Setting contextual conditions to resolve grand challenges through responsible innovation

Citation for published version:
Liu, Y, Xing, Y, Vendrell-Herrero, F & Bustinza, OF 2023, 'Setting contextual conditions to resolve grand challenges through responsible innovation: A comparative patent analysis in the circular economy', *Journal of Product Innovation Management*. https://doi.org/10.1111/jpim.12659

Digital Object Identifier (DOI):
10.1111/jpim.12659

Published In:
Journal of Product Innovation Management

This is the author's copy of a Manuscript published by **Wiley** in *Journal of Product Innovation Management*, accepted 25th November 2022

SETTING CONTEXTUAL CONDITIONS TO RESOLVE GRAND CHALLENGES THROUGH RESPONSIBLE INNOVATION: A COMPARATIVE PATENT ANALYSIS IN THE CIRCULAR ECONOMY

Prof. Dr Yipeng Liu
Founding Dean, Yellow River College of Business
Shandong University of Finance and Economics, China
University of Reading, United Kingdom
University of Mannheim, Germany
Email: Liu@ifm.uni-mannheim.de
ORCID ID: https://orcid.org/0000-0002-4918-925X

Prof. Dr Yijun Xing*
Professor in Healthcare Management
Brunel University London, United Kingdom
Kingston Lane, Uxbridge, Middlesex UB8 3PH
Tel: +44 (0)1895 266615
Email: eugenia.xing@brunel.ac.uk
ORCID ID: https://orcid.org/0000-0003-0192-0063

Dr. Ferran Vendrell-Herrero
Senior Lecturer in International Management
Strategy Group, University of Edinburgh Business School, University of Edinburgh
29 Buccleuch Place, Edinburgh. EH8 9JS, United Kingdom
Tel. +44 (0)131 650 8074
Email: fvendrel@ed.ac.uk
ORCID ID: https://orcid.org/0000-0003-3809-5124

Prof. Dr Oscar F. Bustinza
Professor of Management
Faculty of Economics and Business
Department of Management I, Universidad de Granada
Campus Cartuja C.P. 18071 (Granada), Spain
Tel. +34 958241000 ext. 20177
Email: oscarfb@ugr.es
ORCID ID: http://orcid.org/0000-0002-9071-9494

*corresponding author
Prof. Dr Yijun Xing, Brunel University London, United Kingdom, Email: eugenia.xing@brunel.ac.uk

Acknowledgements:

We thank the Editor-in-Chief, Associate Editor, and three anonymous reviewers for valuable insights and ideas. This research has been supported by the Taishan Scholar Program of Shandong Province. Professor Yipeng Liu is appreciative of the Schoeller Fellowship Award by the Schoeller

Foundation for Business and Society in Germany. This research has been supported by Governments of Spain and Andalusia (Research Project A-SEJ-196-UGR20).

AUTHOR BIOS

Prof. Yipeng Liu FAcSS is Fellow of Academy of Social Sciences, UK. He is the Founding Dean of the Yellow River College of Business at Shandong University of Finance and Economics, China and Visiting Professor at University of Reading, UK. He has worked as Professor and Research Director with leading universities in the UK, Europe and Asia. His research expertise covers innovation and entrepreneurship, business sustainability, mergers and acquisitions, and emerging markets.

Prof. Yijun Xing FRSPH is a Chair (Full Professor) in Healthcare Management at Brunel University London. She serves as Founding Director of Healthcare Management, Culture and Leadership research group. Her research interests center on leadership and HRM, resilience and wellbeing, behavior science in healthcare, and sustainability management. Her paper on poetry and leadership won Inaugural Hermann and Marianne Straniak Stiftung Best Paper Award of Management and Organization Review.

Dr. Ferran Vendrell-Herrero is a Senior Lecturer in International Management at the University of Edinburgh. His research aims to uncover innovation, digitisation and internationalisation dynamics of small and large organisations. Across these themes, he has made a distinctive contribution through publications in top academic journals. He is founder and scientific director of the International Conference on Business Servitization.

Prof. Oscar F. Bustinza is Professor in Management at the University of Granada. His work aims to analyse drivers of firm's boundaries choice, demand chain management, and service innovation based upon data driven analysis. Prof. Bustinza was Principal Investigator on Service Innovation in MAKERS, a H2020 over €1 million project that supported an EU-wide network of researchers.

ABSTRACT

This article draws on responsible innovation (RI), hybrid organizations, institutional rigidity, and national innovation systems (NISs) to assess and contextualize the innovation performance of for-profit firms seeking to resolve grand challenges (GCs). The extant research on RI lacks the theoretical underpinnings to profile the unique characteristics of RI firms and the contextual conditions behind the resolution of GCs through RI. This study aims to fill this important gap by focusing on a specific type of RI firm—a firm seeking to reduce climate change through implementation of a circular economy model. By studying a multi-country sample of 1,153 manufacturing firms, we implemented propensity score matching (PSM) and the Heckman selection model to compare the patent productivity of RI and non-RI firms. Our evidence demonstrates that RI firms display lower likelihood of patenting and lower patent productivity than non-RI firms when they do engage in patenting. Furthermore, we found that a stronger national R&D environment can be conducive to aligning public interests and private incentives by enabling RI firms to enhance their patent productivity. Additionally, RI firms in industries with lower levels of technological complexity capture more value from improvements in R&D environments than firms with higher levels of technological complexity Our argument as a whole contributes to the GC and RI literature streams by considering both the innovation barriers faced by RI-oriented firms and the macro/industry boundary conditions that enable such organizations to overcome them.

Practitioner Points

- Tackling grand challenges need the involvement of hybrid organizations that combine profit orientation with responsible innovation.
- In the context of climate change, hybrid organizations report a lower patent productivity than strictly for-profit organizations. This seems to be consistent with anecdotal evidence from other grand challenges, i.e., space exploration, pandemics and zero hunger.
- Contextual conditions reduce the patent disadvantage of hybrid organizations. Hybrid organization perform better in developed nations with high levels of national R&D investment and in less technological complex industries.

Keywords: grand challenges, responsible innovation, hybrid organization, circular economy, patent productivity, R&D environment

1. INTRODUCTION

Understanding the role played by innovation and the causes and effects of tackling grand challenges (GCs) in the micro- and macro-environments of firms is critical because GCs are complex issues with far-reaching societal implications (George et al., 2016). In dealing with pressing societal GCs—healthcare, climate change, space exploration, and poverty, among others—responsible innovation (RI) (Stilgoe, Owen, and MacNaghten, 2013) requires scientific breakthroughs and technological innovation, as well as the contribution of for-profit firms and policymakers through collaborative endeavors. In brief, achieving and leveraging RI necessitates multidisciplinary and interdisciplinary perspectives involving multi-level and system approaches to tackling GCs (Lee, Spanjol, and Sun, 2019; Noble and Spanjol, 2020).

The extant research on RI has focused mainly on the ethical dimensions of innovation activities (Genus and Stirling, 2018). In connection to GCs, we argue that the study of RI should not be constrained to its ethical dimensions, but rather should embrace a broader perspective by considering performance implications, especially those linked to innovation performance. Despite the increasing scholarly attention paid to RI firms (Arslan and Tarakci, 2020; Blok and Lemmens, 2015), the demonstration of why and how RI firms achieve innovation performance remains elusive. This gap is largely attributed to the lack of theoretical underpinnings suited to characterizing the unique properties of RI firms and their subsequent impact on these firms' innovation performance. Our study aims to fill this important gap by juxtaposing the theoretical lenses of hybrid organizations, institutional rigidity, and national innovation systems (NISs).

From a theoretical perspective, we argue that RI firms can be conceptualized as hybrid organizations capable of coping with the multiple—and often competing—demands of their commercial and societal missions (Battilana and Lee, 2014; Jay, 2013). Essentially, RI firms engage in business activities with societal values and purposes (Kroeger and Weber, 2014). The tension stemming from the profit- and societal-value-driven goals embedded in hybrid organizations can play a substantial role in shaping these firms' strategies and performance outcomes (Xing, Liu, and Lattemann, 2020). To date, however, the existing literature on hybrid organizations has not examined the impact of their characteristics on innovation activities, a vital outcome for RI firms (e.g., Burger et al., 2019; Cainelli, D'Amato, and Mazzanti, 2020). Our study thus aims to determine the conditions under which RI firms, as hybrid organizations, can undermine or enhance their innovation performance, as well as the macro-contextual environment and industry-specific conditions that might influence such performance.

The central argument of our study is that RI firms systematically engage in patenting less than their non-RI counterparts. We propose three mutually reinforcing theoretical explanations consistent with this argument. First, GC-related projects by definition have the potential for meaningful societal and economic impact (George et al., 2016), but they are also characterized by high levels of complexity, uncertainty, and unpredictability (Ferraro, Etzion, and Gehman, 2015) that can undermine the innovation capacity of hybrid organizations (RI firms)—*the hybrid organization effect*. Second, because GCs by definition lack clear solutions and have expected outcomes of a disruptive nature (Markides, 2006), solving GCs may change production, consumption, and work paradigms (Vakili and McGahan, 2016). This reasoning implies that RI firms may lag-behind non-RI firms in patenting when pursuing solutions to GCs—*the disruptive technology effect*. Third, we argue that, paradoxically, the greater likelihood that RI projects will be funded by public institutions diminishes rather than enhances the innovation capacity of RI firms. The strong influence of the rigid criteria and evaluation metrics imposed by public institutions (Grodal and O'Mahony, 2017) limits the independence of RI firms' research decision making (Hargadon and Douglas, 2001)—*the institutional rigidity effect*.

We also argue that the disadvantage in innovation performance that RI firms face can be reduced or even reversed under favorable contextual conditions. For example, developed NISs (Tilleman, Russo, and Nelson, 2020)—i.e., environments rich in R&D investment and innovation—will be more conducive to setting the conditions needed to solve GCs (Schot and Steinmueller, 2018). We thus argue that RI firms can equal the innovation performance of non-RI firms in the presence of more-developed NISs. Furthermore, industry characteristics such as technological complexity can also affect innovation performance. We specifically argue that the development required of NISs to enable RI firms to catch up with non-RI ones will be lower for firms operating in low-tech industries because of the latter's lower degree of knowledge exchange with external companies/agencies (Tang, 2006).

Our study collected data from the ORBIS database (Bureau van Dijk). The sample consisted of 1,153 firms headquartered across 20 countries. We chose the circular economy (CE) as our GC focus due to its accessibility to smaller firms and various industries, which presented a unique opportunity for a large quantitative study. Sample selection covered not only a wide spectrum of manufacturing activities (NAICS codes 31 to 33), but also specified a knowledge-based service sector (NAICS-54) as a secondary criterion. After controlling for sampling issues in the independent variables (PSM) and dependent variables (Heckman selection model) (e.g., Vendrell-Herrero et al., 2022), our findings show underperformance of RI firms (proxied by CE) in terms of patent productivity,[1] suggesting that hybrid organizations do not have the economic incentives needed to solve the most challenging societal issues. Furthermore, our empirical

[1] Patent productivity has been identified as analogous to labor productivity, calculated by dividing a firm's revenue by its number of employees. Patent productivity serves as a relative measure of revenue that is comparable across firms, regardless of their size.

evidence corroborates most of our context-based arguments.

Our study makes three important contributions to innovation management by building new and testing existing theory about GCs. First, it provides the theoretical underpinnings needed to advance GC research by building on hybrid organization theory (e.g., Battilana and Lee, 2014; Jay, 2013), whereby the significant and RI-driven goals of for-profit firms enable them to focus on solving societal GCs related to making profits. We believe that the hybrid organization lens sheds light on a yet unanswered question in GC research: "*Why do organizations commit to resource investments toward GCs?"* (George et al., 2016, p. 1892). Second, our study develops theory that enables country- and industry-level contextualization of GC research and practice. We examine the multi-level influences on RI-firm innovation performance by highlighting the effect of the national R&D environment—as related to national- and industry-level technological complexity—on such firms' patent productivity. Our multi-level framework responds to calls for more research exploring institutional (e.g., Gümüsay et al., 2020) and industry evolution (e.g., Agarwal, Kim, and Moeen, 2021) factors influencing attainment of GCs. Finally, this study provides unique evidence perfectly consistent with status quo criteria (e.g., Grodal and O'Mahony, 2017)—that is, the theory that GC-oriented firms lag behind other organizations relative to patenting because government agencies restrict their research plans, actions, and methods.

2. THEORETICAL BACKGROUND AND HYPOTHESIS DEVELOPMENT

As an emerging and nascent concept, RI may radically transform the concept of and research on innovation (Blok and Lemmens, 2015). The extant research on RI has focused mainly on its ethical dimensions, such as social responsibility and the accountability associated with innovation activities (Genus and Stirling, 2018; Scherer and Voegtlin, 2020). We argue that RI research should not be limited to such dimensions but should explore the broader performance implications of RI for-profit firms that engage in RI research as an innovative pathway to address GCs (e.g., Arslan and Tarakci, 2020). Our analysis drew on four distinctive forms of GC-based RI (see Table 1) to construct a conceptual framework that links RI and patent productivity in different contextual settings (see Figure 1).[2]

– Insert Table 1 and Figure 1 here –

2.1. Responsible Innovation and Patent Productivity

Our theoretical argumentation focuses on three mutually reinforcing effects that explain the patenting capacity of RI firms—namely, the '*hybrid organization*', '*disruptive technology',* and '*institutional rigidity*' effects. We now discuss each effect in turn to develop our hypotheses.

