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# Industrial doctorates: a systematic literature review and future research agenda

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**ABSTRACT**

The aim of this systematic literature review was to understand the features, and the evolution, of industrial doctorates by analysing 54 papers published between 2002 and 2023. Two aspects were considered (i) the state of the art of the literature has been clarified through synthesis and discussion of six key themes: the main features and evolution of industrial doctorates; the design and implementation of industrial PhD programmes; the perspective of PhD candidates; the standpoint of university; the standpoint of industry; and industrial doctorates as policy tools for fostering innovation processes. There was a surge in publications after 2015, but these have mainly focused on the European context. Industrial doctorates are reshaping the doctoral education landscape as they are considered as educational tools for building bridges between academia and industry. However, there are still institutional and cultural barriers to legitimising industrial doctorates which are often considered as alternatives or even as the antithesis of 'traditional' PhDs; (ii) we suggest an agenda for future research to assess whether industrial doctorates do offer an effective response, or an optimal approach to meeting the demands of both the knowledge society and of doctoral candidates. Future research should seek to gather quantitative evidence in a wider variety of geographical areas, taking into account the distinctive features of both institutional contexts, and of the diverse scientific fields and industrial sectors involved. Studies of the long-term impacts of industrial doctorates on students' research outcomes, their career trajectories and, on the performance of local ecosystems are needed.

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**KEYWORDS**
Doctoral education; industrial doctorate; industrial PhD; knowledge transfer; third mission

## 1. Introduction

The term 'Doctor of Philosophy and Theology' appeared for the first time in a letter written by Pope Innocent III in 1207. The letter was about the plight of Stephen Langton, the Archbishop of Canterbury, who had earned his PhD (Jones 2018). Since then, the expansion of doctoral education has been accompanied by important changes, promoted by higher education policies (Bernhard and Olsson 2023; Cardoso 2024; Cardoso et al. 2022; Sarrico 2022), especially in North America (Kehm 2007) and Europe. Both the Bologna Declaration of 1999[1] and the Lisbon Strategy of 2000[2] have contributed to reconceptualising doctoral education, which is no longer exclusively considered as the

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disinterested pursuit of knowledge, but as a resource for fostering the growth and competitiveness of countries (Grant et al. 2022; Kehm 2006; Nerad et al. 2022).

Although the traditional PhD has been the 'gold standard' (Scott et al. 2004, 149) of academic achievement for a long time (Wildy, Peden, and Chan 2015), the knowledge economy, the shortage of faculty positions (Borrell-Damian 2009; Cardoso, Tavares, and Sin 2019b) and skills mismatches (Tavares, Sin, and Soares 2019), have stimulated the diffusion of new forms of doctoral education (Bernhard and Olsson 2023; Sarrico 2022), placing PhD candidates at the intersection between learning, creating and transferring knowledge to industry and society at large (O'Carroll et al. 2012). Along with professional doctorates, applied doctorates and cooperative doctorates (Kehm 2020), industrial PhD programmes have especially attracted the attention of both universities and firms, and have been included in several policy agendas for research, innovation and employment (Borrell-Damian et al. 2010; 2015; Harman 2008; Thune et al. 2012).

According to Roolaht (2015, 257) industrial doctorates are 'educational tools for building bridges between the academic sector and industry. In these programmes, the PhD student studies and carries out research while being employed in a knowledge-based company or R&D agency'. The PhD candidate is usually 'employed by a private enterprise during the project period and the time is spent equally at the enterprise and in the university' (Casano 2015b, 86). On the firm's side, 'industry experts assume several roles, which range from the participation in supervisory committees, to curriculum design and development, to the definition of doctoral research topics' (Cardoso, Tavares, and Sin 2019a, 279). Thus, an industrial PhD student means that 'he/she is exposed to a dual culture' (Tavares, Sin, and Soares 2020a, 349).

Industrial PhD programmes are expected to provide students both with cutting-edge knowledge and experience in a company, and developing soft skills for addressing real-world challenges and labour market needs (Evans 2016; Yang and Jeffrey 2021). This means that industrial doctorates aim to train researchers as future 'triple helix workers' (Thune 2010, 478) so as to contribute to bridging the gap between research and its application (Herman 2013; Kolmos, Kofoed, and Du 2008; Wallgren and Dahlgren 2005; 2007). Indeed, they also help firms to cross the so-called 'Valley of Death', i.e. the early phase of new ventures, when insufficient revenue is being generated despite huge efforts and work (Debois et al. 2015, 54).

Nevertheless, the steady increase in the number of industrial PhD positions (Dominguez-Whitehead and Maringe 2020) has raised various concerns among scholars (Sarrico 2022) regarding the wisdom of organising such doctorates, the preparedness of PhD graduates, and the rigour of training (Grant et al. 2022). Some authors have argued that the large-scale diffusion of industrial PhDs might lead to diminished standing of the degree (Assbring and Nuur 2017; Usher 2002). As reported by Yang (2022) and Yang and Jeffrey (2021) industrial PhD programmes could even compromise both the autonomy of universities and the freedom of PhD candidates. Universities increasingly rely on the financial support deriving from firm partnerships, while doctoral students have to focus on the research interests and challenges of the business sector (Grimm 2018; Usher 2002). Quoting the anthropologist Claude Levi-Strauss, Slaughter et al. (2002, 284) stated that industrial PhD candidates are exploited by professors, since students are part of a 'gift exchange' with industry that offers funding and equipment for research. Students are 'the symbolic token that demonstrates trust between partners in a new alliance' (Slaughter et al. 2002, 308).

Previous literature reviews have only minimally addressed the topic of industrial doctorates. Thune (2009) recognised industrial doctorates as just one among the various forms of cooperation between university and industry that can influence both the training and the career paths of students. Roberts (2018) reviewed contributions on paths for reforming the PhD degree, acknowledging the potential of engaging industry in doctoral programmes. Exploring the transformation of doctoral education, Cardoso et al. (2022) identified industrial PhD courses as a form of collaborative programmes designed both to introduce multiple employment sectors to students and to develop their soft skills for the labour market. Sarrico (2022) has recently offered a historical perspective on the expansion of doctoral education in the developed economies of the OECD. The author argued that industrial doctorates represent one among the many and various attempts to widen the scope of doctoral education and to diversify away from the traditional PhD.

Overall, research on industrial doctorates is still fragmented as regards their distinctive features, forms, and the implementation of university-industry collaboration (Cardoso, Tavares, and Sin 2019a). There is also a lack of systematic organisation of both information and data on industrial PhD programmes across countries. Furthermore, the literature has reported either scant, or inconsistent, empirical evidence regarding the perspective of university (e.g. Cardoso, Tavares, and Sin 2019b; Grant et al. 2022; Usher 2002), the standpoint of firms (e.g. Thune and Børing 2015), and the role and the performance of PhD candidates (e.g. Thune 2009; 2010; Wallgren and Dahlgren 2007).

The aim of this study is to provide a systematic literature review of the state of theoretical and empirical research on industrial PhD education today. This review addresses the topic in a systematic and comprehensive manner by scrutinising 54 papers published between 2002, when the first articles mentioning industrial doctorates appeared, and 2023. It offers a twofold contribution. First, it defines the state of the art of the literature on the industrial PhD programmes which have mushroomed in the last decade. To bring clarity and synthesis to this subject, six key themes and a selection of subthemes have been systematised and discussed, namely: the features and evolution of industrial doctorates; the design and implementation of industrial PhD programmes; the perspective of PhD candidates; the standpoint of university; the viewpoint of industry; and industrial doctorates as policy tools. Second, drawing on the results obtained from the review, a research agenda and a conceptual framework are proposed to extend the understanding of both the theoretical and the practical implications of industrial doctorates.

This paper is structured as follows. Section 2 describes the methodology adopted for conducting this review. Section 3 presents the descriptive analysis. Section 4 illustrates the thematic analysis. Conclusion and future research agenda end the paper.

## 2. Methodology

A systematic literature review process was used to establish the state of current knowledge in the field of interest (Tranfield, Denyer, and Smart 2003), industrial doctorates. Systematic reviews emphasise the principles of rigour, reliability, transparency, reproducibility and updatability to reduce both subjective bias and the risk of overlooking relevant literature (Denyer and Neely 2004). Moreover, these reviews are better able to overcome the limitations of traditional methods of review, as they both inform practice and advance academic research (Briner and Denyer 2012). More recently, systematic reviews have been adopted in the social sciences to explore themes related to the transformation of doctoral education, of the Third Mission of the university and of the relations between academia and industry (e.g. Cardoso et al. 2022; Compagnucci and Spigarelli 2020; Rotolo et al. 2022). The methodology used for this analysis is based on the six-stage procedure which is described below.

*Stage 1. Preliminary exploration*. In order to define the boundaries of the subject, the review began by interviewing thirteen national and international experts with long experience in the field of research policies and industrial doctorates. Both experts who were familiar with research policies and those who had had experience with university governance provided information on the organisation and the role of industrial doctorates; drawing on their experience, academic supervisors suggested a selection of pros and cons of doing an industrial PhD, and of performing research in collaboration with companies; firms representatives shared both the potentials and the concerns of participating in PhD programmes; and PhD school staff who had delved into the management of industrial doctoral programmes.

Interviews were conducted in-person or via videoconferencing and were held in Italian or in English. Each interview lasted on average 30 min. This preliminary step made it possible to obtain some insights into both the general framework of industrial PhD programmes and into the perspective of the different actors involved. Furthermore, the interviews made it possible to identify fifteen recurrent key words: 'industrial doctorate', 'industrial PhD', 'industrial doctoral education', 'professional doctorate', 'professional PhD', 'applied doctorate', 'applied PhD', 'practice-based doctorate', 'practice based PhD', 'applied research', 'innovation', 'third mission', 'knowledge economy', 'knowledge transfer' and 'university-industry collaboration'.

*Stage 2. Database and search terms*. Thomson Reuters Web of Science (WoS) and Elsevier's Scopus were the sources for bibliometric data. These search systems are the most widely used databases of peer-reviewed research literature because they are large and multidisciplinary, and include the Social Sciences and Humanities disciplines which are of interest for this review (Gusenbauer and Haddaway 2020; Paul et al. 2021). Furthermore, the literature demonstrated that WoS and Scopus yield more consistent and accurate results than do other databases (Falagas et al. 2008; Kirk et al. 2015).

