurance coverage (%)	0.0020	75	0.0001	75	0.0002	75
Percentage college grads	0.0015	25	0.00010	25	0.0001	25
Urbanization	0.0000	48	0.0000	48	0.0000	48

TABLE A8 Threhold results of innovation performance (citations) related to the COVID-19 pandemic on mortality rate, risk of infection, and life expectancy

Variable	*COVID-19 mortality rate*		*COVID-19 risk of infection*		*Life expectancy*	
	Coef.	*SE*	*Coef.*	*SE*	*Coef.*	*SE*
	(1)	*(2)*	*(3)*	*(4)*	**(5)**	**(6)**
Social inequality variables						
Income p.c	-0.1032***	(0.0123)	-0.0138	(0.0117)	0.0231*	(0.0135)
Unemployment	0.0012***	(0.0001)	0.0472***	(0.0123)	-0.1238	(0.4824)
Health expenditure p.c	-0.0248***	(0.0065)	-0.0382	(0.0343)	0.0374	(0.0333)
Health insurance coverage (%)	-0.1932	(0.3952)	-0.0284**	(0.0032)	0.0345***	(0.0104)
Percentage college grads	-0.0234	(0.2911)	-0.0323	(0.0293)	0.0546**	(0.0245)
Urbanization	0.0104	(0.0592)	0.0234	(0.0144)	-0.0932***	(0.0233)
Citations I$(Income\ p.c \leq 33312)$	-0.1938	(0.1831)	-0.0143	(0.0285)	0.0034***	(0.0012)
Citations I (Unemployment ≤ 0.06)	-0.2832***	(0.0352)	-0.0324***	(0.0117)	0.0193***	(0.0023)
Citations I (Health expenditure p.c $\leq$ 71938)	-0.2842***	(0.0643)	-0.0428***	(0.0107)	0.0323	(0.4922)
Citations I (Health insurance coverage (%)≤ 75)	-0.0843	(0.0763)	-0.0562	(0.0482)	0.0023	(0.0160)
Citations I (Percentage college grads ≤ 25)	-0.0423***	(0.0135)	-0.0231	(0.0235)	0.0834	(0.0922)
Citations I (Urbanization ≤ 48)	-0.0237	(0.0432)	-0.0345***	(0.0123)	0.0232**	(0.0094)
Citations I$(Income\ p.c > 33312)$	-0.2932***	(0.0392)	-0.2452***	(0.0438)	0.0322***	(0.0100)
Citations I (Unemployment > 0.06)	-0.0323	(0.9471)	-0.0281**	(0.0112)	0.0032	(0.0234)
Citations I (Health expenditure p.c $>$ 71938)	-0.3245***	(0.0542)	-0.4561**	(0.0592)	0.4832***	(0.0492)
Citations I (Health insurance coverage (%) $>$ 75)	-0.0932***	(0.0335)	-0.1233***	(0.0183)	0.0322***	(0.0123)
Citations I (Percentage college grads > 25)	-0.2354***	(0.0434)	-0.0213***	(0.0023)	0.1483***	(0.0230)
Citations I (Urbanizationate > 48)	-0.0235**	(0.0118)	-0.1582***	(0.0421)	0.1033	(0.0832)
Other area characteristics						
Fraction of current smokers	0.1825***	(0.0385)	0.4624**	(0.1932)	-0.0932**	(0.0422)
Fraction of those obese	0.2845	(0.3432)	0.2813	(0.3921)	-0.0392***	(0.0103)
Crime rate p.c	0.0294	(0.0345)	0.0234	(0.0235)	-0.0434***	(0.0132)
Constant	0.1005***	(0.0156)	0.3450***	(0.0942)	0.8482*	(0.4422)
No. of obs.	*1118*		*1118*		*1118*	
R^2	*0.4552*		*0.4939*		*0.4342*	
Adjusted R^2	*0.4024*		*0.4329*		*0.4021*	
Probability of Wald chi-square test	*0.0003*		*0.0001*		*0.0002*	
Year FE	*Yes*		*Yes*		*Yes*	
State FE	*Yes*		*Yes*		*Yes*	

Note: Asterisks denote statistical significance at the 1% (***), 5% (**), and 10% (*) level. Robust standard errors are in parentheses. The probability of the Wald chi-square test examines the null hypothesis that all regression coefficients are equal to zero. FE = fixed effects.

TABLE A9 Results of innovation performance (granted patents) related to the COVID-19 pandemic on mortality rate, risk of infection, and life expectancy, while controlling for endogeneity using instrumental variables (IV): Two-stage least squares estimation