2.1.1. The 'hybrid organization' effect

Despite the vibrant development of RI research, the extant literature lacks the theoretical underpinnings needed to better demarcate the characteristics of RI firms. We suggest that a hybrid organization framework may yield important insights into both the characteristics of RI firms and these characteristics' implications for RI firms' performance. Hybrid organizations must be able to manage the multiple—and often competing—demands that stem from their commercial and societal missions through mobilization of organizational resources and implementation of diverse activities (Battilana and Lee, 2014). We thus argue that RI firms can be conceptualized as hybrid organizations (Bauwens, Huybrechts, and Dufays, 2020). The

[2] To strengthen our theory development, we introduce a series of running cases. As shown in Table 1, all running cases come from well-known GCs (i.e., space exploration, pandemics, Zero Hunger). The information provided, including quotations, comes from secondary sources and is accessible on Internet. Specific sources are provided when running cases are presented.

tension and competing demands arising from the profit- and societally-driven goals embedded in hybrid organizations can shape these firms' strategies and innovation performance outcomes (Jay, 2013). For example, in entering the Chinese healthcare market, foreign hospitals, as hybrid organizations, can balance the tensions between their societal and commercial values by choosing collaborative partnerships as the preferred entry mode (Xing et al., 2020).

To understand whether organizational outcomes can be considered successes or failures for RI firms, scholars have studied the performance paradoxes such firms face (Jay, 2013). Previous research has analyzed innovation as a mechanism whereby RI firms balance the many logics prescribed by multiple institutions at the same time (Mair, Mayer, and Lutz, 2015). The existing literature on hybridization of organizations has not, however, examined the impact of these logics on innovation activities, a vital outcome for RI firms (Genus and Stirling, 2018). More specifically, the literature has thus far failed to theorize the conditions that either undermine or enhance the innovation performance of RI firms as hybrid organizations.

Hybrid organizations must consider their societal and commercial missions in attaining their strategic goals and deploying their resources (Vassallo et al., 2019). That both social and economic strategic goals can affect firms' innovation performance highlights the entwined interrelation between various knowledge-sourcing practices and pursuit of strategic goals (Stephan, Andries, and Daou, 2019). We thus argue that this dual-mission characteristic can cause sustainability-driven firms (such as RI firms) to sacrifice their innovation outcomes partly or fully, due to the need to manage the tensions embedded in organizational hybridity.

2.1.2. The 'disruptive technology' effect

As complex, uncertain, and unpredictable initiatives, GCs require pragmatic approaches and imaginative orientations in seeking creative solutions and RI (Ferraro et al., 2015). RI firms thus face higher levels of problem-solving difficulties than do non-RI firms. GCs lack clear solutions, and the expected outcomes are of a disruptive nature (Markides, 2006), having the potential to change the ways we produce, consume, interact, and work (Vakili and McGahan, 2016). Such outcomes are not necessarily the case for non-RI firms, which might invest a larger proportion of their resources in deploying incremental innovation outcomes. This argument implies that RI firms may lag-behind non-RI ones in patenting when pursuing solutions to GCs. Additionally, consistent with the abovementioned technological complexity, GC-based technologies require knowledge drawn from multidisciplinary and interdisciplinary perspectives (Hekkert et al., 2020), making them more difficult to patent.

2.1.3. The 'institutional rigidity' effect

Due to the significance and complexity of GCs, organizations often establish partnerships involving multiple stakeholders across multiple levels of the policy making, business, and research communities, because the focal phenomena are relevant to multi-stakeholders and system issues (Grodal and O'Mahony, 2017). Institutions actively participate in these partnerships. For instance, the EU introduced its Research and Responsible Innovation (RRI) framework to anticipate and assess "*potential implications and societal expectations with regard to research and innovation, with the aim to foster the design of inclusive and sustainable research and innovation*" (European Commission, 2014). The internal motivations of RI firms may not be aligned, however, with the motivations governing institutional instructions and monitoring (Berrone et al., 2016), and misalignment may further increase the patenting gap between RI and non-RI firms. More specifically, we argue that national and supra-national (e.g., the European Commission and the World Health Organization) institutional rigidity in addressing societal GCs may hinder (rather than promote) solution of them.[3] According to Grodal and O'Mahony (2017), institutional rigidity leads for-profit organizations to rely more strongly on existing metrics than on independent criteria and self-creativity when funding projects. These rigid criteria can stifle the novelty needed to advance GC projects, as the criteria reinforce existing knowledge rather than the novelty needed for breakthrough innovations (Hargadon, 2003).

The GCs associated with pandemics (Pfizer[4]) and space exploration (SpaceX) are good illustrations of the significance of institutional rigidity. In September 2020, Pfizer CEO Albert Boula refused a federal subsidy in order to liberate the company's scientists from any bureaucracy, stating, "*When you get money from someone, that always comes with strings. They want to see how you are going to progress, what type of moves you are going to do. They want reports. I didn't want to have any of that. I wanted them* [the company's scientists]*—basically, I gave them an open checkbook so that they would only need to worry about scientific challenges, not anything else*" (Bump, 2020). The same applies to the case of SpaceX, which has refused institutional funding but has tested several rockets and transported cargo and personnel to the International Space Station, with NASA as its main client (Pessoa, 2021).

2.1.4. Illustrating the combined effect

To illustrate the combined effects of the '*hybrid organization*', '*disruptive technology*', and '*institutional rigidity*', we refer to Zero Hunger, one of the UN's 17 sustainable development

[3] This study defines institutional rigidity as status quo criteria, that is, a set of common objectives, steps-to-follow, and rules for private and public organizations seeking to work on a project with social outcomes. Institutional rigidity can thus be understood as institutional conformity in the context of innovation policy for firms seeking to obtain funding from public resources for sciences and technology projects.
[4] We consider Pfizer a good example of RI. Although Pfizer did not invent RNA vaccines, the company acted immediately in collaboration with BioNTech to develop the COVID-19 vaccine for the market. Pfizer did not draw on federal subsidies in developing the vaccine. Furthermore, Pfizer applied not subsidy but market logic to the vaccine pre-orders made by governments around the world. This market logic was also reflected in the vaccine purchasing (pre-order) endeavors of the UK government, which hired a venture capital veteran (Kate Bingham) from the very beginning.

goals (SDGs). Currently, the use of biotechnology (disruptive technology effect) by some food processing firms is changing the agriculture industry. These dual-objective firms (hybrid organization effect) are increasing agricultural productivity and quality, helping to address the Zero Hunger SDG. Nevertheless, these food processing firms are subject to stricter regulations and grant fewer patents than their non-biotech counterparts. According to the World Intellectual Property Organization (WIPO), the regulations imposed by the European Commission (institutional rigidity effect) between 1998 and 2004 arguably caused a gap between US and European patent filing (WIPO, 2019). In 2018, US seed producers—such as Pioneer Hybrid International and Stine Seed farm—applied for and were granted a higher number of patents related to meat substitutes than their European counterparts. An executive of a Pioneer Hybrid subsidiary (Corteva Agriscience) pointed out that "*genetic improvement in the US over the past 70 years has resulted in an 89% increase in grain yields*" (Mueller, Messina, and Vyn, 2019, pp. 7), showing a close connection between unregulated genetic seed treatments and grain yields. This example of RI aimed at achieving the Zero Hunger SDG shows that hybrid organizations face institutional obstacles that are difficult to overcome—in this case, the need to comply with tougher regulations than those faced by their competitors—and thus achieve lower levels of innovation performance.

2.1.5. Hypothesis development and contextual conditions

Taken together, our arguments imply that RI patenting firms contend with three mutually reinforcing factors that diminish their patenting performance. First, the '*hybrid organization*' effect suggests that RI firms' interest in social objectives makes them more attracted to GC projects. Second, the '*disruptive technology*' effect suggests that GC projects are disruptive in nature and thus harder to achieve. Finally, the '*institutional rigidity*' effect suggests that, precisely because RI firms are more disposed to solving GCs, they are subject to more rigid institutional frameworks. Taken together, these three effects suggest that RI firms exhibit narrower innovation outcomes (e.g., numbers of patents) than their non-RI counterparts[5]. Hence:

Hypothesis 1: RI patenting firms have lower patent productivity than non-RI firms.

The arguments developed so far predict that, among patenting firms, RI firms are likely to lag-behind their non-RI counterparts in terms of patent productivity. This view implies that such difference cannot be overcome. We argue, however, that understanding the innovation performance of RI firms necessitates a more nuanced and contextualized approach, one suited to unpacking multi-level contextual circumstances by considering two key innovation-related contextual factors: (1) national-level R&D environments and (2) industry-level technological complexity. The next two sections analyze these contextual factors.

2.2. Responsible Innovation and Innovation Productivity: The Role of National R&D Environments

A GC should be conceptualized as "*a multinational phenomenon by nature*" (Buckley, Doh, and Benischke, 2017, p. 1052), whereby innovation environments/ecosystems can affect firm-level innovation performance. To obtain a more nuanced understanding of the innovation patterns of RI firms, we should thus consider national-level contextual factors (Gümüsay et al., 2020), such as the R&D environment. The NIS literature posits that circulation of technology and information among individuals, firms, and institutions is central to a nation's capacity (and to

[5] This argument considers that, because RI firms are slower to patent than non-RI firms, their patent productivity will be lower. It is important to highlight, however, that our argument may be compatible with the fact that patents from RI firms are more valuable than patents from non-RI Firms.

that of its private sector) to compete with other nations in achieving high standards of innovation (Acs et al., 2017; Nelson, 1993). For instance, the interaction among university, industry, and government can improve R&D environment, foster regional development, and cultivate entrepreneurship and innovation ecosystems (Liu, 2020; Liu and Huang, 2018). More specifically, a NIS should be treated as part of a multi-level governance system, highlighting the utility of a multi-level approach (Kaiser and Prange, 2004). Furthermore, a NIS must reinstate macro-interpretations by emphasizing the institutional environment and the political processes of institutional capacity building for innovation (Watkins et al., 2015). Unlike rigid institutions, a NIS encompasses both multi-level factors and the influence of the economic environment. Conceptually, rigidity is institution-specific, with a focus on defining clear rules to grant funding for innovation projects. Conversely, a NIS involves other firms, stakeholders, and the broader environment, with a focus on R&D investment by the private and public sectors, although it shares commonalities regarding the role of institutions in innovation. We argue that juxtaposing these two concepts can foster cross-fertilization in innovation studies. To work properly, a NIS requires a high proportion of public and private organizations to invest heavily in R&D, as well as interaction between for-profit private firms and public institutions (Tilleman et al., 2020).

In space exploration, Rocket Lab, another US-based private rocket company, has developed a lunar orbiter as part of NASA's Artemis Program. These highly competitive private aerospace firms have not emerged in the US by accident. They are the outcome of development of a highly innovative environment that has traditionally invested significant resources in military advances, aircraft development and construction (Boeing), and space exploration (NASA). This environment has more recently invested in other related technologies, such as artificial intelligence (Silicon Valley) and shows more likelihood and feasibility of successfully investing in and developing RI. Consistent with this phenomenon, SpaceX CEO Elon Musk has argued that "*NASA's Commercial Crew Development Program fosters competition that forces companies to compete on reliability, capability, and cost. And it leverages private investment*" (House Committee on Science, Space, and Technology, 2011).

A new science, technology, and innovation policy frame is arising to improve tackling of contemporary societal and environmental GCs (Schot and Steinmueller, 2018). This emergent innovation policy frame resonates with the EU's Responsible Research and Innovation (RRI) framework, sharing common ground on innovation while highlighting the distinctive features of RI in addressing GCs. We argue that RI firms working within this new frame—which complements previous ones and is characterized by stimulation of R&D policies to promote anticipation in processes to establish sustainable pathways—should strive to achieve patenting rates similar to, or even higher than, those of non-RI firms. Having access to up-to-date knowledge and technology in the domestic market, as well as platforms for collaboration with other domestic organizations, provides the conditions suited to solving GCs (Buckley et al., 2017; Koschmann, Kuhn, and Pfarrer, 2012).

Overall, we believe that RI firms' disadvantage in innovation performance could be compensated for (or even reversed) in countries with more advanced NISs (operationalized as R&D/GDP). Thus:

Hypothesis 2: NISs positively moderate the relationship between RI and patent productivity, enabling RI firms to achieve the patent productivity levels of non-RI firms under high levels of national R&D investment.

2.3. Responsible Innovation and Innovation Productivity: The Role of Industry-level

Complexity

Because industrial settings generate path dependencies in innovation performance (e.g., Autio et al., 2014; Castellacci and Lie, 2015; Tidd, 2001), it is important to analyze whether industry context can shape the distinctive organizational behaviors of RI firms to affect innovation performance.

We focused specifically on industry-level technological complexity. Wang and Tunzelmann (2000) described how complexity can be dimensioned in terms of breadth (i.e., the range of related areas that need to be investigated to assess a subject) and depth (i.e., a subject's degree of novelty and sophistication). Industrial technological complexity is related to the latter (Carbonell and Rodriguez, 2006), with complex technologies being managed through different knowledge bases built upon different industrial specialized routines (Nelson and Winter, 1982).