The search was limited to journal articles and articles in conference proceedings, in order to ensure the collection of the most representative scientific outputs in the field of analysis, and included both open and non-open access texts. Furthermore, the search was refined to texts published in English so as to ensure that we had a thorough understanding of each eligible article. To maximise the recovery of relevant studies, the search was not limited to any time frame. The first articles mentioning industrial doctorates appeared in 2002. Thus, we collected all the potential eligible articles published from 2002 to 31 December 2023. Drawing on a selection of works by Kehm (2006; 2007; 2020) which described all the different types of doctoral degrees, we refined the keywords obtained from the first stage, in order to fit with the objectives of this review and to exclude potentially less critical topics. Thus, the following search string was used here: 'industrial PhD*' OR 'industrial doctorate*' OR 'industrial doctoral education'. These terms were sought in the titles, abstracts, and keywords of publication records. This initial search yielded a total of 87 records.

*Stage 3. Articles download and selection*. All the papers listed were downloaded from WoS or Elsevier's Scopus (or, if this was not possible, from Google Scholar or ResearchGate). Thirty doubled items were excluded. At this point we had 57 papers that were manually checked by reading the titles, abstracts and keywords. This procedure allowed us to exclude an additional 22 articles that were not relevant to the objectives of this review. Four papers were excluded because they were either related to other types of doctorates, such as professional doctorates, or to programmes for technology transfer. Eighteen articles were excluded because they referred to industrial doctorates only in very general terms: all papers were the outputs of research funded by industrial PhD programmes at national or international level. Although these articles contained one or more key words of interest, e.g. 'industrial doctorate*', such terms have only been used to acknowledge the funding programme. This selection step left us with 35 articles.

Then, the snowballing technique (e.g. Jalali and Wohlin 2012) was adopted. We identified further articles based on those papers citing the article being examined. Drawing on the citation tracking provided by Google Scholar, the title, keywords and abstract of each eligible paper was manually checked (Greenhalgh and Peacock 2005; Vassar et al. 2016). The lower cut-off point for inclusion in the sample was 10 citations This resulted in a further 19 eligible studies. Thus, the final sample of this analysis was made up of 54 texts: 38 journal articles and 16 articles in conference proceedings (Table 1).

*Stage 4. Data extractio*n**.** These 54 papers were fully read, scrutinised and coded. To address potential biases or subjectivity, the two authors participated in coding all the articles, across two rounds. All disagreements were discussed, and agreements reached. Then, an external independent researcher was invited to code a subset of the articles that presented differences in the first round of coding. This external researcher contributed to settling the disagreements (Cooper 2010 Durach, Kembro, and Wieland 2017). Drawing on Brekke (2021), Compagnucci and Spigarelli (2020) and Tranfield, Denyer, and Smart (2003), the content of each paper was systematised using a protocol that was based on assigning the following codes to each article and recording them in a table: (1) author(S); (2) title; (3) year published; (4) journal; (5) abstract; (6) keywords; (7) research gap(S); (8) research question(S); (9) theoretical framework; (10) methodology; (11) geographical area considered in the study; (12) data collection, sample and analysis period; (13) main results; (14) section for further comments. The protocol resulted in a final document of 107 pages.

*Stage 5. Descriptive analysis*. We used the categorisation and coding scheme elaborated by adapting Compagnucci and Spigarelli (2020), and De Carvalho Ferreira et al. (2016). For each article, we

**Table 1.** Final sample: the 54 texts included in the systematic literature review.

| # text identifier | Author(s), year, title and source of publication | Type of text |
|---|---|---|
| 1 | Bernhard, I., and Olsson, A.K. (2023). "One Foot in Academia and One in Work-Life – the Case of Swedish industrial PhD Students." *Journal of Workplace Learning*, 35(6): 506–523 | Journal article |
| 3 | Colacino, M., and Mineo, R. (2023). "The Reggio Childhood Studies PhD as a Learning Community." *9th International Conference on Higher Education Advances (HEAd'23) Universitat Politecnica de Valencia, Valencia* | Proceedings article |
| 8 | Yang, H. (2022). "A Triple Helix Model of Doctoral Education: A Case Study of an Industrial Doctorate." *Sustainability*, 14(17): 10942 | Journal article |
| 14 | Yang, H., and Jeffrey, R. (2021). "Industrial Doctorate: A Case Study of Doctor of Engineering in the United Kingdom." *IEEE International Conference on Engineering, Technology & Education (TALE)*: 1–6 | Proceedings article |
| 15 | Heldal, I, Murby, R., and Tobba Therkildsen, S. (2021). "Assessing Feasibility and Critical Success Factors for Knowledge Sharing within Industrial PhD-Projects in Sweden and Norway: A Case Study." *Proceedings of the European Conference on Knowledge Management, ECKM* | Proceedings article |
| 16 | Barjak, F., and Heimsch, F. (2021). "Organisational Mission and the Involvement of Academic Research Units in Knowledge Sharing with Private Companies." *Industry and Innovation*, 28 (4): 395–423 | Journal article |
| 17 | Sin, C., Soares, D., and Tavares, O. (2021). "Coursework in Industrial Doctorates: A Worthwhile Contribution to Students' Training?" *Higher Education Research & Development*, 40(6): 1298–1312 | Journal article |
| 18 | Jaakkola, H., Mikkonen, T., and Systa, K. (2021). "Anti-Patterns for an Industrial PhD in the Field of ICT." *IEEE Frontiers in Education Conference (FIE)* | Proceedings article |
| 19 | Tavares, O., Soares, D., and Sin, C. (2020). "Industry–University Collaboration in Industrial Doctorates: A Trouble-Free Marriage?" *Industry and Higher Education*, 34(5): 312–320 | Journal article |
| 20 | Karsten, M.M.V. (2020). "Testing Relevance and Applicability: Reflections on Organizational Anthropology." *Journal of Organizational Ethnography*, 9(2): 159–172 | Journal article |
| 21 | Bernhard, I., and Olsson, A.K. (2020). "University-Industry Collaboration in Higher Education: Exploring the Informing Flows Framework in Industrial PhD Education." *Informing Science: The International Journal of an Emerging Transdiscipline*, 23: 147–163 | Journal article |
| 22 | Malm, A., Löfdahl, G.-M. (2020). "Engaging Stakeholders for Improved IAM Implementation." *Water Practice and Technology*, 15(2): 350–355 | Journal article |
| 23 | Cardoso, S., Tavares, O., and Sin, C. (2019). "Can you Judge a Book by its Cover? Industrial Doctorates in Portugal." *Higher Education, Skills and Work-Based Learning*, 9(3): 279–289 | Journal article |
| 24 | Lindén, M., and Björkman, M. (2019). "Experience from Industrial Graduate (PhD) Schools." *IFMBE Proceedings*, 68(3). | Proceedings article |
| 25 | Grimm, K. (2018). "Assessing the Industrial PhD: Stakeholder Insights." *Journal of Technology and Science Education*, 8(4): 214–230 | Journal article |
| 26 | Lindén, M., Björkman, M., Gerdtman, C., and Hök, B. (2018). "Embedded Sensor Systems for Health – Collaboration between Industry, Academia and Healthcare." *IFMBE Proceedings*, 65: 964–967 | Proceedings article |
| 28 | Granata, S.N., and Dochy, F. (2016). "Applied PhD Research in a Work-Based Environment: An Activity Theory-Based Analysis." *Studies in Higher Education*, 41(6): 990–1007 | Journal article |
| 29 | Gustavsson, L., Nuur, C., and Söderlind, J. (2016). "An Impact Analysis of Regional industry—University Interactions: The Case of Industrial PhD Schools." *Industry and Higher Education*, 30(1): 41–51 | Journal article |
| 31 | Sundström, A., Widforss, G., Rosqvist, M., and Hallin, A. (2016). "Industrial PhD Students and their Projects." *Procedia Computer Science*, 100: 739–746 | Journal article |
| 32 | Schlegel, J., and Keitsch, M. (2016). "Bridging the Gap between Professional Practice and Academic Research – The Industrial PhD." *Proceedings of the 18th International Conference on Engineering and Product Design Education: Design Education: Collaboration and Cross-Disciplinarity*: 198–203 | Proceedings article |
| 33 | Bröchner, J., and Lagerqvist, O. (2016). "From Ideas to Construction Innovations: Firms and Universities Collaborating." *Construction Economics and Building*, 16(1): 76–89 | Journal article |
| 35 | Debois, S., Hildebrandt, T., Marquard, M., and Slaats, T. (2015). "Bridging the Valley of Death: A Success Story on Danish Funding Schemes Paving a Path from Technology Readiness Level 1 to 9." *IEEE/ACM 2nd International Workshop on Software Engineering Research and Industrial Practice*, 54–57 | Proceedings article |
| 36 | Roolaht, T. (2015). "Enhancing the Industrial PhD Programme as a Policy Tool for University—Industry Cooperation." *Industry and Higher Education*, 29(4): 257–269 | Journal article |
| 37 | Casano, L.V. (2015). "When Research Moves up Regulation: A Trailblazing Experience of Industrial PhDs in Italy." *International Journal of Technology and Globalisation*, 8 (1): 85–96 | Journal article |

(*Continued*)