Variable	***COVID-19 mortality rate***		***COVID-19 risk of infection***		***Life expectancy***	
	Coef.	***SE***	***Coef.***	***SE***	***Coef.***	***SE***
	(1)	***(2)***	***(3)***	***(4)***	**(5)**	**(6)**
Health patents (granted)	***-0.01394******	***(0.0032)***	***-0.0129******	***(0.0033)***	***0.0103******	***(0.0032)***
Social inequality variables						
Income p.c	-0.0485***	(0.0094)	-0.0284***	(0.0064)	0.0786***	(0.0258)
Unemployment	0.0345**	(0.0146)	0.0859***	(0.0129)	-0.0475	(0.0356)
Health expenditure p.c	-0.0374***	(0.0125)	-0.0684*	(0.0384)	0.0358	(0.0263)
Health insurance coverage (%)	-0.0465**	(0.0196)	-0.0735***	(0.0274)	0.0850	(0.0566)
Percentage college grads	-0.0284	(0.0931)	-0.0673	(0.0646)	0.0643*	(0.0335)
Urbanization	0.0573**	(0.0233)	0.0745***	(0.0273)	-0.0374***	(0.0126)
Other area characteristics						
Fraction of current smokers	0.0684***	(0.0129)	0.6483*	(0.3843)	-0.0790	(0.6748)
Fraction of those obese	0.0463***	(0.0173)	0.1834**	(0.0848)	-0.0976**	(0.0467)
Crime rate p.c	0.0485	(0.0373)	0.2656	(0.2859)	-0.0865	(0.0786)
Constant	0.0396	(0.0806)	0.9343	(0.8595)	0.7554	(0.5876)
No. of obs.	*1118*		*1118*		*1118*	
R^2	*0.6932*		*0.5485*		*0.5903*	
Adjusted R^2	*0.6294*		*0.4967*		*0.5269*	
Probability of Wald chi-square test	*0.0000*		*0.0004*		*0.0001*	
Year FE	*Yes*		*Yes*		*Yes*	
State FE	*Yes*		*Yes*		*Yes*	

Note: Asterisks denote statistical significance at the 1% (***), 5% (**), and 10% (*) level. Robust standard errors are in parentheses. The probability of the Wald chi-square test examines the null hypothesis that all regression coefficients are equal to zero. FE = fixed effects.

TABLE A10 Threshold results of innovation performance (granted patents) related to the COVID-19 pandemic on mortality rate, risk of infection, and life expectancy, while controlling for endogeneity using instrumental variables (IV): Two-stage least squares estimation

Variable	*COVID-19 mortality rate*		*COVID-19 risk of infection*		*Life expectancy*	
	Coef.	*SE*	*Coef.*	*SE*	*Coef.*	*SE*
	(1)	*(2)*	*(3)*	*(4)*	**(5)**	**(6)**
Social inequality variables						
Income p.c	-0.0653***	(0.0088)	-0.0165*	(0.0093)	0.0993***	(0.0165)
Unemployment	0.0288**	(0.0120)	0.0883***	(0.0134)	-0.1593	(0.4722)
Health expenditure p.c	-0.0238***	(0.0090)	-0.0482***	(0.0124)	0.0283	(0.0345)
Health insurance coverage (%)	-0.0332	(0.0449)	-0.0532***	(0.0190)	0.0683***	(0.0234)
Percentage college grads	-0.0119***	(0.0029)	-0.0693	(0.0492)	0.0432*	(0.0204)
Urbanization	0.0832	(0.0515)	0.0060	(0.0126)	-0.0655	(0.0838)
Health patents $I(Income\ p.c \leq 33312)$	-0.0290**	(0.0124)	-0.0201	(0.0234)	0.0453***	(0.0123)
Health patents I (Unemployment ≤ 0.06)	-0.1118***	(0.0235)	-0.0294**	(0.0150)	0.0239***	(0.0048)
Health patents I (Health expenditure p.c $\leq$ 71938)	-0.1035***	(0.0393)	-0.0286**	(0.0143)	0.0050	(0.1233)
Health patents I (Health insurance coverage (%)≤ 75)	-0.0690**	(0.0283)	-0.0843**	(0.0432)	0.0348**	(0.0138)
Health patents I (Percentage college grads ≤ 25)	-0.1934***	(0.0290)	-0.1129	(0.1043)	0.0235	(0.3845)
Health patents I (Urbanization ≤ 48)	-0.0301**	(0.0133)	-0.1124***	(0.0350)	0.1193	(0.1693)
Health patents $I(Income\ p.c > 33312)$	-0.1932***	(0.0311)	-0.1943***	(0.0450)	0.1839***	(0.0290)
Health patents I (Unemployment > 0.06)	-0.0593***	(0.0145)	-0.0139***	(0.0045)	0.0494	(0.1931)
Health patents I (Health expenditure p.c $>$ 71938)	-0.2138***	(0.0290)	-0.0490**	(0.0234)	0.4536***	(0.0625)
Health patents I (Health insurance coverage (%) $>$ 75)	-0.0823**	(0.0390)	-0.1946***	(0.0460)	0.1839***	(0.0324)
Health patents I (Percentage college grads > 25)	-0.1932***	(0.0252)	-0.1235***	(0.0349)	0.1939	(0.1195)
Health patents I (Urbanization > 48)	-0.0290*	(0.0149)	-0.1562***	(0.0420)	0.1275***	(0.0250)
Other area characteristics						
Fraction of current smokers	0.0584***	(0.0084)	0.9322***	(0.1903)	-0.0893	(0.1394)
Fraction of those obese	0.0129***	(0.0038)	0.3352***	(0.0550)	-0.0849***	(0.0224)
Crime rate p.c	0.0573	(0.1492)	0.4456	(0.2932)	-0.9356	(0.9432)
Constant	0.0234	(0.0423)	0.3912	(0.3824)	0.9593*	(0.4942)
No. of obs.	*1118*		*1118*		*1118*	
R^2	*0.5234*		*0.5621*		*0.5832*	
Adjusted R^2	*0.4892*		*0.5029*		*0.5195*	
Probability of Wald chi-square test	*0.0000*		*0.0000*		*0.0003*	
Year FE	*Yes*		*Yes*		*Yes*	
State FE	*Yes*		*Yes*		*Yes*	

Note: Asterisks denote statistical significance at the 1% (***), 5% (**), and 10% (*) level. Robust standard errors are in parentheses. The probability of the Wald chi-square test examines the null hypothesis that all regression coefficients equal to zero. FE = fixed effects.