We argued that RI firms operating in different industries can manifest varying innovation performance due to the technological complexity involved in their activities. For instance, science-based sectors (e.g., the pharmaceutical industry) are characterized by higher degrees of technological complexity and thus face significant risks and uncertainties when they pursue RI (Stilgoe et al., 2013; Tang, 2006). The global COVID-19 health crisis is a pertinent example of this situation, as the development of a vaccine is a highly complex endeavor that requires an experimental mentality in implementing innovation and novel technical solutions (Noble and Spanjol, 2020). The national level of R&D investment necessary for RI firms to catch up with non-RI ones in terms of patent productivity will thus be higher in science-based industries than in less technologically complex industries, such as the food processing industry (Pavitt, 1982; Tang, 2006). This brings us to the case of plant-based meat substitutes, in which the lower innovation complexity of the food processing industry has enabled firms not based in highly innovative countries to develop high-quality competitive products. One such instance is The New Butchers, a Latin American firm motivated by concerns about the environmental impact of livestock farming. This firm has patented technology that enables the production of meat substitutes from vegetable matter (Pooler, 2021). The company's co-founder of the company, Bruno Fonseca, believes there is a demand for environmentally-friendly food, hence "*the constant search for innovation and for bringing new things that surprise our consumer base is in the firm's DNA.*"[6]

Because industries like food processing use techniques involving well-defined measures and procedures aimed at reducing environmental impact (Jurgilevich et al., 2016), RI-oriented patents can be obtained within innovation environments characterized by lower levels of technological knowledge. In other words, RI firms will depend less than non-RI firms on knowledge spillovers to reach levels of patent productivity similar to those of their non-RI counterparts. This argument implies that RI firms can potentially achieve levels of innovation performance higher than those of non-RI firms when national R&D investment is high and technological complexity is low. We therefore posit the following:

Hypothesis 3: RI, NISs, and industry complexity jointly affect patent productivity, such that RI firms can outperform non-RI firms in terms of patent productivity levels under conditions of mid-to-high national R&D investment and low industry technological complexity.

3. METHODS

3.1. Research Context

[6] Quotation translated from the Portuguese. The Portuguese original can be found at https://vegazeta.com.br/marca-de-carnes-vegetais-the-new-lanca-linha-de-marmitas-em-sp/

Our research linked RI to firms' patent productivity, considering different national and industrial environments as moderating variables. The main issue was which type of RI to analyze. In the theoretical section, we used development of plant-based meat substitutes, vaccines, and space exploration as illustrative examples. While these GCs are useful as recognizable examples, they are not suited to a quantitative study due to the very limited number of large powerful companies participating in them and to the fact that they represent very specific industry settings (see Table 1). Further, in the longer run, climate change represents the grandest of challenges currently facing humanity, with devastating, life-threatening consequences (Wright and Nyberg, 2017).

To test our hypotheses, we used the CE because it is accessible to smaller companies and can be applied to all manufacturing industries, making it suitable for our quantitative study. CE is an important and emerging sector that works toward the GC of avoiding/reducing the impact of climate change (Stahel, 2016). CE firms strive to recycle their waste and waste materials, and to repurpose them creatively by taking RI approaches (Pieroni et al., 2019).

3.2. Data

The data for our analyses were collected by merging two separate Bureau van Dijk services—ORBIS and ORBIS IP, both of which cover companies worldwide. ORBIS reports accounting, financial, and industrial membership information, whereas ORBIS IP provides information on firms' patenting outcomes. The resulting database has three important features that made it especially relevant for our study. First, for each firm, it provides the number of patent applications and patents granted, enabling us to capture companies' innovative capacity and innovation performance. Second, the database covers a wide spectrum of countries, enabling cross-country analysis by merging the data with country-level secondary datasets (e.g., World

Bank indicators). Third, and more importantly, the database provides information on the various companies' activity sectors—the primary and secondary industry sectors for each firm. Previous studies have used secondary industry sectors to evaluate different forms of industrial hybridization, such as the servitization of manufacturing (Gomes et al., 2019; Sforzi and Boix, 2019). Our study uses this methodological approach to identify the manufacturing companies operating in the CE.

One limitation of using secondary sectors is that their declaration by company is voluntary. This limitation complicated construction of a control group. It was impossible for us to consider the ORBIS manufacturing firms without a secondary sector as a control group, because those firms might have decided not to declare their CE activities in their financial statements, raising the possibility of non-response bias. To avoid this limitation, our study's sample population contained only companies that had declared at least one secondary sector. More specifically, we considered firms that had declared manufacturing as their primary sector code and knowledge/technologically-based services as their secondary codes.

Our search process followed three steps. First, we restricted our analysis to three manufacturing industry sectors covering a wide spectrum of activities: (i) food, beverage, and textile processing (NAICS-31); (ii) non-mineral manufacturing, including wood, petroleum, plastics, chemical processes, and the pharmaceutical industry (NAICS-32); and (iii) mineral manufacturing, including construction of hardware, vehicles, machines, turbines, and engines (NAICS-33). This search yielded a global sample population of 4,119,560 firms. Second, we restricted the study's scope to large companies, as they have sufficient internal resources to solve GCs (Andries and Faems, 2013). Operationally, we considered a company as large if it employed at least 250 workers (Goel, Göktepe-Hultén, and Grimpe, 2017). This second filter yielded a global sample population of 25,332 firms. Third, we considered the sample's secondary industry sectors, selecting the professional, scientific, and technical service sector (NAICS-54) as a secondary industry sector, because it reflects a knowledge/technology component (Opazo-Basaez, Vendrell-Herrero, and Bustinza, 2018). After applying this third filter, our sample consisted of 1,153 firms headquartered across 20 countries and active in 2018 (see Appendix for full list). We converted all monetary values into current US$.

3.3. Measures

Dependent variable. We measured each sample firm's innovation outcome in two ways: *Patenting behavior* and *Patents per employee*. Patenting behavior reflected whether a firm had been active in patenting or not. The variable took the value '1' if a firm had had at least one patent granted, and '0' otherwise. This variable has been applied widely in innovation studies (Artz et al., 2010; Liu et al., 2008). Number of patents has traditionally been used as an objective variable (e.g., Bendig et al., 2020; Pavitt, 1982). As our data highlighted significant firm size heterogeneity, however, we divided each firm's number of patent applications and patents granted by its number of employees to obtain relative measures. *Patent applications per employee* and *patents granted per employee*—which can be defined as a form of patent productivity—were comparable across companies (Blind et al., 2006; Gu and Zhang, 2017). In our sample, all firms with patent applications had been granted at least one patent.

Independent variable. Our aim was to identify those firms that had devoted efforts to the CE. To do so, we adopted a strategy of applying an additional industry sector search criterion to our sample—waste management, remediation, and disposal (NAICS-562)—to identify the firms in our sample that had a specific interest in the environment and pollution reduction (Abbott and

Sumaila, 2019). Moreover, management of waste remediation and disposal is a necessary condition for development of CE (Tomić and Schneider, 2020). NAICS-562 manufacturing and technological firms are categorized as *CE* firms. Our independent variable was therefore a dummy that took the value '1' if a firm had declared NAICS-562 as a secondary sector, and '0' otherwise. Through this procedure, we identified 263 firms in our sample (22%) as our treatment group, with the rest (890 firms) forming the control group of non-CE firms. As all firms in our sample had declared at least one secondary industry sector (NAICS-54), we were able to rule out non-response bias in our control group.[7] We also ruled out the possibility that additional secondary industries affected our results.[8]

Moderating Variables. We adopted country-level moderators to measure a country's relative level of R&D investment, operationalizing this variable as the ratio of R&D expenditure over GDP (obtained from the World Bank Indicators).[9] We referred to this measure, which has been used extensively in NIS studies (Alcorta and Peres, 1998; Fabrizi, Guarini, and Meliciani, 2016) as *R&D/GDP*. Country-level information for this variable is available in Table A1 (see Appendix).

Our industry-level moderator aimed to measure the industry's degree of technological complexity. We considered processing industries to be characterized by a lower level of complexity than science- and machinery-based ones (Pavitt, 1982). Based on this assumption, we

[7] Non-response bias could have been a problem if we had used only each firm's primary industry code to construct our sample, as some manufacturing firms could have been operating in NAICS-562 but not have reported it.
[8] Following an anonymous reviewer's suggestion, we examined all secondary industries declared by our sample firms. Finding 42.6% of non-CE firms had declared additional industries, we performed additional analysis to separate this group from the other non-CE firms and found no significant differences in their patenting productivity in any of the contexts considered. We thus concluded that our results were not explained by the number of secondary industries, but by their quality, that is, by NAICS-562. Furthermore, when adding the number of secondary industries as a control variable, we found the results to be qualitatively the same as those reported in Table 5. These tests are not reported in tables in this paper but can be made available upon request.
[9] For more information, see: https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS?view=chart

used industry dummy variables to operationalize these industries. We considered our sample of NAICS-31 firms as operating in the processing industry sectors (including mainly food, beverages, and textiles), our NAICS-32 firms as part of the science-based industry sectors (mainly chemistry and pharmaceutical), and our NAICS-33 firms as operating in the machinery-based industry sectors (including machinery, vehicles, and electronic goods among metallic and production-intensive firms). NAICS-31 firms are considered as less technologically complex than NAICS-32 and NAICS-33 firms.[10]

Control Variables. Our analysis included a number of firm- and country-level control variables suited to potentially describe each firm's patenting activity and analyzed three firm-level control variables. First, firm size—a key determinant of patenting activity (Andries and Faems, 2013)—was measured by *number of workers*. Second, *labor productivity*—that is, total revenue divided by number of employees, a variable positively associated with patenting level (Kline et al., 2019)—measured each firm's efficiency (Vendrell-Herrero et al., 2017). Third, *Human Capital*—measured as the average hourly pay of each firm (Chemmanur, Cheng, and Zhang, 2013)—is positively associated with patenting level (Liu, 2014). The variable was operationalized by dividing each firm's labor cost by its number of employees and the number of hours worked in the firm's home country (OECD, 2021). Any missing values for the *labor cost* variable were attributed using a single imputation with expectation maximization bootstrap technique, which is designed for repeated cross-sectional data (Honaker and Gary, 2010). We considered a single country-level variable, *government effectiveness*, which we used as an

[10] According to Tang (2006), the NAICS-31 industry sector exhibits a more constant influx of competing products and faster change in production technologies than the NAICS-32 and NAICS-33 sectors (which exhibit similar values for these constructs). This industrial dynamism is largely linked to the lower level of knowledge resources required to enter these industries and improve the technologies currently in use in them, and hence to their lower level of industrial complexity.

exclusion restriction. Previous studies indicate that, although government effectiveness enhances the probability of patenting (Jiao, Koo, and Cui, 2015), it does not influence patent productivity in R&D-active firms (Somaya, Williamson, and Zhang, 2007). We obtained government effectiveness from World Bank indicators. The country values for this variable are reported in Table A1 (Appendix). Our analysis also included country and industry dummies.

3.4. Analytical Procedures

Following the method proposed by Vendrell-Herrero et al. (2022), our empirical approach corrected for two potential sources of bias. Firstly, PSM accounted for any firm-level heterogeneities (e.g., industry and size differences) arising due to the distinct characteristics of hybrid organizations. Second, a Heckman selection model was used to account for sample selection bias—i.e., how the causes leading to patenting influence patent productivity. Each topic is discussed in turn.

Propensity Score matching (PSM). To construct a control group (non-CE) that would be statistically equal in terms of size and industry to our treatment group (CE), we took advantage of the fact that our non-CE firm sample (890) was almost four times larger than our CE firm sample (263). We thus used PSM to construct pairs of CE and non-CE firms through the 1:1 nearest neighbor technique (Abadie and Imbens, 2016; Dehejia and Wahba, 2002). This process produced a matched subsample. Any analyses performed on this subsample would be more robust, as PSM would mitigate the effect of the endogeneity underlying any observed confounding factors. For consistency, all estimations were conducted on the matched sample. We elaborate further on the matching procedure in the results section.

The Heckman selection model. Patenting is a truncated variable, a variable type prevalent in studies using observational data. *Patents per employee* was truncated because, by construction, it contained a substantial proportion of zeros associated with non-patenting firms. This finding required detaching the decision to patent from patent productivity (Fischer and Leidinger, 2014). We thus tested our hypotheses using a Heckman selection model (Certo et al., 2016), which divided the analysis into two stages. First, the selection equation analyzed the decision to patent (Probit). Second, the outcome equation evaluated patent productivity—e.g., patents per employee—through the ordinary least squares (OLS) method.

The Heckman selection model had to satisfy two conditions. Firstly, the first stage had to include an exclusion restriction correlated with the decision to patent but not with patent productivity. As discussed earlier, government effectiveness can be a good exclusion restriction, as it correlates with patent propensity but not with patent productivity (Jiao et al., 2015; Somaya et al., 2007). Second, the Mill's Lambda—the term enabling joint estimation and measured through predicted probability to patent in the selection equation—had to be statistically significant in the second stage. We discuss the exclusion restriction and Mill's Lambda conditions, as well as the other relevant parameters, in the results section.