**Table 1.** Continued.

| # text identifier | Author(s), year, title and source of publication | Type of text |
|---|---|---|
| 38 | Kitagawa, F. (2015). "Crossing Boundaries Between Science and Innovation – Career Mobility and Impacts of Graduates of the UK Industrial Doctorate Centres." *International Journal of Technology and Globalisation*, 8(1): 51–63 | Journal article |
| 41 | Yearworth, M. (2011). "Systems Practice in Engineering: Reflections on Doctoral Level Systems Supervision." *55th Annual Meeting of the International Society for the Systems Sciences 2011*: 1073–1082 | Proceedings article |
| 42 | Kihlander, I., Nilsson, S., Lund, K., Ritzén, S., and Bergendahl, M.N. (2011). "Planning Industrial PhD Projects in Practice: Speaking both 'Academia' and 'Practitionese'." *ICED 11 – 18th International Conference on Engineering Design – Impacting Society Through Engineering Design*, 8: 100–109 | Proceedings article |
| 45 | Kolmos, A., Kofoed, L.B., and Du, X.Y. (2008). "PhD Students' Work Conditions and Study Environment in University – and Industry-Based PhD Programmes." *European Journal of Engineering Education*, 33(5-6): 539–550 | Journal article |
| 51 | Vitiello, V., and Castelluccio, R. (2019). "University and Enterprise: Research in Doctoral Studies with Industrial Characterization." *Proceedings of INTED2019 Conference* | Proceedings article |
| 53 | Cardoso, S., Tavares, O., and Sin, C. (2019). "Reinventing Doctoral Education through University-Industry Collaboration: The Case of Industrial Doctorates in Portugal". *INTED2019 Proceedings*, 891–899 | Proceedings article |
| 54 | Tavares, O., Sin, C., and Soares, D. (2019). "Are Industrial Doctorates Capable of Overcoming Skills Mismatch?" *EDULEARN19 Proceedings*, 3019–3024 | Proceedings article |
| 55 | Ganzarain, J., Markuerkiaga, L., and Igartua, J.I. (2019). "How Does Working on University-Business Collaborative Projects Foster the Industrial Doctorates' Learning Process?". *Engineering Digital Transformation. Lecture Notes in Management and Industrial Engineering* | Proceedings article |
| 56 | Izquierdo, M., Marzal, P., Álvarez-Hornos, F.J., Gabaldón C. (2015). "Design and Implementation of a University-Industry Training Programme for Early-Stage Researchers of Marie Curie Actions–Itn Projects: The Trainonsec Case Study." *EDULEARN15 Proceedings*: 5209–5213 | Proceedings article |
| 57 | Evans, D. (2016). "Advanced Manufacturing Industrial Doctorate Centre: Engineering Doctorate Students Collaborating with Industry within an Academic and Industrial Environment." *Proceedings of the 18th International Conference on Engineering and Product Design Education (E&PDE16)*: 632–637 | Proceedings article |
| 58 | Casano, L.V. (2015). "Building Employability in Higher Education and Research Paths: Experimental Forms of Higher Apprenticeships and Industrial Doctorates in Italy". *E-Journal of International and Comparative Labour Studies*, 4(1) | Journal article |
| 60 | Thune, T. (2010). "The Training of "Triple Helix workers"? Doctoral Students in University–Industry–Government Collaborations." *Minerva*, 48: 463–483 | Journal article |
| 61 | Borrell-Damian, L., Brown, T., Dearing, A., Font, J. Hagen, S., Metcalfe, J., and Smith, J. (2010). "Collaborative Doctoral Education: University-Industry Partnerships for Enhancing Knowledge Exchange." *Higher Education Policy*, 23: 493–514 | Journal article |
| 62 | Thune, T. (2009). "Doctoral Students on the University–Industry Interface: A Review of the Literature." *Higher Education*, 58: 637–651 | Journal article |
| 63 | Manathunga, C., Pitt, R., Cox, L., Boreham, P., Mellick, G., and Lant, P. (2012). "Evaluating Industry-Based Doctoral Research Programs: Perspectives and Outcomes of Australian Cooperative Research Centre Graduates." *Studies in Higher Education*, 37(7): 843 – 858 | Journal article |
| 64 | Wallgren, L., and Dahlgren, L.O. (2005). "Doctoral Education as Social Practice for Knowledge Development: Conditions and Demands Encountered by Industry PhD Students." *Industry and Higher Education*, 19(6): 433–443 | Journal article |
| 65 | Wallgren, L., and Dahlgren, L.O. (2007). "Industrial Doctoral Students as Brokers between Industry and Academia: Factors Affecting their Trajectories, Learning at the Boundaries and Identity Development." *Industry and Higher Education*, 21(3): 195–210 | Journal article |
| 66 | Assbring, L., and Nuur, C. (2017). "What's in it for Industry? A Case Study on Collaborative Doctoral Education in Sweden." *Industry and Higher Education*, 31(3): 184–194 | Journal article |
| 67 | Harman, K.M. (2002). "The Research Training Experiences of Doctoral Students Linked to Australian Cooperative Research Centres." *Higher Education*, 44: 469–492 | Journal article |
| 68 | Harman, K.M. (2004). "Producing 'Industry-Ready' Doctorates: Australian Cooperative Research Centre Approaches to Doctoral Education." *Studies in Continuing Education*, 26(3): 387–404 | Journal article |
| 69 | Usher, R. (2002). "A Diversity of Doctorates: Fitness for the Knowledge Economy?" *Higher Education Research & Development*, 21(2): 143–153 | Journal article |
| 70 | Tennant, M. (2004). "Doctoring the Knowledge Worker." *Studies in Continuing Education*, 26 (3): 431–441 | Journal article |

(*Continued*)

**Table 1.** Continued.

| # text identifier | Author(s), year, title and source of publication | Type of text |
|---|---|---|
| 71 | Herman, C. (2013). "Industry Perceptions of Industry–University Partnerships related to Doctoral Education in South Africa". *Industry and Higher Education*, 27(3), 217–225 | Journal article |
| 72 | Bröchner, J., and Sezer, A.A. (2020). "Effects of Construction Industry Support for PhD Projects: The Case of a Swedish Scheme". *Industry and Higher Education*, 34(6), 391–400 | Journal article |
| 73 | Moghadam-Saman, S. (2020). "Collaboration of Doctoral Researchers with Industry: A Critical Realist Theorization". *Industry and Higher Education*, 34(1), 36–49 | Journal article |
| 74 | Chiang, K.-H. (2011). "A Typology of Research Training in University – Industry Collaboration: The Case of Life Sciences in Finland". *Industry and Higher Education*, 25(2), 93–107 | Journal article |
| 75 | Thune, T., and Børing, P. (2015). "Industry PhD Schemes: Developing Innovation Competencies in Firms?" *Journal of the Knowledge Economy*, 6, 385–401 | Journal article |
| 76 | Santos, P.S., and Patrício, M.T. (2020). "Academic Culture in Doctoral Education: Are Companies Making a Difference in the Experiences and Practices of Doctoral Students in Portugal?" *International Journal of Doctoral Studies*, 15, 685–704 | Journal article |
| 77 | Roberts, A.G. (2018). "Industry and PhD Engagement Programs: Inspiring Collaboration and Driving Knowledge Exchange." *Perspectives: Policy and Practice in Higher Education*, 22(4): 115–123 | Journal article |
| 78 | Salminen-Karlsson, M., and Wallgren, L. (2008). "The Interaction of Academic and Industrial Supervisors in Graduate Education". *Higher Education*, 56(1), 77–93 | Journal article |

Source: Authors' elaboration.

first identified the geographical area considered in the studies (category 1). To do so, we used the codes A-K to identify the location where the analysis was conducted. Second, we coded the methodology adopted in the article (category 2). To do this, we involved the codes A-F to distinguish theoretical–conceptual studies; qualitative papers; quantitative studies; quali-quantitative analysis; and, literature reviews. Third, we identified the timeframe of analysis considered in the study (category 3) by using the codes A-E. Fourth, we specified the typology of sample investigated in the study by using the codes A-F. Table 2 shows the categorisation and coding scheme adopted for the descriptive analysis of the 54 papers.

*Stage 6. Thematic analysis*. Based on previous systematic reviews in the field of doctoral education (e.g. Cardoso et al. 2022), first we adopted a manual inductive review process (Gioia, Corley, and Hamilton 2013) to scrutinise, for each of the 54 papers, their keywords, titles of sections, and content. Second, we clustered the results into thematic areas by applying a concept mapping approach (Rosas and Kane 2012). We considered the aspects related to the distinctive features of industrial PhD programmes and their transformation across time (35 out of 54 articles), as well as the design and implementation of industrial doctorates (38 out of 54), were those that emerged most systematically in the literature. Within these themes, it is worth noting subthemes, such as training of doctoral students (14 out of 54) and, the organisation and management of PhD schools (7 out of 54). Among the most recurrent aspects are those related to the perspectives of stakeholders participating in industrial doctorates: PhD candidates, university and industry (33 out of 54 articles). These were followed by aspects concerning industrial doctorates and policy-making (17 out of 54). Within this theme, it is worth considering the subtheme relating to the role of doctoral students (13 out of 54). Table 3 shows the themes and subthemes obtained by clustering the texts included in the final sample of the review.

The methodological strategy adopted, as well as the features of this systematic literature review may explain some of its limitations. A first limitation concerns the use of a manual search process to obtain a sample of texts, rather than using an automated software-driven search process. This could mean that the authors might have missed some relevant studies, thus may have underestimated the extent of industrial doctorates-related research. A second limitation is the way in which eligible studies were evaluated and coded. Both authors coded all the articles in two separate rounds so as to eliminate, as far as possible, any potential bias or subjectivity. An external, independent researcher, was then asked to resolve the disagreements that emerged during the first round of coding. Thus the articles were manually scrutinised and coded, and subjective bias may have been, at least to some extent, avoided (Figure 1).