3.5. Estimation Strategy

The estimation strategy defines the different approaches to estimating the direct effect between CE participation and patent productivity (**H1**), the moderation effect of R&D environment on the relationship between CE and patenting (**H2**), and the three-way interaction involving CE, R&D environment, and industry complexity (**H3**) in Heckman's two-stage model. Each effect is discussed in turn.

Direct effect. To investigate the effect of CE participation on patent productivity, we estimated models based on Equation (1), where $patent_i$ is patents per employee, CE_i is the treatment variable (i.e., firms that are in the CE), $\boldsymbol{\Omega}_i$ includes a set of control variables, ϑ_s are the industry dummies, ϑ_c are the country dummies, and ε_i is the robust standard error term. In this model, **H1** would be supported if β_1 is negative.

$$Patent_i = \beta_0 + \beta_1 CE_i + \boldsymbol{\Omega_i} + \vartheta_s + \vartheta_c + \varepsilon_i \qquad (1)$$

Moderation effect. To incorporate the moderation effect of a country's relative level of R&D (**H2**), we considered an extended model as per Equation (2). This model considered *R&D/GDP* as the moderating variable. In this model, **H2** would be supported if β_3 is positive. For CE firms to converge toward the patent productivity of non-CE firms, the catch-up point ($-\beta_1/\beta_3$) could not exceed 4% (the highest R&D/GDP ratio observed globally).

$$Patent_i = \beta_0 + \beta_1 CE_i + \beta_2 R\&D_c + \beta_3 CE_i * R\&D_c + \boldsymbol{\Omega_i} + \vartheta_s + \vartheta_c + \varepsilon_i \qquad (2)$$

Three-way interaction effect. The industry-level effect was tested through a three-way interaction model (e.g., Dawson and Richter, 2006) that considered the NAICS-31 dummy (N31) along with *R&D/GDP* and *CE status* (see Equation 3), leaving the other two industries as a baseline group because they were considered to have similar levels of complexity. **H3** would be supported if β_6 is positive. To confirm that CE firms in the NAICS-31 industry sector (which has a lower degree of complexity than NAICS-32 and NAICS-33 [Tang, 2006]) can converge to the patenting levels of non-CE firms with low R&D/GDP ratios, the catch-up point [$-(\beta_1 + \beta_4) / (\beta_3 + \beta_6)$] had to be considerably lower in NAICS-31 than in NAICS-32/33 ($-\beta_1/\beta_3$).

$$Patent_i = \beta_0 + \beta_1 CE_i + \beta_2 R\&D_c + \beta_3 CE_i * R\&D_c + \beta_4 CE_i N31_s + \beta_5 N31_s * R\&D_c + \beta_6 CE_i * N31_s * R\&D_c + \boldsymbol{\Omega_i} + \vartheta_s + \vartheta_c + \varepsilon_i \qquad (3)$$

4. RESULTS

4.1. Descriptive Results

We started our descriptive analysis by examining the patenting distribution and industrial heterogeneities of the sampled firms. Table 2 exhibits patent behavior, productivity, and success by industry. From this data, we observe that 49.26% of firms had at least one patent. We also observe that the medians of *patent applications* and *patents granted* were 10 and 6, respectively. This result translates into an average success rate (i.e., percentage of patent applications granted) of 63.46%. Analysis of the industrial heterogeneities shows that firms operating in NAICS-31 have lower propensity to patent than those in other manufacturing industries. 27.74% of NAICS-31 firms had had at least one patent granted, and firms in the NAICS-32/33 industry sectors had roughly double this percentage (~52%). This difference persisted when we analyzed the medians of patent applications and patents granted. Our NAICS-31 sample firms had had four times fewer patent applications (medians: 3 vs. 13) and patents granted (medians: 2 vs. 8) than firms in other manufacturing industries. This industrial heterogeneity in patenting is consistent with the findings of previous research (Pavitt, 1982). Interestingly, these differences do not translate into success rate. All our sample industry sectors had an average success rate of 60%-70%. This means that, on average, roughly two thirds of their patent applications were granted and that this percentage transcended industry boundaries.

- Insert Table 2 here -

We continued our descriptive analysis by examining the differences across the treatment (CE) and control groups (non-CE). In Table 3, we report the mean values obtained for patent behavior, patenting productivity, number of workers, labor productivity, and activity sector by CE status. CE firms are less likely to patent than are non-CE firms. We found that 51.4% of our sample's non-CE firms had patented, compared to only 41.4% of the CE firms, and this difference was significant at the 1% level (p-value = 0.003). Analysis of patenting productivity showed that the CE firms had submitted fewer patent applications (0.061 vs. 0.403) and had fewer patents granted (0.029 vs. 0.187) per employee than non-CE firms. This difference was found to be statistically significant at the 10% level (p-value = 0.089) for patents granted, and to be close to significant for patent applications (p-value = 0.102). This evidence is in line with **H1**. Although labor productivity (US$211,000 per employee vs. US$218,000 per employee) and hourly pay (US$32.05 vs. US$33.40) were found to be nearly the same in our sample CE and non-CE firms, the firms' respective numbers of employees differed. On average, our sample CE firms had 89.67 (776.90 - 687.23) fewer employees than our non-CE firms. This difference in firm size was not statistically significant, but the p-value was not far from the 10% threshold (p-value =0.157). Industrial composition was also found to differ across our sample CE and non-NCE firms, although both CE and non-CE firms were concentrated mostly in NAICS-33 (65.7% and 58.2%, respectively) and less in NAICS-31 (12.7% and 15.9%) and NAICS-32 (21.6% and 25.8%). The differences were statistically significant.

- Insert Table 3 here –

4.2. Matching Strategy

The heterogeneities in industrial composition and firm size observed between CE and non-CE firms could have affected the robustness of our results. They could have been a source of endogeneity in the model as confounding factors, explaining both CE status and patenting. To mitigate this concern, we performed PSM,[11] obtaining the related scores by estimating a logit

[11] Since we used a Heckman selection model in our estimation strategy, we could not use other matching strategies that weight with (e.g., Kernel, Radius) or without (coarsened exact matching) propensity scores.

regression with a binary dependent variable indicating whether each firm was CE or non-CE. We first ensured common support by verifying that none of our sample CE firms had a propensity score higher than the maximum or lower than the minimum non-CE firms' propensity scores (Dehejia and Wahba, 2002). In our PSM procedure, we employed the 1:1 nearest-neighbor method without replacement and with a caliper of 0.01 (Abadie and Imbens, 2016). The resulting sample consisted of 526 firms equally distributed between the treatment (CE) and control (non-CE) groups. Of these firms, 234 were found to have at least one patent (44.4%).

Table 4 presents the results of the matching procedure and the mean differences in values before and after matching. All mean differences found to be significant before matching became non-significant afterwards. Moreover, average reduction bias was 72.9%. The difference in number of employees was reduced to 69.70 (from 89.67), implying a 22.2% bias reduction. Bias reduction is almost complete in industry sectors, as it approaches 100% across the board. Additionally, the Kolmogorov-Smirnov test showed that the differences in propensity score distributions observed before matching (p-value = 0.02) were no longer significant afterward (p-value = 1.00).

- Insert Table 4 here -

4.3. Hypothesis Testing

The results of the Probit regression (Heckman's first stage) are shown in Column 1 of Table 5, which reports the percentage of correctly predicted cases in which the cut-off level equaled the average in patenting (44.4%). The model fit well, correctly predicting 79.5% of a firm's patenting decisions. The pseudo-R^2 value was 0.136, and the C-statistic (or LROC) 0.737, above the commonly accepted 0.7 threshold. Considering that the rest of the variables remained constant (et ceteris paribus), CE led to a decrease of 6.8 percentage points in a firm's likelihood to patent. This result was statistically significant at the 1% level (p-value = 0.000).

- Insert Table 5 here -

From the Probit model, we estimated Mill's Lambda, which was introduced in Heckman's second stage to control for selection bias. Importantly, Mill's Lambda was positive and significant in all outcome equation models (Columns 2-7 of Table 5), confirming evidence of selection bias (Heckman, 1979). The correlation between Mill's Lambda and the independent variable in the second stage (CE status) was 0.18, below the threshold of 0.3 proposed by Certo et al. (2016). As discussed earlier, we introduced government effectiveness as the exclusion restriction. As expected, this variable was found to be positive and statistically significant (p-value =0.000) in the Probit but not to correlate with measures of patent productivity (p-value = 0.185). As a whole, the evidence suggested that the Heckman model was well-specified.

In the second stage, a series of OLS were estimated for the sample of patenting firms (Table 5, Columns 2 to 7). The estimated models were found to have a good fit, with the R^2 ranging between 0.55 and 0.57. This means that the model explained roughly 55% of the variance of the dependent variable. **H1** proposed that CE firms would have lower patent productivity than their non-CE counterpart. We tested this relationship for two measures of patent productivity—*patent applications per employee* (Column 2) and *patents granted per employee* (Column 5). On average, our sample CE firms had filed 0.266 fewer patent applications per employee and had 0.137 fewer patents granted per employee than their non-CE counterparts. This result was significant at the 5% level (p-values equal to 0.024 and 0.011, respectively), supporting **H1**.

H2 postulated that, in high national R&D environments, CE firms would achieve the same level of patent productivity as non-CE firms. For this to occur, R&D/GDP had to moderate the relationship between CE and patent productivity positively, corroborated by a positive interaction term between CE and R&D/GDP (β_3) (Equation 2). The interaction term was positive for both patent applications (Column 3) and patents granted (Column 5). The result was significant at the 10% level for patents granted (p-value = 0.0628) and at the 5% level for patent applications (p-value= 0.0490). The second condition was that the catch-up point ($-\beta_1/\beta_3$) had to be below established world-leading benchmarks (R&D/GDP < 4%). The left portion of the diagram in Figure 2 represents graphically the moderation effect of R&D/GDP for the full sample, showing the catch-up point as 7.02% for patents granted and 8.57% for patent applications. This value above the proposed threshold suggests that firms devoting efforts to GCs should be located in highly competitive and innovative environments and that, at the current rates of investment in R&D, they would still not be able to converge fully with the patent productivity of non-CE firms.

- Insert Figure 2 here –

H3 postulated that CE firms in high national R&D environments and low-complexity industries would outperform non-CE firms in terms of patent productivity. To test this hypothesis, we estimated a three-way interaction effect. The results presented in Columns 4 and 7 of Table 5 show that the three-way interaction term between CE status, R&D environment, and NAICS-31 were positive and highly significant for patent applications (β_6 = 0.3793, p-value = 0.005) and patents granted (β_6 = 0.1779, p-value = 0.0128). This result shows that the catch-up point was much lower for low-tech industries (e.g., the processing industry). As the right portion of Figure 2 shows, CE firms operating in the processing industries reached the same level of patents granted (patent applications) as non-CE firms when R&D/GDP equals 1.95% (1.94%).

The catch-up point is therefore considerably lower than that for the full sample (7.02% and 8.57% respectively) and for firms operating in more technologically complex industries (10.23% and 7.82%, respectively), fully supporting **H3**. Furthermore, in high R&D environments, CE outperform non-CE firms. When R&D/GDP = 4%, CE firms exhibit 0.42 (0.85) more patents granted (patents applications) per employee than non-CE firms.

4.4. Structuring the Results for Patenting Firms

Figure 3 graphically summarizes the differences in patent productivity (P) between CE and non-CE patenting firms as a function of the different contextual conditions analyzed. **H1** refers to the default case and compares CE and non-CE firms in a unidimensional approach. When no contextual conditions are considered, non-NCE firms outperform CE firms. Important nuances begin to appear, however, when the national R&D environment is introduced (**H2**). In this case, we took a two-dimensional approach and found that CE firms can reach the same level of patent productivity as non-CE firms in the presence of very high R&D/GDP ratios. More importantly, when we added the industry-level dimension, we took a three-dimensional approach and identified a contextual condition in which CE firms can outperform non-CE firms in terms of patent productivity—that is, when CE firms operate in low complexity industries and moderate-to-high national R&D investment environments (**H3**). This summary demonstrates that CE firms' pursuit of RI may also lead to good innovation performance in the presence of adequate contextual conditions.

- Insert Figure 3 here –

5. DISCUSSION AND CONCLUSION

5.1. Theoretical Contributions and Implications for Research

Our study makes three theoretical contributions to innovation management within the topic of GCs by: (1) articulating the characteristics of RI firms that pursue GCs by utilizing hybrid organization theory; (2) examining macro- and industry-level factors such as national R&D environment and industrial technological complexity that enable a more efficient route to GC attainment; and (3) by providing rare empirical evidence that shows a somewhat counterintuitive negative relationship between orientation towards GCs and innovation performance. We now elaborate further on each of these contributions.