**Table 2.** Categorisation and coding criteria.

| Category | Significance | Code | Significance | Number of texts |
|---|---|---|---|---|
| 1 | *Geographical area considered in the study* | A | USA and Canada | 0 |
| | | B | Europe | 45 |
| | | C | China | 0 |
| | | D | Japan, South Korea, Taiwan and Singapore | 0 |
| | | E | Rest of Asia | 0 |
| | | F | Africa | 1 |
| | | G | South America | 0 |
| | | H | Australia and New Zealand | 3 |
| | | I | Rest of the world | 0 |
| | | J | Multiple* | 0 |
| | | K | Not applicable | 5 |
| Total for category 1 | | | | **54** |
| 2 | *Methodology* | A | Theoretical-conceptual study/model building | 5 |
| | | B | Qualitative analysis | 36 |
| | | C | Quantitative analysis | 5 |
| | | D | Quali-quantitative analysis | 6 |
| | | E | Literature review | 2 |
| Total for category 2 | | | | **54** |
| 3 | *Time frame of data analysis* | A | Cross sectional | 36 |
| | | B | Longitudinal: two years | 0 |
| | | C | Longitudinal: three years | 0 |
| | | D | Longitudinal: more than three years | 0 |
| | | E | Not applicable | 18 |
| Total for category 3 | | | | **54** |
| 4 | *Sample* | A | PhD candidates and PhD graduates | 14 |
| | | B | Scholars and academic supervisors | 6 |
| | | C | Firm representatives | 2 |
| | | D | University managers, administrative staff and PhD schools | 7 |
| | | E | Multiple** | 18 |
| | | F | Not applicable | 7 |
| Total for category 4 | | | | **54** |

*Some studies consider two or more geographical areas.
**Some papers analyse two or more types of sample.
Source: Authors' elaboration.

**Table 3.** Themes, subthemes and texts.

| | | | Subthemes | # text identifier |
|---|---|---|---|---|
| **THEMES** | *1* | *What are industrial doctorates?* | • definition of industrial PhD programmes<br>• features of industrial PhD programmes<br>• evolution of industrial PhD programmes | 1; 3; 8; 14; 15; 17; 18; 19; 20; 22; 23; 24; 25; 28; 29; 32; 36; 37; 38; 42; 45; 51; 54; 56; 57; 60; 61; 62; 63; 64; 66; 68; 69; 70; 77 |
| | *2* | *Design and implementation of industrial doctorates* | • selection and admission of PhD candidates<br>• training and skill development<br>• knowledge production<br>• supervision<br>• doctoral schools | 1; 3; 8; 14; 15; 17; 18; 19; 20; 22; 23; 24; 25; 28; 29; 32; 36; 37; 38; 42; 45; 51; 54; 56; 57; 58; 60; 61; 62; 63; 64; 65; 66; 68; 69; 70; 77; 78 |
| | *3* | *The perspective of PhD candidates* | • PhD candidates' career development<br>• PhD candidates' motivations and expectations | 1; 3; 17; 21; 22; 25; 26; 29; 31; 32; 33; 36; 37; 41; 42; 53; 54; 55; 60; 61; 62; 63; 64; 65; 66; 67; 68; 71; 72; 74; 75; 76; 78 |
| | *4* | *The perspective university* | • industrial doctorates through the lens of the university | |
| | *5* | *The perspective of industry* | • industrial doctorates through the lens of industry | |
| | *6* | *Industrial doctorates and policies for innovation* | • policy tool<br>• Triple Helix Model of innovation<br>• role of doctoral candidates | 8; 20; 23; 29; 36; 51; 55; 60; 64; 65; 66; 67; 68; 71; 73; 77; 78 |

Source: Authors' elaboration.

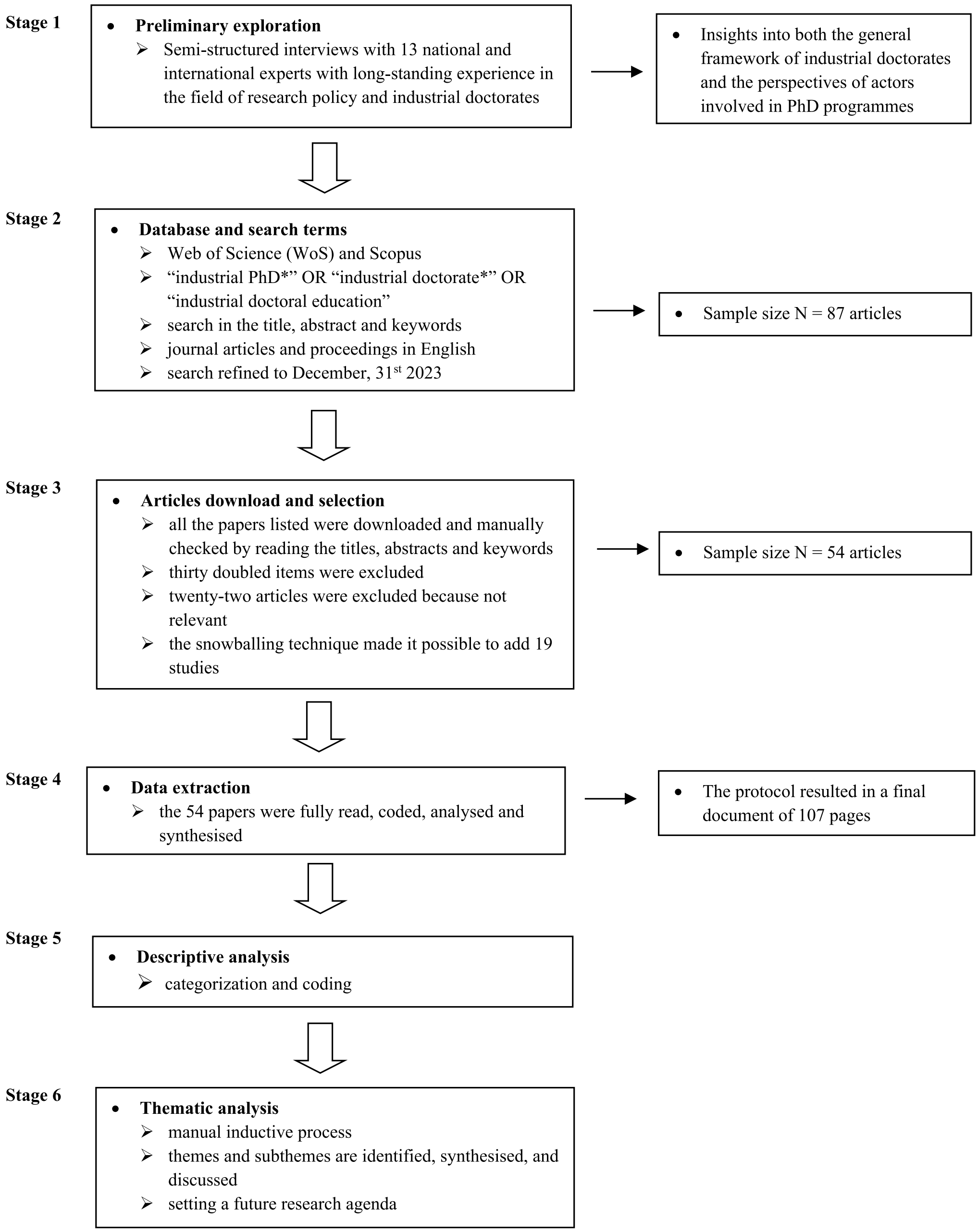


**Figure 1.** Flowchart of the systematic literature review. Source: Authors' elaboration.

Section 3 presents the descriptive analysis of the 54 papers. Section 4 illustrates the thematic analysis, by focusing on the themes and subthemes that have been outlined in Table 3.

## 3. Descriptive analysis

Papers on industrial doctorates have been published in a wide range of international journals. Table 4 shows that, to 31 December 2023, Industry and Higher Education, Higher Education,

**Table 4.** Top 4 academic journals ranked by number of publications on industrial doctorates to December, 31st 2023.

| Rank | Journal | Number of papers* |
|---|---|---|
| 1 | Industry and Higher Education | 10 |
| 2 | Higher Education | 3 |
| 3 | Studies in Higher Education | 2 |
| 4 | Higher Education Research & Development | 2 |

*Final sample size $N = 54$ articles.
Source: Authors' elaboration.

Studies in Higher Education, and Higher Education Research & Development, had published the highest (still quite limited) number of articles about industrial doctorates. Overall, the scope of the journals was higher education. However, given the practical and cross-sectoral nature of the issues related to industrial doctorates, texts appeared more frequently in Industry and Higher Education ($N = 10$). Indeed, this journal focuses on theoretical and practical aspects related to developments in education-industry collaboration. Figure 2 shows that the first articles mentioning industrial doctorates appeared in 2002, since then research interest in such doctorates has grown rapidly especially in the past decade. Indeed, about two-thirds of the 54 articles in the final sample were published after 2015.

As regards the geographical area considered in the studies reviewed, the majority of the papers focused on Europe. The Danish case is worth a special mention as Denmark has been one of the pioneers of government-supported industrial PhD programmes (Kolmos, Kofoed, and Du 2008). Indeed, the Danish Industrial PhD Programme was introduced in 1970 (Roolaht 2015). Such programmes only started to appear much later in various European countries, such as Sweden (e.g. Gustavsson, Nuur, and Söderlind 2016), Norway (e.g. Thune 2010), Finland (e.g. Jaakkola, Mikkonen, and Systa 2021), Germany (e.g. Grimm 2018), Italy (e.g. Tiraboschi 2015), Portugal (e.g. Cardoso, Tavares, and Sin 2019a) and the United Kingdom (e.g. Kitagawa 2015). It is worth noting that one stream of research focuses on the Australian case (e.g. Harman 2002; Manathunga et al. 2012; Tennant 2004). Although the literature has extensively investigated industrial doctorates in advanced countries, there are no studies on such programmes in developing economies.