First, our research contributes to achieving a nuanced understanding of RI firms and innovation performance (Arslan and Tarakci, 2020; Blok and Lemmens, 2015). From an organizational perspective, the substantial prevalence of the UN's SDGs in predicting firm activities and the somewhat less-contextualized understanding of innovation performance in the extant literature necessitate a theoretical anchor suited to capturing the nuances and motivations of firms that pursue RI in relation to the SDGs (George et al., 2016). Our framework and findings provide insight into the characteristics of RI firms and their impact on innovation outcomes. By juxtaposing RI and organizational hybridization (e.g., Battilana and Lee, 2014; Jay, 2013), our findings reveal a salient condition that underpins the innovation performance of RI firms by highlighting the role played by hybridity (Vassallo et al., 2019). Our findings advance the RI management literature by demonstrating that the tension embedded in hybrid organizations may serve as a trigger, forcing RI firms to sacrifice their innovation productivity. The restrictions on behaviors imposed by the European Commission from 1998 to 2004 arguably diminished RI patent productivity (WIPO, 2019). In this vein, restricting the funding of a specific research area can reduce scientific output across the entire research area. Such reduction occurred in 2001, when the US cut the resources for research in the specific field of human embryonic stem cells, reducing patents across the entire field of stem cell research (Blomfield and Vakili, 2022). We thus contribute to attaining nuanced understanding of RI firms' innovation performance by articulating the contextual characteristics of institutional environments, RI, and hybrid organizations. Our study may significantly expand understanding of GCs and innovation by highlighting the influence of institutional environments, in conjunction with the nature of RI firms, characterized as hybrid organizations. From a theoretical standpoint, our paper advances the literature on GCs and RI by articulating how and why the characteristics of hybrid organizations impact innovation performance.

Second, our study contributes to the GC literature from a multi-level perspective by highlighting the role of the innovation environments in which firms operate as an element important for solving society's technical and scientific problems. To date, research on GCs has tended to focus on either the organizational or the institutional levels. With some exceptions (e.g., Grodal and O'Mahony, 2017), however, it has failed to uncover the cross-level interactions from a multi-level perspective. Our analysis in the context of the CE suggests specifically that high national investment in R&D can mitigate any patent productivity differences between RI and non-RI firms, highlighting the importance of strong national R&D systems in tackling GCs. Our results demonstrate that projects devoted to GC resolution are more likely to succeed in the presence of more-developed national R&D systems. The US spacecraft industry exemplifies this success, in which SpaceX and Rocket Lab have entered into public-private partnerships that are developing projects to establish human communities in space (Pessoa, 2021). Our evidence thus suggests that stronger NISs can serve as a practical solution to align public interests and private incentives by providing remedies suited to making RI firms more innovative. Furthermore, our study joins the recent transformative change frame for innovation policy (Schot and Steinmueller, 2018) by investigating the role of the R&D environment in different industrial contexts (Agarwal et al., 2021). In this new transformative frame, specific sectors—such as those that characterize transformation through RI (healthcare, eco-friendly production)—are crucial to tackling GCs. This might not be a straightforward process because transformational industries tend to be more technologically complex and we have shown that RI firms will be able to achieve the innovation performance of non-RI firms under such industrial contextual conditions if and only if the pertinent national R&D environments are global leaders. This finding accentuates the need to champion a new regulatory model for science and technology that focuses on innovation guided by societal objectives.

Finally, our study extends the recent discussion on societal GCs (Brammer et al., 2019) by articulating the importance of CE in innovation performance settings. Our analysis reveals that RI firms patent less than non-RI firms, supporting existing research (Hargadon, 2003) by suggesting that breakthrough innovations needed to overcome GCs are not developed as frequently as desired. This result helps to advance the interplay between GCs, public-private sector misalignment, and disruptive innovation. The role of innovation in tackling GCs is gaining increasing attention, from the perspective of both process (Gittelman, 2016) and context (Mowery, 2012).

Our findings reveal one salient institutional characteristic that hinders GC attainment: institutional rigidity (i.e., the status quo criteria imposed by institutions). This finding further contributes to the GC debate, opened by Grodal and O'Mahony (2017), on whether public interventions are effective for GC resolution. We find that institutional rigidity hinders the motivation and practicality of innovation activities and can thus have negative consequences for innovation performance. This finding aligns with the behaviors of pioneer COVID-19 vaccine developers such as Pfizer, whose CEO refused government funding for development to keep workers focused on the scientific challenges (Bump, 2020). We believe that our conceptualization of institutional rigidity can contribute to the institutional theory community by providing a novel concept, like that of institutional fragility (Shi et al, 2017) or institutional escapism (Witt and Lewin, 2007). In so doing, we expect our research to draw the attention of institutional scholars, and to showcase both how innovation studies can advance institutional theory and how institutional theory can expand GC research (e.g., Gümüsay et al., 2020).

5.2. Implications for Practice and Policy

Our study has several implications for managers and policymakers. First, it has implications for those managers involved in RI firms and innovation. Highlighting that RI firms patent less than non-RI firms, our findings suggest that resource-constrained companies should not focus on single objectives, however honorable. Individual companies cannot afford heavy investments with the high uncertainty and intricacy involved in addressing GCs such as climate change or global health crises (Liu, Lee, and Lee, 2020). Solving humankind's most significant challenges necessitates collaborations and partnerships involving external factors and requiring decades to develop. Our findings therefore suggest that hybrid organizations should diversify their projects and not systemically reject those that have no societal impact. We suggest that hybrid organizations consider diversification approaches through strategic alliances and/or open innovation processes (Bustinza, Opazo-Basaez, and Tarba, 2022; He et al., 2020). Accessing the knowledge and resources possessed by other companies may provide opportunities to diversify while embarking on very ambitious projects (e.g., overcoming GCs).

In business and management studies, RI constitutes an important area of research with important broader implications for business and management education. The Responsible Research for Business and Management (RRBM) community, for example, has attracted increasing attention in both research and policy with their landmark Position Paper Vision 2030 embracing the philosophy and practices of responsible research. The global trend of responsible business and management education also gained momentum with the signature Responsible Business Education Awards, sponsored by the *Financial Times* in 2022. Out of the award's full shortlist, only one study addresses how product transformation salience increases recycling, a result that resonates with our research findings on GCs and RI in the context of recycling (e.g., CE).

As for policy implications, governments around the globe must engage in collective endeavors to tackle GCs. Establishing new transformative innovation systems requires changing systems marked by path dependencies (Schot and Steinmueller, 2018). Governments would gain legitimacy by intervening to influence the developmental trajectory of innovation aimed at addressing GCs such as environmental protection (Hekkert et al., 2020). The Horizon Europe framework has strengthened the importance of the CE and its role in dealing with GCs and sustainable development. Cluster 4 specifically focuses on industrial and technological aspects and raw material supply, including lower environmental footprint construction modularization, digital technologies, circularity, and advanced materials. Cluster 6 targets systemic regional and local (i.e., territorial) circular and bioeconomy with a cross-sector systemic approach that includes civil society and covers the whole value chain, including technological, business, governance, and social innovation aspects. The COP26 climate conference, held the first week of November 2021 in Glasgow, drew significant attention and debate from world leaders, policymakers, and climate activists. It is widely acknowledged that climate change is close to its historical turning point. Individuals, organizations, and societies across both developed and emerging economies must take serious action and engage in collaborative efforts to deal with climate change. If they do not, humanity faces a life-threatening crisis with potentially devastating consequences.

Our study sustains legitimation of more developed NISs to enable RI firms' efforts in innovation performance to equal those of non-RI firms. Moreover, the study shows that one need not adhere to institutional rigidity when missions and their objectives are clearly defined (Hekkert et al., 2020). To enable a wider range of actors to develop innovative patents properly, most developed NISs should be less rigid in defining objectives related to GCs. Furthermore, the governments of more-developed nations should stimulate increases in public and private R&D expenditure. In less-developed nations, in contrast, governments might consider attracting large MNEs capable of establishing R&D labs and centers to counter these nations' less-developed national R&D environments (Collinson and Liu, 2019). Such nations should focus their GC strategy on low-tech industries (e.g., the food processing industry) that require considerably lower levels of national R&D investment to equalize the innovation performance of RI and non-RI firms.

5.3. Limitations and Future Research Avenues

Our research has some limitations but defines several potentially fruitful research directions that can build on our initial attempt to investigate GCs and innovation performance through the theoretical lens of organizational hybridity. First, our research was based on the ORBIS database, which provided some advantages (such as identification of CE firms as an example of RI organizations) but also some limitations (e.g., some firms may not have declared their secondary sectors, limiting our sample's size and our capacity to identify hybrid organizations). With more firms declaring their secondary sectors voluntarily (or due to legal requirements), this method could produce larger samples and more opportunities to construct treatment groups through secondary industries. Moreover, while ORBIS IP provided information on the numbers of patent applications and patents granted, we could not determine the quality (e.g., citations, revenue generation) or age of the patents. Future research conducted using other data sources could unravel how these factors might affect the results. Second, our empirical setting focused on climate change as a societal GC through quantitative analysis and highlighted how an RI firm's dual mission influences its innovation performance and its interaction with the R&D environment. Status variables are used primarily in innovation management; for instance, Community Innovation Surveys are designed based on them, and several papers using this type of data have measured product/process/open innovation as a dichotomy (status) rather than as a continuous (productivity) measure (e.g., Cricelli et al., 2016; Tsinopoulos et al., 2018). Although we were unable to observe CE productivity,[12] this shortcoming could be a beneficial research avenue for future research using other empirical strategies. We recommend that further research adopt a comparative approach by investigating other GCs. For instance, prior research has demonstrated the impact of international trade agreements on healthcare challenges in low-income countries (Vakili and McGahan, 2016). A nuanced understanding of how GCs influence innovation thus awaits future scholarly inquiry, as well as the related paradox of ambidexterity, whereby firms must simultaneously perform exploratory and exploitative activities (Cunha et al.,

[12] We believe it would be very difficult to identify activities related to GCs through secondary databases, and nearly impossible to capture them in a multi-country setting through primary data. Our secondary industry approach is a smart empirical strategy for observing CE status.

2019), illustrating the prevalence of organizational hybridity. We believe that advancing understanding of the tensions between social and private goals as a management paradox is a promising future research endeavor. Third, future research could extend our focus on manufacturing firms by considering services and the digital economy (Del Giudice et al., 2021). As to the global rise of the servitization of manufacturing firms (Baines et al., 2017), a servitization perspective linked to RI firms in the manufacturing sector could yield significant insights into the mechanisms governing organizational hybridity (Bustinza et al., 2019). Conceptually, product-service duality may also be understood as a form of hybridity. Hybrid product-service offerings can present both opportunities and challenges for RI firms in their pursuit of servitization. As such, they may generate enhanced understanding of the complex interactions between GCs, RI, and organizational hybridity.

To conclude, this article presents our investigation of the innovation performance of RI firms to tackle GCs on the road to effective achievement of the UN's SDGs through RI. In the context of the CE, our analysis revealed that RI firms tend to have lower patenting productivity than non-RI firms, highlighting the influence of characteristics of organizational hybridity, disruptive technology, and institutional rigidity. Our findings also suggest that high levels of national R&D investment can mitigate and even reverse the negative relationship between RI firms and patent productivity, supporting arguments for the importance of the national R&D environment when dealing with GCs and innovation. Further, the findings indicate that a nuanced understanding of the role played by the R&D environment and industry technological complexity is important to advancing research on GCs and RI from a multi-level perspective. More specifically, our findings contribute to the GC and RI literature by showing that interventions can be more effective in the presence of more-developed national R&D environments.

References

Abadie, A., and G. W. Imbens. 2016. "Matching on the Estimated Propensity Score." *Econometrica* 84 (2): 781–807.

Abbott, J. K., and U. R. Sumaila. 2019. "Reducing Marine Plastic Pollution: Policy Insights from Economics." *Review of Environmental Economics and Policy* 13 (2): 327–36.

Acs, Z. J., Audretsch, D. B., Lehmann, E. E., and G. Licht. 2017. "National Systems of Innovation." *The Journal of Technology Transfer* 42 (5): 997–1008.

Agarwal, R., Kim, S., and M. Moeen (2021). "Leveraging Private Enterprise: Incubation of New Industries to Address the Public Sector's Mission-oriented Grand Challenges". *Strategy Science* 6 (4): 385–411.

Alcorta, L., and W. Peres. 1998. "Innovation Systems and Technological Specialization in Latin America and the Caribbean." *Research Policy* 26 (7–8): 857–81.

Andries, P., and D. Faems. 2013. "Patenting Activities and Firm Performance: Does Firm Size Matter?" *Journal of Product Innovation Management* 30 (6): 1089–98.

Arslan, B., and M. Tarakci. 2020. "Negative Spillovers across Partnerships for Responsible Innovation: Evidence from the 2014 Ebola Outbreak." *Journal of Management Studies* 59 (1):126–62.

Artz, K. W., Norman, P. M., Hatfield, D. E., and L. B. Cardinal. 2010. "A Longitudinal Study of the Impact of R&D, Patents, and Product Innovation on Firm Performance." *Journal of Product Innovation Management* 27 (5): 725–40.

Autio, E., Kenney, M., Mustar, P., Siegel, D., and M. Wright. 2014. "Entrepreneurial Innovation: The Importance of Context." *Research Policy* 43 (7): 1097–1108.

Baines, T., Bigdeli, A. Z., Bustinza, O. F., Shi, V. G., Baldwin, J., and K. Ridgway. 2017. "Servitization: Revisiting the State-of-the-art and Research Priorities." *International Journal of Operations and Production Management* 37 (2): 256–78.

Battilana, J., and M. Lee. 2014. "Advancing Research on Hybrid Organizing: Insights from the Study of Social Enterprises." *Academy of Management Annals* 8 (1): 397–441.

Bauwens, T., Huybrechts, B., and F. Dufays. 2020. "Understanding the Diverse Scaling Strategies of Social Enterprises as Hybrid Organizations: The Case of Renewable Energy Cooperatives." *Organization & Environment* 33 (2): 195–219.

Bendig, D., Foege, J. N., Endriß, S., and M. Brettel. 2020. "The Effect of Family Involvement on Innovation Outcomes: The Moderating Role of Board Social Capital." *Journal of Product Innovation Management* 37 (3): 249–72.

Berrone, P., Gelabert, L., Massa-Saluzzo, F., and H. E. Rousseau. 2016. "Understanding Community Dynamics in the Study of Grand Challenges: How Nonprofits, Institutional Actors, and the Community Fabric Interact to Influence Income Inequality." *Academy of Management Journal* 59 (6): 1940–64.

Blind, K., Edler, J., Frietsch, R. and U. Schmoch. 2006. "Motives to Patent: Empirical Evidence from Germany." *Research Policy* 35 (5): 655–72.

Blok, V,, and P. Lemmens. 2015. "The Emerging Concept of Responsible Innovation. Three Reasons Why It Is Questionable and Calls for a Radical Transformation of the Concept of Innovation." In *Responsible innovation 2: Concepts, approaches, and applications*, edited by Koops B.J., Oosterlaken I., Romijn H., Swierstra T., van den Hoven J., 19–35. Cham, UK: Springer.

Blomfield, M., and K. Vakili. 2022. "Incentivizing Effort Allocation Through Resource Allocation: Evidence from Scientists' Response to Changes in Funding Policy." *Organization Science*. Published: 15 February 2022, https://doi.org/10.1287/orsc.2021.1565

Brammer, S., Branicki, L., Linnenluecke, M., and T. Smith. 2019. "Grand Challenges in Management Research: Attributes, Achievements, and Advancement." *Australian Journal of Management* 44 (4): 517–33.

Bryant, M., and V. Higgins. 2019. "Managing the Grand Challenge of Biological Threats to Food Production: The Importance of Institutional Logics for Managing Australian Biosecurity." *Australian Journal of Management* 44 (4): 534–50.

Buckley, P. J., Doh, J. P., and M. H. Benischke. 2017. "Towards a Renaissance in International Business Research? Big Questions, Grand Challenges, and the Future of IB Scholarship." *Journal of International Business Studies* 48 (9): 1045–64.

Buehler, M., Iagnemma, K., and S. Singh. 2007. *The 2005 DARPA grand challenge: The great robot race*. Berlin: Springer.

Bump, P. 2020. "No, Pfizer's Apparent Vaccine Success Is Not a Function of Trump's 'Operation Warp Speed." Accessed July 15, 2021. *The Washington Post* (online posted Monday, November 9, 2020).

Burger, M., Stavropoulos, S., Ramkumar, S., Dufourmont, J., and F. van Oort. 2019. "The Heterogeneous Skill–base of Circular Economy Employment." *Research Policy* 48 (1): 248–61.

Bustinza, O. F., Gomes, E., Vendrell-Herrero, F., and T. Baines. 2019. "Product–service Innovation and Performance: The Role of Collaborative Partnerships and R&D Intensity." *R&D Management* 49 (1): 33–45.

Bustinza, O. F., Opazo–Basaez, M., and S. Tarba. 2022. "Exploring the Interplay between Smart Manufacturing and KIBS Firms in Configuring Product-service Innovation Performance." *Technovation* 118: 102258.

Cainelli, G., D'Amato, A., and M. Mazzanti. 2020. "Resource Efficient Eco-Innovations for a Circular Economy: Evidence from EU Firms." *Research Policy* 49 (1): 103827.

Carbonell, P., and A. I. Rodriguez. 2006. "Designing Teams for Speedy Product Development: The Moderating Effect of Technological Complexity." *Journal of Business Research* 59 (2): 225–32.

Castellacci, F., and C. M. Lie. 2015. "Do the Effects of R&D Tax Credits Vary Across Industries? A Meta-regression Analysis." *Research Policy* 44 (4): 819–32.

Certo, S. T., Busenbark, J. R., Woo, H., and M. Semadeni. 2016. "Sample Selection Bias and

Heckman Models in Strategic Management Research." *Strategic Management Journal* 37 (13): 2639–57.

Chemmanur, T. J., Cheng, Y., and T. Zhang. 2013. "Human Capital, Capital Structure, and Employee Pay: An Empirical Analysis." *Journal of Financial Economics* 110 (2): 478–502.

Collinson, S., and Y. Liu. 2019. "Recombination for Innovation: Performance Outcomes from International Partnerships in China." *R&D Management* 49 (1): 46–63.

Cricelli, L., Greco, M., and M. Grimaldi. 2016. "Assessing the Open Innovation Trends by Means of the Eurostat Community Innovation Survey." *International Journal of Innovation Management* 20 (03): 1650039.

Cunha, M. P., Fortes, A., Gomes, E., Rego, A., and F. Rodrigues. 2019. "Ambidextrous Leadership, Paradox and Contingency: Evidence from Angola." *The International Journal of Human Resource Management* 30 (4): 702–27.

Dawson, J. F., and A. W. Richter. 2006. "Probing Three-way Interactions in Moderated Multiple Regression: Development and Application of a Slope Difference Test." *Journal of Applied Psychology* 91 (4): 917–26.

Dehejia, R. H., and S. Wahba. 2002. "Propensity Score-matching Methods for Nonexperimental Causal Studies." *Review of Economics and Statistics* 84 (1): 151–61.

Del Giudice, M., Scuotto, V., Papa, A., Tarba, S., Bresciani, S., and M. Warkentin. 2021. "A Self-tuning Model for Smart Manufacturing SMEs: Effects on Digital Innovation." *Journal of Product Innovation Management* 38 (1): 68–89.

European Commission. 2014. "Responsible Research and Innovation: Europe's ability to respond to societal challenges." *Publications Office.*

Fabrizi, A., Guarini, G., and V. Meliciani. 2016. "Public Knowledge Partnerships in European Research Projects and Knowledge Creation across R&D Institutional Sectors." *Technology Analysis & Strategic Management* 28 (9): 1056–72.

Ferraro, F., Etzion, D., and J. Gehman. 2015. "Tackling Grand Challenges Pragmatically: Robust Action Revisited." *Organization Studies* 36 (3): 363–90.

Fischer, T., and J. Leidinger. 2014. "Testing Patent Value Indicators on Directly Observed Patent Value: An Empirical Analysis of Ocean Tomo Patent Auctions." *Research Policy* 43 (3): 519–29.

George, G., Howard-Grenville, J., Joshi, A., and Laszlo T. 2016. "Understanding and Tackling Societal Grand Challenges through Management Research." *Academy of Management Journal* 59 (6): 1880–95.

Genus, A., and A. Stirling. 2018. "Collingridge and the Dilemma of Control: Towards Responsible and Accountable Innovation." *Research Policy* 47 (1): 61–69.

Gittelman, M. 2016. "The Revolution Re-visited: Clinical and Genetics Research Paradigms and the Productivity Paradox in Drug Discovery." *Research Policy* 45 (8): 1570–85.

Goel, R. K., Göktepe-Hultén, D., and C. Grimpe. 2017. "Who Instigates University–Industry

Collaborations? University Scientists versus Firm Employees." *Small Business Economics* 48 (3): 503–24.

Gomes, E., Bustinza, O. F., Tarba, S., Khan, Z., and M. Ahammad. 2019. "Antecedents and Implications of Territorial Servitization." *Regional Studies* 53 (3): 410–23.

Grodal, S., and S. O'Mahony. 2017. "How Does a Grand Challenge Become Displaced? Explaining the Duality of Field Mobilization." *Academy of Management Journal* 60 (5): 1801–27.

Gu, Y., and L. Zhang. 2017. "The Impact of the Sarbanes-Oxley Act on Corporate Innovation." *Journal of Economics and Business* 90: 17–30.

Gümüsay, A. A., Claus, L., and J. Amis. 2020. "Engaging with Grand Challenges: An Institutional Logics Perspective." *Organization Theory* 1 (3): 1–20.

Hargadon, A. 2003. *How breakthroughs happen: The surprising truth about how companies innovate*. Cambridge, MA: Harvard Business School Press.

Hargadon, A., and Y. Douglas. 2001. "When Innovations Meet Institutions: Edison and the Design of the Electric Light." *Administrative Science Quarterly* 46 (3): 476–501.

He, Q., Meadows, M., Angwin, D., Gomes, E., and J. Child. 2020. "Strategic Alliance Research in the Era of Digital Transformation: Perspectives on Future Research." *British Journal of Management* 31 (3): 589–617.

Heckman, J. J. 1979. "Sample Selection Bias as a Specification Error." *Econometrica* 47 (1): 153–61.

Hekkert, M. P., Janssen, M. J., Wesseling, J. H., and S. O. Negro. 2020. "Mission-oriented Innovation Systems." *Environmental Innovation and Societal Transitions* 34: 76–79.

Hoffman, A. J. 1999. "Institutional Evolution and Change: Environmentalism and the U.S. Chemical Industry." *Academy of Management Journal* 42 (4): 351–71.

Honaker, J., and G. King. 2010. "What to Do about Missing Values in Time-series Cross-section Data." *American Journal of Political Science* 54 (2): 561–81.

House Committee on Science, Space, and Technology. 2011. NASA's Commercial Crew Development Program: Accomplishments & Challenges. Accessed September 1, 2021. https://www.govinfo.gov/content/pkg/CHRG-112hhrg70800/html/CHRG-112hhrg70800.htm

Jay, J. 2013. "Navigating Paradox as a Mechanism of Change and Innovation in Hybrid Organizations." *Academy of Management Journal* 56 (1): 137–59.

Jiao, H., Koo, C. K., and Y. Cui. 2015. "Legal Environment, Government Effectiveness and Firms' Innovation in China: Examining the Moderating Influence of Government Ownership." *Technological Forecasting and Social Change* 96: 15–24.

Jurgilevich, A., Birge, T., Kentala-Lehtonen, J., Korhonen-Kurki, K., Pietikäinen, J., Saikku, L., and H. Schösler. 2016. "Transition towards Circular Economy in the Food System." *Sustainability* 8 (1): 69.

Kaiser, R., and H. Prange. 2004. "The Reconfiguration of National Innovation Systems: The Example of German Biotechnology." *Research Policy* 33 (3): 395–408.

Kline, P., Petkova, N., Williams, H., and O. Zidar. 2019. "Who Profits from Patents? Rent-Sharing at Innovative Firms." *The Quarterly Journal of Economics* 134 (3): 1343–1404.

Koschmann, M. A., Kuhn, T. R., and M. D. Pfarrer. 2012. "A Communicative Framework of Value in Cross–sector Partnerships." *Academy of Management Review* 37 (3): 332–54.

Kroeger, A., and C. Weber. 2014. "Developing a Conceptual Framework for Comparing Social Value Creation." *Academy of Management Review* 39 (4): 513–40.

Kulikowski, C. A. 2021. "Pandemics: Historically Slow "Learning Curve" Leading to Biomedical Informatics and Vaccine Breakthroughs." *Yearbook of Medical Informatics,* 30 (01): 290-301.

Lee, R. P., Spanjol, J., and S. L. Sun. 2019. "Social Innovation in an Interconnected World: Introduction to the Special Issue." *Journal of Product Innovation Management* 36 (6): 662–70.

Liu, K. 2014. "Human Capital, Social Collaboration, and Patent Renewal within US Pharmaceutical Firms." *Journal of Management* 40 (2): 616–36.

Liu, K., Arthurs, J., Cullen, J., and R. Alexander. 2008. "Internal Sequential Innovations: How Does Interrelatedness Affect Patent Renewal?" *Research Policy* 37 (5): 946–53.

Liu, Y. 2020. "The Micro-foundations of Global Business Incubation: Stakeholder Engagement and Strategic Entrepreneurial Partnerships." *Technological Forecasting and Social Change* 161: 120294.

Liu, Y., and Q. Huang. 2018. "University Capability as a Micro-foundation for the Triple Helix Model: The Case of China." *Technovation* 76–77: 40–50.

Liu, Y., Lee, J. M., and C. Lee. 2020. "The Challenges and Opportunities of a Global Health Crisis: The Management and Business Implications of COVID-19 from an Asian Perspective." *Asian Business & Management* 19 (3): 277–97.

Mair, J., Mayer, J., and E. Lutz. 2015. "Navigating Institutional Plurality: Organizational Governance in Hybrid Organizations." *Organization Studies* 36 (6): 713–39.

Markides, C. 2006. "Disruptive Innovation: In Need of Better Theory." *Journal of Product Innovation Management* 23 (1): 19–25.

Mowery, D. C. 2012. "Defense-related R&D as a Model for "Grand Challenges" Technology Policies." *Research Policy* 41 (10): 1703–15.

Mueller, S. M., Messina, C. D., and T, J. Vyn. 2019. "Simultaneous Gains in Grain Yield and Nitrogen Efficiency over 70 years of Maize Genetic Improvement." *Scientific Reports* 9 (1): 1–8.

Nelson, R. R. 1993. *National innovation systems: A comparative analysis*. New York, NY: Oxford University Press.