As regards the methodology adopted by the papers included in this review, the sample can be divided into three main groups: the majority of cases are qualitative analyses (36 out of 54), and a

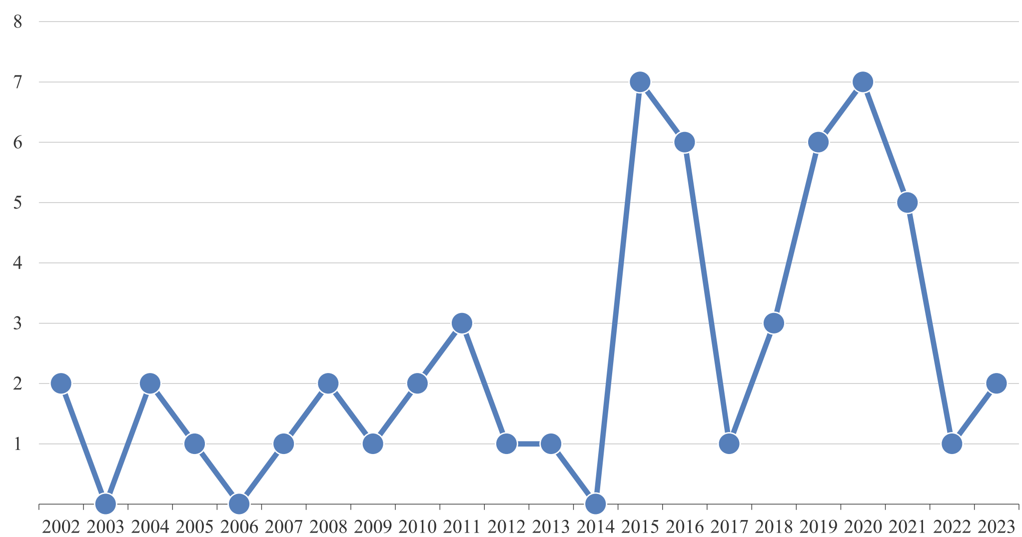


**Figure 2.** Publication trend for industrial doctorates from 2002 to December, 31st 2023. Source: Authors' elaboration.

few papers are theoretical–conceptual studies/model building (5 out of 54). However, there is limited quantitative evidence about the impacts of industrial doctorates on PhD students and graduates, firms, and the local entrepreneurship and innovation ecosystem. Indeed, few studies were based on either quantitative approaches (5 out of 54) or quali-quantitative analyses (6 out of 54). Almost all the quantitative papers were cross-sectional studies which collected data from different individuals at a single point in time and there are no quantitative longitudinal studies. This means that there is scant knowledge about the long-term dynamics at work in both the implementation and the impacts of industrial PhD programmes.

Regarding the characteristics of the samples examined in the papers, about one-third of the studies analysed two or more types of actors involved in industrial doctorates, bringing together, for instance, either the perspectives of both PhD candidates and representatives from the funding organisation (e.g. Bernhard and Olsson 2020), or the positions of both company representatives and academic supervisors (e.g. Grimm 2018). It is worth noting that 14 out of 54 articles were exclusively dedicated to the perspectives of PhD students and graduates. Few papers explored the position of firms.

Although industrial PhD programmes are increasingly supported and implemented by national and regional governments (Bernhard and Olsson 2020; Yang 2022), that benefit from funding firms, there is still very little empirical evidence in the literature regarding the impact of policies for industrial doctorates.

## 4. Thematic analysis

The following subsections illustrate the thematic analysis by focusing on the six key themes obtained from the systematic review: what industrial doctorates are; the design and implementation of industrial doctorates; the perspective of PhD candidates; industrial doctorates through the lens of the university; industrial doctorates through the lens of industry; and, industrial doctorates as policy tools. In addition, subthemes are presented for each theme, following Table 3.

### *4.1 What are industrial doctorates?*

The literature has defined industrial doctorates as educational programmes which 'involve collaboration between universities and companies to promote innovation with the cost, supervision and outcomes of doctoral work being shared by industrial actors, funding bodies and academia' (#53, 891). PhD students must be enrolled in a doctoral programme and focus on a research project that starts from challenges identified by or in cooperation with business organisations. This applied approach is then reframed together with researchers (#15; #42). Indeed, academic supervisors usually adapt the research topics in order to ensure their alignment with the PhD programme, also ensuring scientific quality (#53).

Industrial doctorates should give candidates both cutting-edge knowledge and soft skills (#14; #57). Thus, such PhD programmes broaden 'the spectrum of graduates' career paths by providing real professional alternatives to an academic career […] and thus enhancing graduates' employability (#53, 897). However, the content and regulations of industrial doctorates vary slightly between countries and funding agencies (#14; #28; #38), since there might be differences in objectives, institutional forms, structures of the programmes, funding sources, procedures for admission and supervision (#28; #38; #62; #66).

The term 'industrial' does not necessarily always refer to employment in manufacturing industries or private companies (#36). Initially, industrial doctorates targeted firms seeking to develop products that could benefit from academic research in the Science, Technology, Engineering and Mathematics (STEM) disciplines. Over the years, other academic fields, including the Social Sciences and the Humanities (SSH), have started to offer similar doctoral formats, thus broadening the perspective of industrial doctorates (#20; #22) as training for a new generation of researchers (#56). According to the European Commission (2011, 6) 'the term 'industry' is used in the widest sense, including all fields of workplaces and public engagement, from industry to business, government, NGOs, charities and cultural institutions.

Indeed, of late, industrial doctorates have become more and more cross-disciplinary and cross-sectoral as they contribute to the development of products, technologies and services that might be useful to various economic actors (#51). In this context it is worth mentioning the emergence of flagship industrial PhD programmes, such as the Innovative Training Network (ITN) and the Integrative Graduate Education Research Traineeship (IGERT), which have been created and funded, respectively by the European Commission and the National Science Foundation of the US government (Balaban 2020). Although such programmes are still nascent, and more common in the STEM fields than in the SSH disciplines (Nerad 2020), they have been recognised as promising models because they are '(…) meant to "lead the way" in doctoral education and show what "future-oriented" programmes ought to be like' (Balaban 2020, 327–328). In particular, these programmes are aimed at training highly versatile professionals by adopting a cross-disciplinary approach. The latter seeks to address complex real-world problems, including environmental issues and data security, by leveraging on soft skills training and international collaboration (Nerad 2020).

On the one hand, industrial PhD programmes do offer an innovative model of university-industry cooperation (#25) that especially targets young graduates (#37), providing benefits for all stakeholders (#8; #24; #32; #53) as such doctorates 'seek to increase the match through collaboration between the university and the private company, or other research agency' (#36, p. 257). In particular, industrial PhD programmes can build bridges between the academic and the business sector, both by addressing competence gaps at company level (#23; #24), and by developing collaborative research where theory and practice converge (#63).

On the other hand, the literature has recognised industrial doctorates as alternatives (#14; #68; #70) or even as contraposed to 'traditional' PhDs (#15; #18). It means that there are cultural barriers to the diffusion of the industrial doctorate (#1; #22; #37; #57) which is still often seen as being a less important model of the conventional PhD (#25).

## 4.2 Design and implementation of industrial doctorates

### 4.2.1 Selection and admission of PhD candidates

Industrial doctorates have heterogeneous rules and procedures that discipline the selection of students and their admission to such programmes (#8; #65). In general, admission to industrial doctorates requires the candidate to show a high degree of correspondence of his/her profile and research aptitude for research and professional training (#51). In particular, recruiters have to assess the candidate's real interest and aptitude for integrating knowledge from both the industry and the university (#29).

However, the most challenging step of the recruitment process is assessing the candidate's real motivations for joining an industrial PhD programme (#18; #22; #25; #29; #71). While the motivation of traditional PhD candidates comes from academic career needs, the motivation of industrial PhD students should be related to stronger personal ambitions for non-academic positions (#18). It has been also asked whether it is worth for young people enrolling in an industrial PhD programme. Indeed, universities struggle to search, motivate and enrol industrial PhD students since industry has been increasingly attracting talents by offering higher salaries and by providing more benefits than academia (#71).

As regards Italy, the recruitment of industrial candidates is regulated through an open competitive selection process, like traditional PhD programmes. However, this procedure has proved to be unsuitable when doctoral programmes are organised in collaboration with companies which seek candidates with a particular motivation (#37). Indeed, it is important that during the selection process, all parties, including the candidate, should be made aware of the shared responsibility for achieving the project's goals and for adapting tasks to unforeseen situations (#25; #36). In the case of Sweden, recruitment is formally a university task. However, the selection process usually involves both university and firm representatives. Moreover, recruitment should comply with the policies aimed at ensuring gender quotas for financed PhD positions (#72)

#### *4.2.2 Training and skill development*

The literature has shown that industrial PhD training provides students with additional transferable competences to those offered by traditional PhD programmes (#28; #37). Indeed, courses offered by industrial doctorates usually place greater emphasis upon elements which strengthen the acquisition of soft skills that are valued by the non-academic labour market (#72). In particular, industrial PhD training focuses on work-based learning, envisioning a close interdependence between research, teaching activities, and the fulfilment of special assignments within the company or the funding organisation (#37). The training trajectories of industrial candidates can vary depending on five key factors: entrance conditions, the doctoral thesis project, supervision, individual ambitions, and institutional aspects, such as the organisation of the PhD school (#65). However, some studies emphasised that there is still no consensus between the funding partners and, even within the same university, about the opportunity of fostering such soft skills during PhD formation (e.g. #36).

On the one hand, candidates benefit from the training opportunities related to university-industry collaboration. Industrial doctorates provide students with work placements in multiple environments which strengthen professional skills and enable the development of solutions to industry-focussed challenges (#77). Along with individual research, candidates are also engaged in work groups, courses on intellectual property rights protection, financial management, marketing, communication and, the use of social media to disseminate research outputs (#36; #37; #63). Furthermore, industrial doctorates aim to develop a broad range of entrepreneurial soft skills, including networking, teamwork, problem solving, intercultural knowledge and negotiation (#36; #54; #60; #63; #68).

It has demonstrated that the competence that emerged as the most important was business awareness, a term which, for PhD candidates, includes learning about the business environment and practices, as well as producing research outputs with practical applications (#54). It means that students should develop an 'entrepreneurial mind-set' (#54, 3021). Furthermore, compared to traditional doctorates, industrial PhD programmes seem to be more and more focused on understanding sustainability challenges and the development of environmental awareness (#63).

On the other hand, some works have revealed that transferable skills are acquired only during on-demand occasions. In addition, the degree of acquisition of these skills depends on the characteristics of the funding partner and might vary considerably from candidate to candidate (#28). Assbring and Nuur (2017) (#66) stated that skills development seems inadequate when it is provided by small and medium sized enterprises, or when there is lack of structured placements under the joint supervision of both the firm and the university. In the case of Portugal, it has been demonstrated that compulsory coursework seems not to add value to students' skills development. The relevance of coursework increases when PhD candidates are given the opportunity to choose courses which are related to their research topic (#17).

#### *4.2.3 Knowledge production*

Industrial doctorates have been regarded as 'learning communities in support of specific research projects' (#3, 368), providing PhD candidates with the tools for developing and disseminating cutting-edge knowledge, which falls at the intersection between research and training within an industrial context (#38).

Industrial programmes provide candidates with the opportunity to apply research techniques in emerging fields and to create an impact on the business environment (#57). The most important benefit for PhD students is that of being close to business networks, and of having privileged and rapid access to empirical data, producing valuable academic knowledge (#1; #21; #42; #72).

Nevertheless, industrial candidates have to manage tensions regarding their research outputs. On the academic side, students are expected to produce and disseminate knowledge, which implies the publication of scientific articles. On the industry side, since data confidentiality and firms' policies on intellectual property are paramount, research findings need to be protected from competitors. The obligations to publish research results and, at the same time, to ensure data confidentiality might well reduce academic freedom and so pose barriers to open science (#8; #19; #36; #57).

While extant research has demonstrated that industrial PhD candidates achieve good performances in knowledge production according to established academic standards, it has been recently argued that several industrial programmes do not fully meet academic standards (#15). Furthermore, some empirical studies have revealed that industrial candidates spend more hours per week on knowledge production tasks than do students enrolled in traditional doctorates (#67; #68).

It is worth considering that knowledge production does not only depend on the availability of, and access to libraries and services, financial resources, business networks and specialised equipment (#67; #68). Indeed, knowledge production is also influenced by the university-industry relationship and, especially, by the business environment where the student has to spend half of his/her time (#32; #45; #65). Wallgren and Dahlgren (2005) (#64) identified three types of environment that affect the research activity of the PhD candidate. The research-intense environment is close to the academic context where knowledge is collectively generated and assessed through peer review. In an engineering environment knowledge production is context-related as it depends more on the company's processes. Moreover, responsibility for the knowledge developed is varied. Whereas, in a consultancy environment, there is no common knowledge developed between the firm and the academic institution.

#### *4.2.4 Supervision*

Supervision makes the management of industrial doctorates even more complex than traditional doctorates because, on the one hand, it implies higher accountability for the PhD candidate who has to respond to both an academic and a company supervisor; on the other hand, there is greater responsibility put upon both supervisors whose duties are not always clear and risk overlapping.

The literature agrees upon the importance of ensuring effective joint supervision in order to guide a PhD candidate during training and developing a shared research project (#29; #53; #66). To do so, industry needs and academic research must be aligned through an ongoing process of revision, performed by both the university and the firm supervisors, for the entire duration of the PhD programme (#41). This enhances both a continuous exchange of information and the quality of research (#19; #22; #28). Furthermore, supervision should focus on the coordination of all the disciplinary sectors and initiatives related to the PhD project, in order to ensure both the acquisition of soft skills and a broader impact of the research project (#41; #51).

One stream of the literature revealed that divergences at the level of supervisors might hinder, or even interrupt, doctoral training. In particular, it seems unclear whether the academic supervisor should manage the relationship with the funding firm or he/she should cooperate with the company tutor (#8; #28). Salminen-Karlsson and Wallgren (2008) (#78) suggested that academic supervisors do seem to look after the interests of their industrial sponsors at the expense of their PhD students.

For the academic supervisor, data confidentiality, and the firm's policy on IPRs, might lead to non-publishable research, thus discouraging the supervisor from dedicating sufficient time to the PhD candidate (#36). Moreover, growing workloads and diminishing resources, are forcing academic supervisors to focus more on the search for funding, thus they may spend less time supervising their students (#68). Indeed, it has been demonstrated that this has a negative impact especially on the integration of industrial PhD candidates into a supervisor's research group (#36).

Whereas, a firm's supervisor, who has to manage the interests of the company, may not be motivated, willing, or sufficiently experienced in coordinating doctoral students (#14; #19; #25; #36). To improve the quality of PhD supervision in firms, it has been suggested that the employee's role as PhD supervisor should be formally acknowledged within the firm's incentives system (#25). Moreover, given that the candidate has to work both at the university and in the company, physical proximity of the two locations makes it easier to carry out the doctoral programme in an effective way. Indeed, it has been empirically demonstrated that the closer the physical proximity of the supervisors and the PhD student is, the higher will be both the quality of the supervision and the level of the student's participation in the training programme (#65).

#### 4.2.5 Doctoral schools

Along with the diffusion of doctoral education, there has been a progressive professionalisation in the organisation of the doctorate which usually takes the form of a doctoral school (Amaral and Carvalho 2020). On the basis of the exemplary model of American Graduate Schools, different types of PhD schools have also been established in several European universities (Baschung 2016; 2020). To do this, higher education institutions and governments have adopted a managerial approach, seeking to align tertiary education with their regional and national targets (Amaral and Carvalho 2020).

Under this framework some PhD schools have started to offer cross-disciplinary and cross-sectoral programmes, including industrial doctorates. In some cases, such structures have been formally established as industrial doctorate centres (#37; #65; #68). It is worth noting that the names attributed to such schools, as well as their organisation and activities vary widely depending on their geographical location, national regulations, the nature of the collaboration between the university and the actors of the innovation ecosystem and, the distinctive features of the industrial sectors involved in the doctoral programme (#38; #65). However, the increasing interest in doctoral schools to provide cross-sectoral programmes and training in soft skills, has mainly been determined by the growing expectations of both policy-makers and students, respectively, to promote and undertake employment in sectors of strategic importance for their regions, given the lack of academic positions (Amaral and Carvalho 2020).

One branch of the literature maintained that PhD schools contribute to establishing a long-term linkage mechanism for cooperation between universities, funding firms, public bodies and knowledge users (#24; #37; #68), thus leading to a wider network with increased career and mobility opportunities for both PhD students and graduates (#24; #68). However, PhD schools do give results beneficial to all those funding partners who can benefit from a privileged position within the initiatives set up by the school. Indeed, doctoral classes can focus on introducing current challenges related to various domains, such as business, engineering, environment, and humanities (#37), thus stimulating students to develop innovative ideas that could be turned into new products, services or job positions (#68).

In Sweden, both universities and their PhD schools have been offered funding on condition that they agree to cooperate with companies to train industrial PhD candidates (#65). Thus, doctoral schools have been used there as a platform for achieving national innovation goals by linking stakeholders of the entrepreneurial and innovation ecosystem (#68). Innovative technologies and processes have also been developed in the UK, using a similar type of framework in order to address environmental issues, such as in the water sector, and for fostering the social acceptability of public policies. In the Italian case, Casano (2015a) (#58) stated that PhD schools focused on industrial programmes, fostering the conditions which support the cooperation between heterogeneous stakeholders, including public institutions and firms. To promote ad-hoc training programmes and to plan effective placement schemes, both academic and industry representatives should be engaged in the design of flexible courses which tend to balance the needs of the stakeholders involved in the doctoral programme.

### 4.3. The PhD candidate's perspective

The literature has argued that the motivations to attend an industrial PhD programme are heterogeneous. Furthermore, PhD candidates' expectations vary considerably depending on the distinctive features of the programme selected, the socio-economic characteristics of the regional and national contexts, and the degree of engagement of industrial partners in the doctoral programme (#60; #77).

Some candidates desire to become academics. However, the lack of positions and the slowness of career progression within the university, impacts negatively on the willingness of industrial PhD students to remain in the academic environment. Doctoral students also seek to earn a higher salary than 'traditional' PhD holders. This is especially true in the case of STEM candidates who are more frequently employed in the business sector rather than for PhD holders in SSH disciplines. The latter expect to work for government institutions rather than being employed at the university or performing research-driven activities in the business environment (Horta 2020). Moreover, students enrol in industrial PhD programmes because they expect to get in-depth knowledge of a specific topic or to train their soft skills in order to develop an entrepreneurial-driven approach (Balaban 2020). In addition, candidates may be motivated by the learning a PhD programme provides or by the feeling of accomplishment it evokes (#18; Tavares, Sin, and Soares 2020a). PhD candidates also have expectations in terms of further and more heterogeneous rewards, including grades, and social and parental approval (Tavares, Sin, and Soares 2020a).

Although some studies did demonstrate that industrial candidates show a level of satisfaction with their training and study outcomes, similar to traditional PhD students (#62), the literature also reported that the majority of industrial PhD candidates often have little understanding of what it really means to be a doctoral student when they began the programme. In particular, they find it difficult to understand what is expected of them, and the boundary between practice and theory. Furthermore, candidates usually have little knowledge about what they will be able to do after they have finished their studies (#65).

Several scholars argued that industrial PhD candidates may struggle to balance their time between university and industry because they have both to accomplish multiple professional tasks, and work on their research project (#21; #42; #45). PhD students consider time as a scarce resource that needs to be allocated effectively (#31; #32) because a firm may impose both a high workload and tasks that change rapidly, thus stressing the student (#26) and forcing him / her to interrupt their research work, sometimes for long periods of time (#18; #24).

The majority of industrial PhD students have experienced feelings of loneliness (#21; #45; #65). Among the causes is the fact that they find it difficult to perform their academic and industrial tasks, which are very different, simultaneously. Since PhD candidates 'have one foot in academia and one in work–life', they may often find it difficult to both balance and switch between, the different roles (#1).

Sometimes, the lack of quality of the supervision (#68) and the supervisor' lack of commitment to the role (#65), pose important difficulties for PhD candidates. According to the students, these constraints might, or could, be partially overcome by encouraging supervisors to arrange more informal contacts when the opportunity arises (#33; #42). Overall, it has been stressed that a more student-centred focus in the university-firm cooperation could also improve students well-being. To do this, the interests, culture, and practices of both the university and the business representatives, should be shared with the students (#76).

One stream of literature focused on employment and career development for industrial PhD candidates. Thune (2010) (#60) is among the first scholars who highlighted that the results of research on whether industry–university partnerships lead to better employability are inconclusive, since, at that time, the majority of studies focused on PhD candidates' career ambitions or perceptions, rather than on their real careers. Several studies also discovered that the majority of industrial PhD graduates do find employment outside universities. Indeed, recent data have shown that there has been a steady growth in the number of PhD graduates employed in the private sector, in government agencies or in public organisations (#37; #53; #62; #63; #67). Moreover, several PhDs continue to work in the same business sector, or even in the company, that funded the research project (#32; #66).