Nelson, R. R., and S. G. Winter. l982. *An evolutionary theorv of economic change*. Cambridge, MA: Harvard University Press.

Noble, C. H., and J. Spanjol. 2020. "How are We Faring? Reflections on Coronavirus and its Effects on the Innovation Management Scholarly Community." *Journal of Product Innovation Management* 37 (6): 474–82.

OECD. 2021. "OECD Employment Outlook." Accessed July 8, 2021. https://www.oecd-ilibrary.org/employment/oecd-employment-outlook_19991266

Opazo-Basáez, M., Vendrell-Herrero, F., and O. F. Bustinza. 2018. "Uncovering Productivity Gains of Digital and Green Servitization: Implications from the Automotive Industry." *Sustainability* 10 (5): 1524.

Pavitt, K. 1982. "R&D, Patenting and Innovative Activities: A Statistical Exploration." *Research Policy* 11 (1): 33–51.

Pessoa, J. B. (2021). "Space Age: Past, Present and Possible Futures." *Journal of Aerospace Technology and Management* 13: 3421.

Pieroni, M. P., McAloone, T. C. and D. C. A. Pigosso. 2019. "Business Model Innovation for Circular Economy and Sustainability: A Review of Approaches." *Journal of Cleaner Production* 215: 198–216.

Pooler, M. 2021. "Plant-based Meat Hopefuls Square up to Brazil's Beef Giants." *Financial Times*. Accessed July 21, 2021. https://www.ft.com/content/8f80017b-56b7-4ea2-bdb7-059b5fd9f6a6

Scherer, A. G., and C. Voegtlin. 2020. "Corporate Governance for Responsible Innovation: Approaches to Corporate Governance and their Implications for Sustainable Development." *Academy of Management Perspectives* 34 (2): 182–208.

Schot, J., and W. E. Steinmueller. 2018. "Three Frames for Innovation Policy: R&D, Systems of Innovation and Transformative Change." *Research Policy* 47 (9): 1554–67.

Sforzi, F., and R. Boix. 2019. "Territorial Servitization in Marshallian Industrial Districts: The Industrial District as a Place-based Form of Servitization." *Regional Studies* 53 (3): 398–409.

Shi, W. S., Sun, S. L., Yan, D., and Z. Zhu. 2017. "Institutional Fragility and Outward Foreign Direct Investment from China." *Journal of International Business Studies* 48 (4): 452–76.

Somaya, D., Williamson, I. O., and X. Zhang. 2007. "Combining Patent Law Expertise with R&D for Patenting Performance." *Organization Science* 18 (6): 922–37.

Stahel, W. R. 2016. "The Circular Economy." *Nature* 531 (7595): 435–38.

Stephan, U., Andries, P., and A. Daou. 2019. "Goal Multiplicity and Innovation: How Social and Economic Goals Affect Open Innovation and Innovation Performance." *Journal of Product Innovation Management* 36 (6): 721–43.

Stilgoe, J., Owen, R., and P. Macnaghten. 2013. "Developing a Framework for Responsible Innovation." *Research Policy* 42 (9): 1568–80.

Tang, J. 2006. "Competition and Innovation Behaviour." *Research Policy* 35 (1): 68–82.

Tidd, J. 2001. "Innovation Management in Context: Environment, Organization and Performance." *International Journal of Management Reviews* 3 (3): 169–83.

Tilleman, S. G., Russo, M. V., and A. J. Nelson. 2020. "Institutional Logics and Technology Development: Evidence from the Wind and Solar Energy Industries." *Organization Science* 31 (3): 649–70.

Tomić, T., and D. R. Schneider. 2020. "Circular Economy in Waste Management: Socio-Economic Effect of Changes in Waste Management System Structure." *Journal of Environmental Management* 267: 110564.

Tsinopoulos, C., Sousa, C. M., and J. Yan. 2018. "Process Innovation: Open Innovation and the Moderating Role of the Motivation to Achieve Legitimacy. *Journal of Product Innovation Management* 35 (1): 27–48

UNICEF, WHO, IBRD, WB. 2019. *Levels and trends in child malnutrition: Key findings of the 2018 edition of the joint child malnutrition estimates*. New York: United Nations Children's Fund (UNICEF).

Vakili, K., and A. M. McGahan. 2016. "Health Care's Grand Challenge: Stimulating Basic Science on Diseases that Primarily Afflict the Poor." *Academy of Management Journal* 59 (6): 1917–39.

Vassallo, J. P., Prabhu, J. C., Banerjee, S., and R. Voola. 2019. "The Role of Hybrid Organizations in Scaling Social Innovations in Bottom-of-the-pyramid Markets: Insights from Microfinance in India." *Journal of Product Innovation Management* 36 (6): 744–63.

Vendrell–Herrero, F., Gomes, E., Mellahi, K., and J. Child. 2017. "Building International Business Bridges in Geographically Isolated Areas: The Role of Foreign Market Focus and Outward Looking Competences in Latin American SMEs." *Journal of World Business* 52 (4): 489–502.

Vendrell-Herrero, F., Darko, C., Gomes, E., and D. Lehman. 2022. "Home Market Economic Development as a Moderator of the Self-selection and Learning-by-exporting Effects." *Journal of International Business Studies* 53: 1519–35

Wang, Q., and N. Tunzelmann. 2000. "Complexity and the Functions of the Firm: Breath and Depth." *Research Policy* 29 (7–8): 805–18.

Watkins, A., Papaioannou, T., Mugwagwa, J., and D. Kale. 2015. "National Innovation Systems and the Intermediary Role of Industry Associations in Building Institutional Capacities for Innovation in Developing Countries: A Critical Review of the Literature." *Research Policy* 44 (8): 1407–18.

Witt, M. A., and A. Y. Lewin. 2007. "Outward Foreign Direct Investment as Escape Response to Home Country Institutional Constraints." *Journal of International Business Studies* 38 (4): 579–94.

WIPO. 2019. "Plant Biotechnology: Connecting Urban Innovation and Rural Application." In *the geography of innovation: Local hotspots, global networks*, 87–112. Geneva, Switzerland: World International Property Organization.

Wright, C., and D. Nyberg. 2017. "An Inconvenient Truth: How Organizations Translate Climate

Change into Business as Usual." *Academy of Management Journal* 60 (5): 1633–61.

Xing, Y., Liu, Y., and C. Lattemann. 2020. "Institutional Logics and Social Enterprises: Entry Mode Choices of Foreign Hospitals in China." *Journal of World Business* 55 (5): 100974.

TABLES

Table 1 Types of Grand Challenge-based responsible innovation

	Exemplary type of innovation	Historical background	Manufacturing industries dealing with this issue	Size of average firm	Evidence based on this study
Climate change	Lower emission levels through the circular economy (Hoffman, 1999)	Combating of climate change was officially kicked off by Article 3 of the 1992 U.N. Framework Convention on Climate Change. Subsequently, various protocols have been negotiated: Kyoto (1997-2012), Kyoto extension (after 2012), and the current Paris Agreement (2016).	All	Medium-sized and large organizations	Large multi-industry sample of firms engaged in circular economy innovations
Space exploration	Building technology that enables safer, faster space travel (Buehler, Iagnemma, and Singh, 2007)	Started with satellites orbiting Earth in the 60s and evolved with sending men to the Moon, space stations, and sending satellites to map space.	Machinery- and vehicle-based (NAICS-33)	Large organizations only	Running case: SpaceX
Pandemics / healthcare	Development of vaccines and treatments to combat pandemics such as COVID-19 or Ebola (George et al., 2016; Kulikowski, 2021)	In 1796, Jenner began to transfer fluid from infected individuals with smallpox to the skin of others, hoping to generate immunity. Throughout the 19th century, scientists tested various vaccines, a process that clearly accelerated throughout the 20th century.	Pharmaceutical-based (NAICS-32)	Large organizations only	Running case: Pfizer
Zero Hunger	Biotechnology enabling increased efficiency in food production (Bryant and Higgins, 2019)	Second Sustainable Development Goal (SDG2) seeks to "end hunger, achieve food security and improved nutrition and promote a sustainable agriculture" by 2030 (UNICEF, WHO, IBRD, WB, 2019).	Food-processing (NAICS-31)	Medium-sized and large organizations	Running case: The New Butchers

Note: Other global GCs were not considered in our research, as they were not led by the private sector. These GCs include government initiatives addressing an ageing population, data privacy, and economic inequality.

Table 2 Patent behaviors, volume, and success by industry

Primary industry (NAICS)	Secondary industry (NAICS)	Firms with Patents (%)	Patent applications (median)	Patents Granted (median)	Success rate (%)
NAICS-31	NAICS-54	27.74%	3	2	68.24%
NAICS-32	NAICS-54	52.69%	13	7	60.27%
NAICS-33	NAICS-54	52.57%	13	8	64.05%
ALL	NAICS-54	49.26%	10	6	63.46%

Success rate is the mean of the firm-level ratio of patents granted over total patent applications

Table 3 Means and standard deviations by Circular Economy participation status

	Non-CE firms	CE firms	t-test *p-value*
# Observations	890	263	
% Observations	77.18%	22.82%	
Patent (dummy)	0.514	0.418	2.7527***
	(0.017)	(0.030)	*0.003*
Patents Applications per employee	0.403	0.061	1.270
	(0.132)	(0.013)	*0.102*
Patents Granted per employee	0.187	0.029	1.344*
	(0.058)	(0.006)	*0.089*
Number of Workers	776.90	687.23	1.006
	(46.18)	(49.40)	*0.157*
Labor Productivity (thousands US$)	218.83	211.94	0.242
	(14.16)	(21.15)	*0.405*
Human capital (hourly pay US$)	33.40	32.05	0.537
	(13.79)	(14.08)	*0.295*
NAICS-31	0.127	0.159	1.367*
	(0.011)	(0.022)	*0.086*
NAICS-32	0.216	0.258	1.460*
	(0.014)	(0.027)	*0.072*
NAICS-33	0.657	0.582	2.245**
	(0.016)	(0.030)	*0.012*

Standard deviations are in parentheses. Mean values for patent applications and patents granted correspond to patenting firms. P-values for t-test are in *italics*. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 4 Propensity Score Matching (PSM) results

	Full Sample		**1:1 PSM**		Bias Reduction
	Difference in means	p-value	Difference in means	p-value	
CE firms vs. non-CE firms	263 vs 890		263 vs 263		--
Kolmogorov-Smirnov	0.106	0.02	0.01	1.00	--
Number of Workers	-89.67	0.157	-69.70	0.391	22.2%
NAICS 31	0.033	0.086	0.003	0.452	90.9%
NAICS 32	0.043	0.072	-0.007	0.421	83.8%
NAICS 33	-0.075	0.012	0.004	0.465	94.7%

Acronym PSM refers to Propensity score matching. We applied 1:1 nearest neighbor without replacement. Caliper equal to 0.01. The Kolmogorov-Smirnov test compares the equality of distributions for propensity scores before and after matching.

Table 5 Heckman Selection Model

		Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
		Heckman 1st stage	**Heckman 2nd stage**					
	Dep. Variable:	Patent Propensity	Patent applications			Patents Granted		
H1	CE Firm	-0.0679***	-0.2659**	-0.3549***	-0.3593**	-0.1369**	-0.1974**	-0.2012**
		(0.008)	(0.042)	(0.029)	(0.046)	(0.014)	(0.022)	(0.032)
		0.0000	*0.0244*	*0.0066*	*0.0157*	*0.0106*	*0.0119*	*0.0246*
	Number of Workers/1000	0.0543***	0.0849***	0.0980***	0.0991***	0.0364**	0.0453***	0.0454***
		(0.007)	(0.006)	(0.003)	(0.002)	(0.005)	(0.003)	(0.003)
		0.0000	0.0042	0.0011	0.0004	0.0152	0.0040	0.0042
	Government Effectiveness	0.0877***						
		(0.019)						
		0.0000						
	R&D/GDP		0.1388	0.1364	0.1614*	0.0302	0.0286	0.0400
			(0.053)	(0.057)	(0.049)	(0.019)	(0.021)	(0.018)
			0.1197	*0.1375*	*0.0819*	*0.2494*	*0.3036*	*0.1554*
	Human Capital (hourly pay)		0.0064	0.0064	0.0072	0.0045**	0.0045**	0.0049***
			(0.003)	(0.003)	(0.002)	(0.001)	(0.001)	(0.000)
			0.1989	*0.1770*	*0.1011*	*0.0201*	*0.0138*	*0.0005*
	Labor Productivity/1000		0.5059	0.5068	0.5073	0.3001	0.3007	0.3008
			(0.202)	(0.199)	(0.198)	(0.118)	(0.116)	(0.115)
			0.1293	*0.1258*	*0.1245*	*0.1252*	*0.1214*	*0.1202*
H2	CE Firm * R&D/GDP			0.0414**	0.0351***		0.0281*	0.0257*
				(0.010)	(0.002)		(0.007)	(0.008)
				0.0490	*0.0036*		*0.0628*	*0.0860*
	CE Firm * NAICS-31				-0.4462***			-0.1949***
					(0.009)			(0.010)
					0.0004			*0.0028*
	R&D/GDP * NAICS-31				-0.2509**			-0.1184*
					(0.055)			(0.031)
					0.0449			*0.0609*
H3	CE Firm * R&D/GDP * NAICS-31				0.3793***			0.1779**
					(0.028)			(0.020)
					0.0053			*0.0128*
	Mill's Lambda		1.9799***	2.2128***	2.2623***	1.0008***	1.1591***	1.1777***
			(0.133)	(0.092)	(0.051)	(0.023)	(0.017)	(0.048)
			0.0045	*0.0017*	*0.0005*	*0.0005*	*0.0002*	*0.0017*
	Constant	-0.5103***	-2.3863***	-2.6049***	-2.3869***	-1.1706***	-1.3191***	-1.2175***
		(0.017)	(0.190)	(0.151)	(0.024)	(0.049)	(0.058)	(0.058)
		0.0000	*0.0063*	*0.0033*	*0.0001*	*0.0017*	*0.0019*	*0.0022*
	Observations	526	234	234	234	234	234	234
	McFadden Pseudo-R^2	0.136						
	R^2		0.562	0.563	0.571	0.551	0.553	0.559
	Log-Likelihood	-348.98						
	LROC	0.737						
	Correctly Predicted: Sensitivity	79.5%						
	Country dummies	YES	YES	YES	YES	YES	YES	YES
	Sector dummies	YES	YES	YES	YES	YES	YES	YES

Robust standard errors in parentheses. p-values in *italics*. Significance levels are reported by *** p<0.01, ** p<0.05, * p<0.1. Column 1 reports marginal effects from a Probit model. Remaining columns report parameters obtained from ordinary least squares. Acronyms: CE refers to Circular Economy, GDP refers to Gross Domestic Product, R&D to Research and Development national expenditure, and LROC refers to the area below the Receiver operating characteristics curve.