Unlike students enrolled in traditional doctoral programmes, industrial PhD candidates emphasise the value of working in a professional environment, of being exposed to business dynamics (#63), and of learning competences, such as negotiation and project management, that can help them to better understand the potential applications of their research (#68). More recently, Bröchner and Sezer (2020) (#72) have found that industrial PhD graduates usually achieve managerial positions. Indeed, they show strong confidence in themselves about managing a company's resources and targets, since doctoral education has strengthened their ability to address knowledge-based challenges in a more holistic manner.

Industrial candidates usually agree that firm funding has long term impacts on career patterns (#60; #67; #68). Furthermore, both the distinctive features of the national context and disciplinary differences exert an important impact on candidates' career prospects in terms of sector of employment (#73). This means that further longitudinal studies, considering national features, are needed to monitor and understand the career development of industrial PhD graduates.

A stream of literature has argued that industrial PhD holders who choose to remain within academia, often find themselves working at its interface with other parts of society. In addition, they state that traditional academic values are not threatened by corporate values and practices (#67). On the other hand, it has recently been reported that the business culture negatively influences PhD students' career prospects in academia, especially with regard to research outputs, since publishing may even act as a barrier during doctoral training (#76).

### 4.4. Industrial doctorates through the lens of the university

Although the number of industrial doctorates is growing globally, scholars and academic institutions remain divided as regards the legitimation of such new forms of doctoral education and question their further development. A large body of the literature argued that there is a need for change in doctoral education because the knowledge economy challenges the idea of the university as a community of autonomous scholars isolated from society. Furthermore, graduates are increasingly expected to be equipped with knowledge of how to apply their skills for innovation and entrepreneurship in practice. This reform could take two directions. One is to slightly modify the traditional PhD to accommodate more practical forms of research; the other is to further develop new PhD programmes such as industrial doctorates (#8; #70).

Several studies have recently demonstrated that industrial PhD programmes reinforce the academic environment in various ways: (i) by increasing the number of doctoral students enrolled; (ii) by involving the business sector in defining applied research projects; (iii) by accessing external funds; (iv) by implementing innovative projects that increase the competence level of both individual academics and research groups (#29; #32; #53). Some authors have also argued that industrial doctorates are especially beneficial to academic institutions located in peripheral regions and to those universities which do not have a long-standing research tradition (#66), as they enhance both their performance in the commercialisation of research and their participation in the knowledge-based economy (#16). Furthermore, industrial doctorates offer an effective way of enhancing university-industry collaboration, as a response to the expectations of doctoral candidates (#53).

On the other hand, it has been argued that further transformations of doctoral programmes towards the knowledge economy, should be rejected. According to Grimm (2018) (#25) and Usher (2002) (#69), it would be better to strengthen both the cultural function of universities and traditional theory-based doctoral education. Since funding is limited, it might seem reasonable to allocate resources to reinforcing the role of academic institutions as knowledge producers rather than offering further support for university-firm collaborations for industrial doctorates (#25).

Some studies have also suggested that further increase in the number of industrial PhD candidates could lead to 'overproduction' of PhD holders, which could reduce the standing of the PhD (#66; #69). When considering the distinctive features of a developing country, Herman (2013) (#71) warned that doctoral knowledge is regarded as 'desirable', 'a luxury' or 'superfluous', with firms usually preferring lower-grade skills (#71, 217). More recently, it has been highlighted that industrial doctorates could compromise both the universities' autonomy and the candidates' freedom to choose their research interests because students will have to focus on a set of business challenges and on a firm's obligations (#8; #14), which may result in lower research quality and lower publication incentives (#25).

### *4.5. Industrial doctorates through the lens of industry*

Firms involved in the funding and the implementation of industrial PhD programmes, are usually knowledge-intensive firms which have previously collaborated with academic institutions and which employ staff with postgraduate qualifications (#60). These firms have strengthened their ties with research environments and also contribute to designing the research project, to organising initiatives for building the relationship between PhD candidates, academic supervisors, and companies' representatives, and to fostering students' entrepreneurial skills (#23).

As regards the motivations for participating in industrial PhD programmes, Thune and Børing (2015) (#75) found that both small and large companies are quite similar in terms of motivations since they both seek to develop innovation-related competences, and knowledge in core area of their business. Furthermore, companies often seek to have better access to the customised scientific knowledge they need to develop products or processes (#21; #29; #32; #36; #55). Firms also engage in doctoral programmes in order to review processes, functions, and services (#37), so as to reinforce their competitiveness (#21; #26; #32; #36; #66).

Along with creating collaborations with business actors and research institutions (#21; #24; #66), firms may also play an active role in doctoral education in order to both enhance their attractiveness as an employer (#26; #32; #75) and to legitimise, or valorise, their organisation and products (#21; #26; #66).

Although representatives of firms usually report that companies are not familiar with long-term academic deliverables such as papers, books and conference presentations, they do usually seek to understand the tasks of PhD candidates (#42) and to match their targets to the overall goals of the research project (#15). However, caution should be exercised when generalising such results. Indeed, the dynamics between the representatives of firms and students should be evaluated on a case-by-case basis, since both a company's size, and R&D intensity, exert an important impact on how research is carried out by the PhD candidate (#23; #25; #37; #38; #60). In particular, firms that are more focused on R&D are also more active in doctoral supervision, and report more positive gains than those that have little experience in the R&D field (#62). Given the lack of their resources, small firms operating in less-developed areas, are often not able to either participate in PhD programmes or to provide adequate supervision and training (#36; #66).

One branch of the literature emphasised that industrial doctorates are not always a 'trouble-free marriage' (#19, 1). Kihlander et al. (2011) (#42), firms usually have to manage challenges related both to integrating academic knowledge into business practice, and to adapting their workflows to the university's longer times for task accomplishment (#21). There are also divergences, or even conflicts, between the representatives of firms and academic supervisors mainly due to differences in organisational cultures, values, and interests (#15; #36; #57).

In particular, some firms report that academic incentive systems, and the time devoted to research, are rarely compatible with a company's workload (#21; #25). Along with frequent, severe delays in the dissertation, that represent an extra cost for the company (#31), firms argue that PhD candidates often have only limited pre-understanding of both the industrial or commercial environment and of the dynamics involved. Furthermore, within industrial PhD programmes, firms have to spend too much time balancing their need to protect IPRs (#21) and the candidate's need to publish research results, which may not be advantageous for, or in favour of, the company (#42).

### *4.6. Industrial doctorates and policies for innovation*

The interwoven relations between university, industry and government are becoming an important feature of industrial doctoral training (#29). The literature has placed partnerships for industrial doctorates within the Triple Helix Model of innovation (#62; #65; #66). This model includes the following agents: university, industry and government (Etzkowitz 1998); and it explores these stakeholders' relationships in order to explain the dynamics of knowledge-based economies. Furthermore, the Triple Helix Model seeks to foster a systemic framework for the generation, diffusion and exploitation of knowledge and innovative solutions (Etzkowitz and Leydesdorff 2000).

The Model focuses on the expanded role of higher education institutions which should be providing doctoral students with cross-disciplinary knowledge and knowledge transfer skills. As regards the industry helix, companies offer both research grants and training opportunities. The government-helix stimulates university-industry collaboration for doctoral education through support policies and grants (#8). Furthermore, governments usually mediate the interactions between academia and businesses (#28), by engaging regional industries in a continuous entrepreneurial discovery process for building knowledge and designing strategies accordingly (#66).

Under the Triple Helix Model, industrial doctorates have been recognised as a strategic policy tool for diversifying the role of PhD graduates in the economy (#66), for fostering cooperation at both the national and the European level, and for implementing regional innovation strategies (#36; #51). Indeed, this model is being adopted more and more as a source of inspiration for local development policies, aimed at improving the conditions for innovation (Etzkowitz and Zhou 2018). For instance, the European Union finances industrial doctorates when there is consistency between the PhD research topic and, at least, one of the areas of regional specialisation (#36). In international settings, for example in Australia, industrial PhD programmes are government-led initiatives that educate 'industry-ready graduates' (#68, 387) to generate and use innovative ideas through long-term strategic research and technology transfer (#67). To do so, some Australian universities seek to enhance the capabilities that PhD students develop through independent research into the abilities required for employment within the helix model (#60).

Within the framework of the Triple Helix Model, industrial doctorates train PhD students to speak 'both academia and practitionese' in order to translate knowledge into a language that the company is familiar with (#42). Three main roles are assigned to PhD candidates: (i) they produce knowledge in collaborative research projects; (ii) they channel knowledge transfer between universities and firms by forming a critical mass with other researchers and companies; and (iii) they are crucial in network configurations between academia and businesses (#24; #29; #55; #60; #62). This means that PhD students participate in the formation of a new paradigm for knowledge formation (#64), thus further expanding triple helix interactions (#60).

## 5. Conclusion

This review has sought to define the state of the art of the literature on industrial doctorates which has mainly focused on six key themes, namely: the distinctive features and evolution of industrial PhD programmes; the design and implementation of industrial doctorates; the perspective of PhD candidates; the standpoint of university; the viewpoint of industry; and, industrial doctorates as policy tools for fostering innovation processes.

Our results could be useful in terms of their implications for policymakers, academic governance, and scholars.

Our analysis revealed both a temporal and geographical concentration of papers on industrial doctorates. Most studies only appeared after 2015, despite the fact that the first industrial PhD programme was introduced in Denmark in 1970. Furthermore, the majority of the papers have, so far, focused on the European context.

One reason why scholars interest in industrial doctorates has increased only relatively recently might be the result of changes in doctoral education itself brought about by the emergence of the Third Mission of universities. This latter has effectively challenged the role of academia in leveraging talents, and has further stimulated applied research and collaboration between university, industry and government. Second, there might well also be policy reasons, mostly in Europe, for scientists increased interest in industrial doctorates. Indeed, the European Union (EU) has now recognised higher education as a priority area for achieving smart, sustainable, and inclusive growth and, since 2011, it has included industrial doctorates in its policy agenda for research, innovation and employment (European Commission 2010). Furthermore, Marie Skłodowska-Curie Actions (MSCA) Industrial Doctoral programmes, a flagship initiative for the advancement of industrial doctorates, was introduced in 2014 and has, since then, been promoting PhD programmes via partnerships between universities, firms and other socio-economic actors. In the US, similar goals were sought in the Integrative Graduate Education Research Traineeship (IGERT), of the National Science Foundation of the US government (Balaban 2020). As highlighted by Cardoso et al. (2022, p. 893), initiatives by supranational actors can have a 'transformative effect on doctoral education' and, also, on the way diverse stakeholders in the innovation ecosystem perceive doctoral education. Indeed, following such umbrella programmes, various national governments, especially in Europe, have been encouraging universities to increase the variety of PhD programmes, and doctoral degrees awarded, thus providing graduates with the skills required to address the needs of both academic and non-academic organisations, and thus stimulate more cross-disciplinary and cross-sectoral cooperation. This has led to the increase in industrial doctorates in European countries e.g. Sweden, Norway, Finland, Italy, Germany, France, Portugal, Estonia and the United Kingdom.

To the best of our knowledge, there is little empirical evidence regarding industrial doctorates in other contexts or areas, such as Australia, China, or emerging economies. There could be various reasons for this lack: the specific geographical area, the distinctive features of university system (public vs private), as well as the innovation strategies developed by governments. These latter might, or might not, see tertiary education as one of the tools for promoting industry-academia cooperation. For example, Europe has a mainly public university systems and the EU, and its Member States, have been using education as part of their strategy to reduce domestic innovation capacity gaps.

Our results also show that there have been several qualitative studies on industrial doctorates; however, quantitative approaches are rarely adopted, perhaps due to the difficulties posed by collecting comparable data from a wide variety of heterogeneous actors (e.g. local and regional governments, universities, industries, PhD candidates, PhD graduates) or, more simply, that such doctoral initiatives have only been promoted relatively recently. In particular, there is a lack of longitudinal studies on the impact of industrial PhD programmes. This deficit must be addressed in order to advance theoretical investigation and to provide empirical evidence to support, and assist in, the design and implementation of policies and measures for industrial doctorates. To do this, data collection among the key actors involved in PhD programmes must be increased and, importantly, aligned. Furthermore, data collection should continue even after such programmes have concluded, in order to capture, understand the dynamics at work in PhD students' career development paths.

The literature has reported that industrial doctorates have changed doctoral education in many countries, especially as regards the mechanisms through which knowledge flows between university, industry, government and society, and render doctorate boundaries even more porous. Such doctorates reflect how much universities and firms share when coping with the 'matching dilemma' between doctoral education and regional industries (Assbring and Nuur 2017, 191). Overall, there has been increasing collaboration between universities and firms for industrial PhD programmes, suggesting that both the number of such programmes, and of doctoral positions, could increase in the coming years. Nevertheless, industrial doctorates vary from country to country as regards research policies, objectives, programmes, selection procedures, supervision, training, and skills development. This means that there must be further exploration, understanding, of the distinctive features of national contexts in order to identify a set of common, agreed, good practices that are generated by the partnerships set up for industrial doctorates. As the literature confirms, industrial doctorates are reshaping the doctoral education landscape in several countries, but there further investigations are required to assess whether they offer an effective response, or an optimal approach, to meeting the demands of both the knowledge society and doctoral candidates. Indeed, there is still disagreement regarding the legitimation, diffusion, and further development of such doctorates. The literature has emphasised that there are both institutional and cultural barriers to the establishment of industrial doctorates.

As regards the institutional barriers, several studies have considered the question of the appropriateness of standards and the evaluation criteria of a traditional PhD that are used for assessing both industrial PhD programmes and candidates. Because research outcomes, training and workload differ considerably from conventional doctorates, new indicators should be elaborated in order to consider both the unique features of the collaborative research performed within industrial doctorates, and their role within the ecosystem of entrepreneurship and innovation. Furthermore, the literature has argued that there are still inadequate resources for industrial doctorates. The lack of appropriate funding is also one reason why students may not complete their degrees. Funding also implies complex negotiations between university-firm-government all of which have heterogeneous values and interests at stake.

As regards the cultural dimension, the rationale for collaboration seems to be the prior existence of relations between academics and firm representatives. Other reasons are promoting knowledge transfer, strengthening firms' innovation and competitiveness, increasing universities' research funding, and fostering PhD holders' employability outside academia. Indeed, industrial PhD graduates experience a learning process in a dual context, thus developing the capacity of adaptation, flexibility, and an applied-driven approach to addressing business challenges.

However, universities and firms may have a different conception of research. This often results in these stakeholders having unrealistic expectations as regards one another. The literature has highlighted the different understandings of a PhD workload, timespan for assigned tasks, use of research outcomes, and heterogeneous value systems. Furthermore, policy-makers usually have exaggerated expectations of PhD candidates, presuming that students will be 'academic doers making a difference straight away' (Malm and Löfdahl 2020, 353).

In conclusion, doctoral research training should meet the dual challenge of preparing future academics and industrial/societal scientists at the same time. To do so, the academic supervisor should stimulate the PhD student to develop an entrepreneurial mind-set and the firm supervisor should also try to understand and respect the values and the institutional missions of the university. Instead of contraposing industrial doctorates to traditional PhD programmes, academic institutions, scholars, firms, and governments should acknowledge and enhance the distinctive features of industrial doctorates.

Despite the limitations of our paper, presented in Section 2, mainly in terms of outlined methodological strategy, and characteristics of the systematic literature review, our findings may well pave the way for an agenda for future research.

Future studies should consider both the distinctive features of industrial doctorates and the growing interactions between university, industry and government. Moreover, there is the need to further investigate, and to design, an effective university-industry ecosystem of innovation for PhD students. Future analyses should also examine both the impact of industrial doctorates and the perspectives of candidates, university, industry, and government, when designing and implementing policies and measures for industrial PhD programmes. Lastly, it could be interesting to compare different practices at the international level, involving also emerging economies, such as China for example, that have enacted long-term industrial policies for structural change coupled with the transformation of tertiary education. Two promising research areas could be related to 'the rules of the game' and 'the key players in the game'.

### *5.1. The rules of the game: beyond traditional criteria and settings*

Future research should provide further quantitative and qualitative evidence to assist in the design of good practices and tools for implementing and evaluating industrial PhD programmes, especially as regards selection procedures, training, skills development, knowledge production, evaluation criteria, the study/work environment and supervision (Bernhard and Olsson 2020; Casano 2015b; Jaakkola, Mikkonen, and Systa 2021; Kolmos, Kofoed, and Du 2008; Malm and Löfdahl 2020; Roolaht 2015). In addition, future studies should promote understanding of any cultural divergences that hinder further development of such PhD programmes. To do this, the distinctive features of different national and institutional contexts, and of diverse scientific fields must be taken into account (Santos and Patrício 2020).

### 5.2. The players in the game

a) University and candidates

Further attention should be paid, especially through longitudinal analyses, to the impact of industrial doctorates on PhD students' expectations, future employability, mobility, and career development (Assbring and Nuur 2017; Bernhard and Olsson 2020; Cardoso, Tavares, and Sin 2019a; 2019b; Chiang 2011; Izquierdo et al. 2015; Jaakkola, Mikkonen, and Systa 2021; Kolmos, Kofoed, and Du 2008; Manathunga et al. 2012; Roolaht 2015; Schlegel and Keitsch 2016; Thune 2010; Wallgren and Dahlgren 2005). In addition, future research should explore how industrial doctorates influence students' research outcomes, freedom of research and, importantly, the potential conflicts that may arise from dual (academic-firm) supervision (Cardoso, Tavares, and Sin 2019a; Granata and Dochy 2016; Sin, Soares, and Tavares 2021; Thune 2009; 2010; Wallgren and Dahlgren 2007).

b) Industry

Industrial PhD education is transforming along with societal needs, and creating a future workforce of researchers. Such changes require further empirical studies regarding university-industry collaborative arrangements for mutual learning and skills development (Bernhard and Olsson 2020; 2023). In addition, there is limited empirical evidence regarding the points of view of firms (Bernhard and Olsson 2020), regarding the impacts of industrial doctorates on firms, and on their interactions with other helix actors (Assbring and Nuur 2017; Grimm 2018; Thune 2010). Future analysis should contribute to advancing understanding of how to promote a shift from a traditional, unidirectional, technology transfer from university to firms, to a more dynamic concept of co-creation for innovation that involves all actors in the ecosystem of innovation, including also public entities, non-profit organisations, culture and creative industries, and associations. Perhaps the expression 'industrial doctorate' should be changed, as it seems too narrow, too restrictive to encompass all the areas it really extends to reach. Indeed, the new European Doctoral Networks implement PhD programmes, by partnerships between a wide variety of socio-economic actors, not only industry, thus promoting a broader meaning of knowledge transfer.

c) Government

Although industrial doctorates have broadly been presented as strategic policy tools (Assbring and Nuur 2017; Kitagawa 2015) for enriching PhD student training and employability (Cardoso, Tavares, and Sin 2019b), and for boosting the development of key industries (Assbring and Nuur 2017; Roolaht 2015; Vitiello and Castelluccio 2019), there is limited, at times inconsistent, evidence regarding the economic and social impacts of such programmes, which have to be integrated into cost–benefit analyses when supported by public resources (Danish Agency for Science Technology and Innovation 2011). In particular, there is little knowledge, at either the national or regional level, about the long-term effects exerted by industrial doctorate programmes on innovation performance and, also, on how such programmes might be able to contribute to enhancing, strengthening the alignment between education and innovation policies (Marinelli et al. 2018). Furthermore, there is also little information regarding the dynamics at work between, and among, the governments, universities and firms involved in designing, funding, and implementing industrial doctorates (Gustavsson, Nuur, and Söderlind 2016; Yang 2022).

## Notes

1. The Bologna Declaration aimed at creating a European Higher Education Area.
2. The Lisbon Strategy aimed at defining a European Research and Innovation Area.

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