FIGURES

Figure 1. Conceptual framework

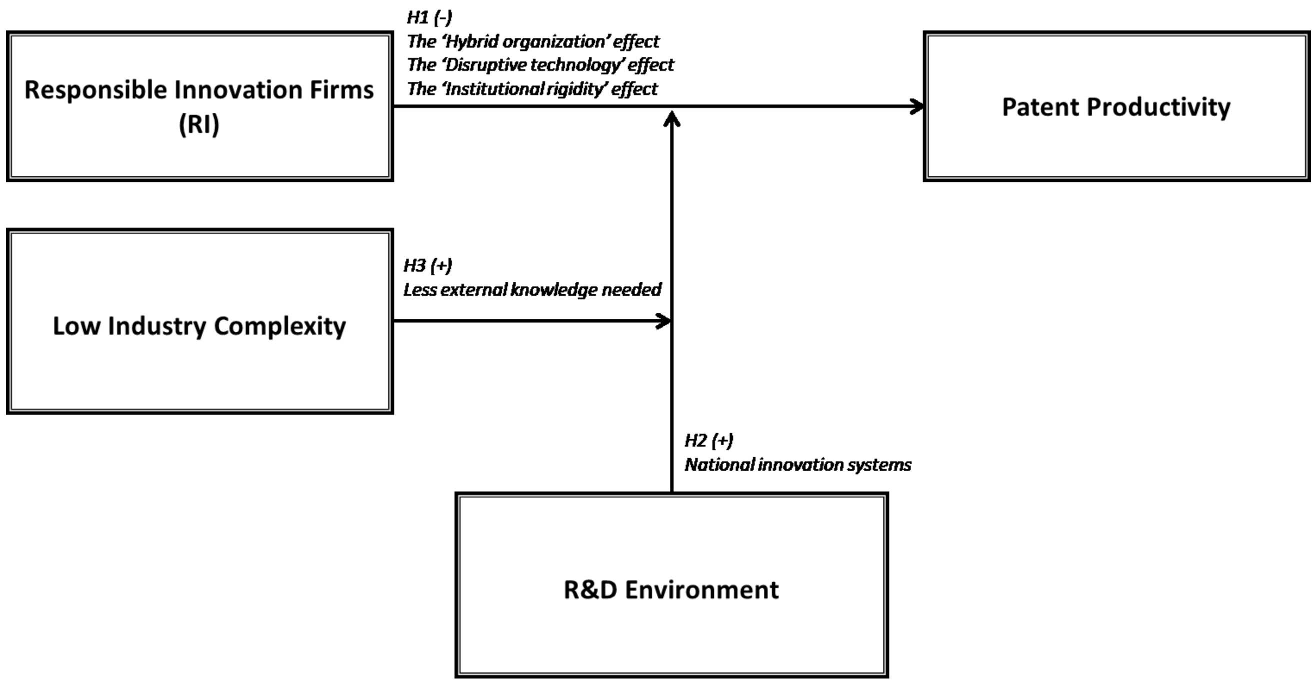
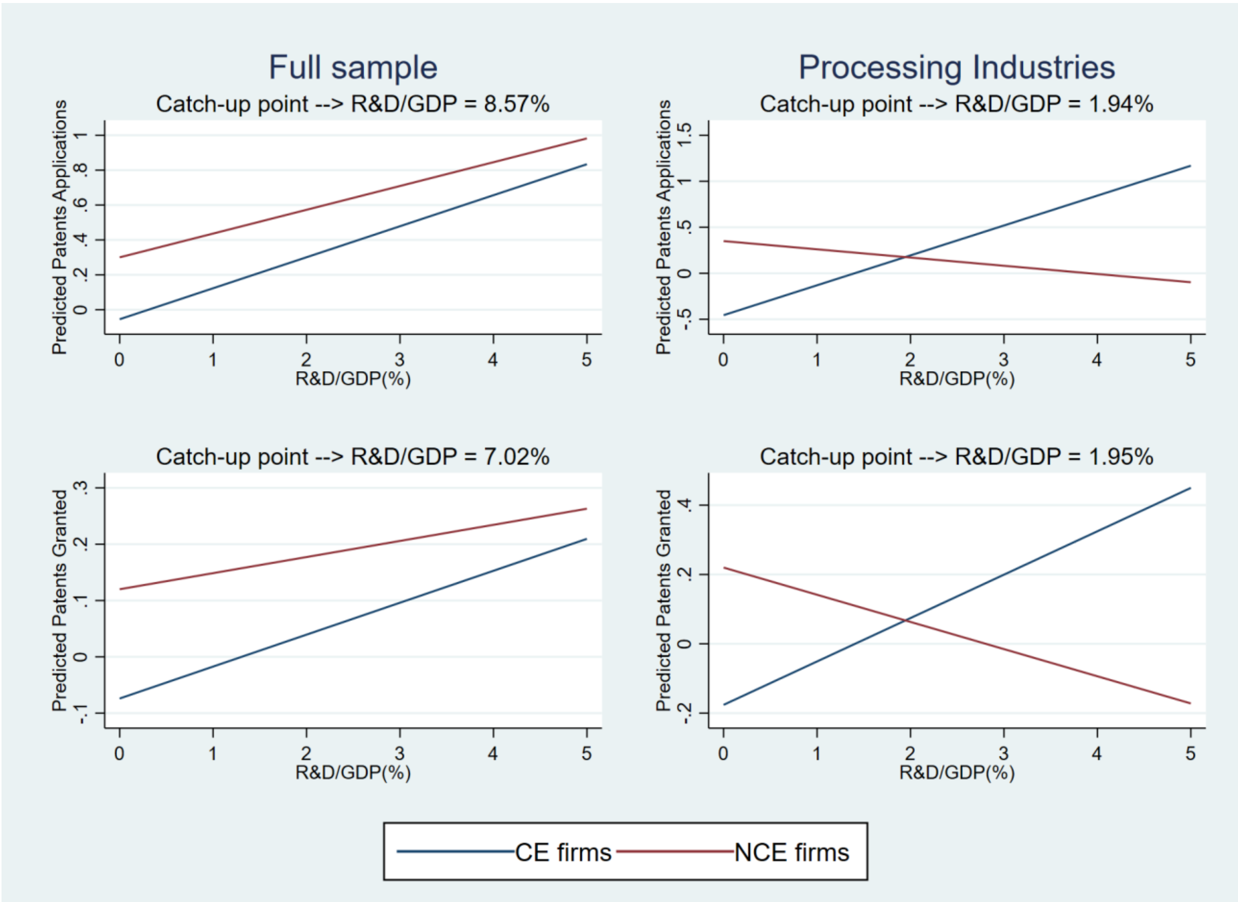
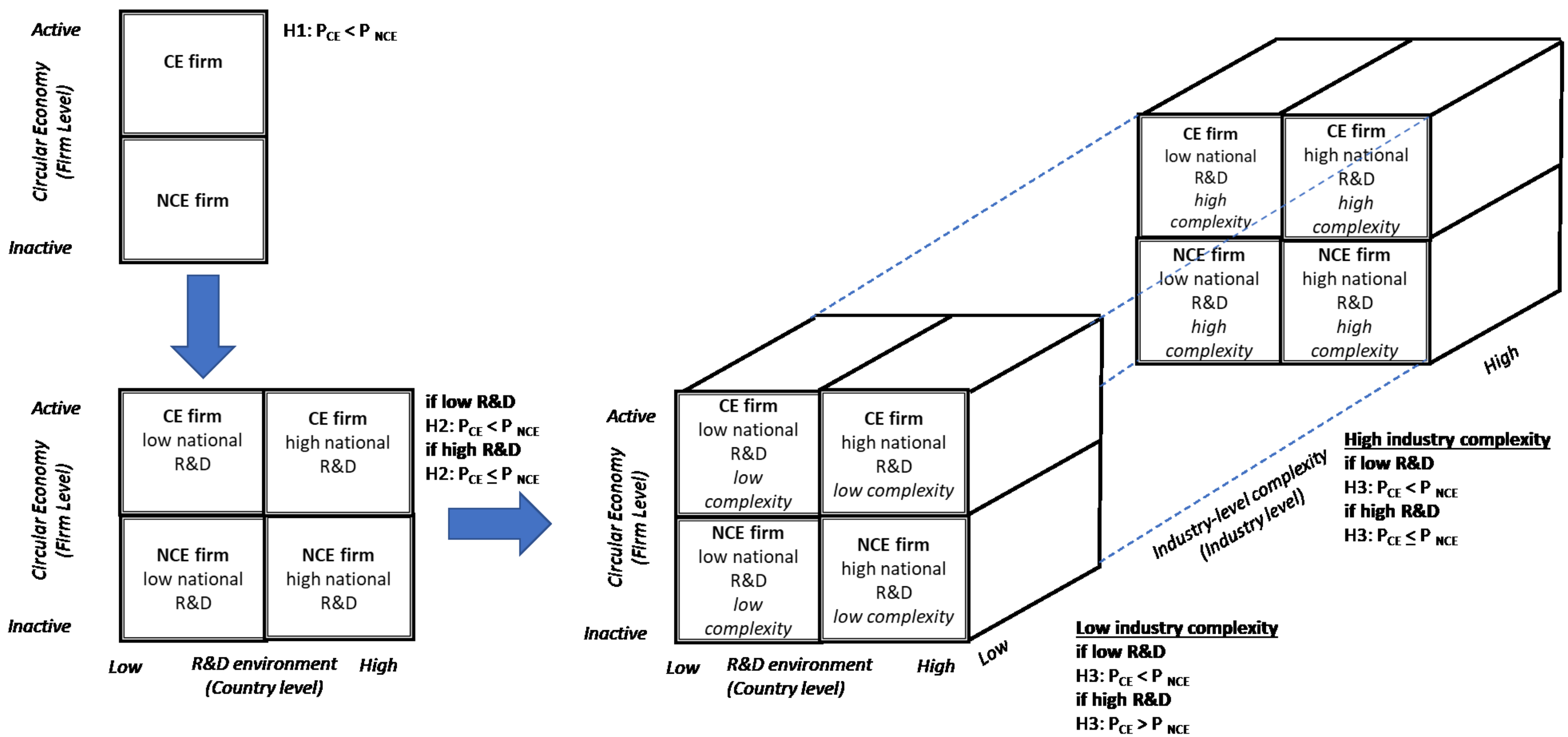


Figure 2. Moderation effect of R&D/GDP, full sample, and processing industries



Acronyms: CE refers to Circular Economy and NCE refers to No Circular Economy. GDP refers to Gross Domestic Product and R&D to Research and Development national expenditure.

Figure 3. Three-dimensional typology framework to determine CE patent (dis)advantage



Acronyms: P is innovation performance measured as patent productivity. CE refers to Circular Economy and NCE refers to No Circular Economy. GDP refers to Gross Domestic Product and R&D to Research and Development national expenditure.

APPENDIX

Table A1 Country representativeness in the matched sample and country-level variables

Country	Government effectiveness	R&D/GDP
Austria	1.45	3.17
Belgium	1.17	2.82
Brazil	-0.44	1.26
Czech Republic	1.93	0.92
Germany	1.62	3.09
Greece	0.34	1.18
Hungary	0.49	1.55
India	0.28	0.65
Ireland	1.14	1.46
Japan	1.67	3.26
Netherlands	1.85	2.16
Romania	-0.25	0.50
Russia	-0.06	0.99
Slovakia	0.70	0.86
Spain	1.00	1.24
Sweden	1.83	3.33
Ukraine	-0.41	0.47
United Kingdom	1.34	1.72
United States	1.57	2.83
Vietnam	-0.00	0.53