https://doi.org/10.51408/issi2025_011

Shaping Innovation: A Regional Perspective on Industrial PhD Programs in Italy

Tindaro Cicero[1], Annalisa Di Benedetto[2]

[1]*tindaro.cicero@unimercatorum.it*
Department of Engineering and Science, Universitas Mercatorum (Italy)

[2]*annalisa.dibenedetto@istat.it*
Directorate for Social Statistics and Population Census, Italian National Institute of Statistics (ISTAT) (Italy)

Abstract

Doctoral education has evolved into a strategic asset for connecting academic research with industry needs. Industrial PhDs promote collaboration between universities and the private sector, aligning with the Triple Helix model of interaction among academia, industry, and government. In Italy, reforms under the National Research Plan 2015–2020 and Ministerial Decree n. 45/2013 introduced innovative doctoral programs, including industrial and intersectoral PhDs, emphasizing integration with non-academic sectors. These programs benefit from EU FSE/FESR funding, requiring formal agreements with companies, joint project design, and training periods within companies or abroad. In 2021, stricter criteria for Industrial PhDs mandated specific scientific projects and company representation in Steering Committees, enhancing their alignment with industry needs. This study examines Industrial PhD programs in 2022–2023, using text analysis (LDA) on program titles to identify thematic areas like digital transformation, sustainability, and advanced manufacturing. Spatial analysis explores the relationship between program distribution and regional innovation performance.

Preliminary findings suggest a growing alignment of Industrial PhDs with innovation hotspots, as evidenced by changes in spatial distribution and program focus. This indicates strategic diversification, influenced by funding policies and strengthened academia-industry partnerships, fostering innovation and regional economic development.

Introduction

The importance of doctoral education has grown significantly in recent years, not just as a means of advancing academic knowledge but also as a strategic asset in bridging the gap between research and industry needs (Shin et al., 2018). This transformation is particularly evident in the case of industrial PhDs (Roolaht, 2015; Borrell-Damian et al., 2015; Borrell-Damian et al., 2010; Harman, 2008; Thune et al., 2012), which aim to align closely with the needs of modern economies by fostering collaboration between universities and the private sector. The shift in doctoral education reflects broader societal and technological changes, emphasizing practical skills and knowledge transfer relevant to non-academic careers (Bernhard & Olsson, 2020; Haapakorpi, 2017; Jones, 2018).

Industrial PhD programs are increasingly recognized as vital in promoting innovation, particularly within the framework of the Triple Helix model, which highlights the interplay between universities, industry, and government (Thune, 2010; Gustavsson et al., 2016). Doctoral students are increasingly recognized as central to fostering university–industry collaboration, serving as conduits for

knowledge transfer and sharing. Studies have shown that their research activities enhance these interactions, particularly when public policy initiatives actively promote such relationships (Santos et al., 2021; Thune, 2009). By embedding PhD students directly into industry settings, these programs enable a continuous exchange of knowledge and skills that benefit both academic and industrial partners. This approach not only accelerates the application of research but also enhances the employability of graduates in sectors outside academia, addressing the often-cited challenge of underemployment among doctorate holders (Grimm, 2018; Leogrande at al 2022).

Studies have shown that industrial PhD initiatives contribute to regional economic development by leveraging university expertise to solve practical industrial challenges, thereby enhancing competitiveness (Gustavsson et al., 2016). Moreover, they foster a culture of innovation through collaborative projects that bring together diverse stakeholders to co-produce knowledge and technological solutions (Sjöö & Hellström, 2019). This model has been particularly successful in countries like Sweden, where industrial PhDs have been used to strengthen ties between academia and industry, promoting sustainable economic growth (Olsson & Bernhard, 2023).

However, despite these advantages, challenges remain in effectively managing these collaborations. Conflicting priorities between academic and industrial stakeholders can complicate the execution of joint projects, as each party may have different expectations regarding outcomes and timelines (Grimm, 2018; Bienkowska & Klofsten, 2012). Addressing these challenges requires robust frameworks that facilitate communication, trust-building, and mutual commitment, ensuring that industrial PhD programs deliver value to all participants (Bernhard & Olsson, 2020; Thune, 2010).

While much of the existing literature has focused on the broader benefits of industrial PhD programs and their successful implementation in countries like Sweden and Norway (Gustavsson et al., 2016; Thune, 2010; Sjöö & Hellström, 2019), relatively little attention has been paid to their development and characteristics in the Italian context. The dynamics of industrial PhD programs in Italy remain largely underexplored, particularly in terms of their integration within the national doctoral education framework, their relative weight in the overall doctoral system, and their geographical distribution. Existing studies have often focused on local or regional contexts (Compagnucci et al. 2024), thereby limiting a comprehensive understanding of their role at the national level.

This study seeks to fill this gap by providing a detailed analysis of the Italian case, in order to situate Italy's approach within the broader European landascape and allow for an assessment of best practices and policy transferability.

The purpose of this paper is to analyze the characteristics of industrial PhD programs, focusing on their development at the academic level and their geographical distribution. Specifically, the study addresses the following research questions:

i. What are the characteristics of Industrial PhD programs in Italy and in the main European experiences?

ii. What is the proportion of industrial PhDs within the entire set of doctoral programs?

iii. What is their geographical distribution across the territory?
iv. The concentration of industrial PhD programs are linked to the region's innovation performance?
To address these questions, public data provided by ANVUR, the Ministry and the European Commission will be utilized, as described in the specific section. By examining these aspects, this study aims to contribute to the ongoing discussion on how to optimize industrial PhD programs to maximize their impact on innovation, regional development, and the broader goals of economic and social sustainability. Furthermore, this analysis provides a foundation for understanding how the Italian experience compares to international benchmarks, contributing to the global literature on the role of industrial PhDs in fostering innovation and economic development.

The Italian context and the main European experiences

In Italy, with a note dated August 31, 2016, as part of the implementation of the National Research Plan 2015–2020, the Research Ministry introduced significant updates regarding innovative doctorates and work-based learning. The new ministerial guidelines set criteria to differentiate traditional PhDs from innovative doctorates, including the industrial/intersectoral doctorate, which promotes integration with sectors outside academia. These types are not mutually exclusive, with emphasis on valuing combinations among them.
Based on the concept of "collaboration with companies" of the Ministerial Decree n. 45/2013, the ministerial note now clarifies that accredited courses labeled as "Industrial PhDs" can be of two types: (1) courses in partnership with companies, which may reserve positions for employees of one or more companies; (2) conventional doctoral courses that include curricula developed in collaboration with companies. Specifically, the PON aimed at utilizing EU FSE/FESR funds[1] provides co-financing for innovative industrial doctoral courses. These programs require joint design, including for individual PhD students, and offer opportunities for students to spend training periods at companies or abroad.
In 2021, the Italian Ministry of University and Research tightened the criteria for qualifying as an Industrial PhD programme providing specific requirements regarding the collaboration with companies (Ministerial Decree n. 226/2021). It is required for every company involved in an Industrial PhD programme a formal agreement and for each one a company member must be included in the Steering Committee. Furthermore, a specific scientific project must be outlined, consistently with the programme theme and scopes.
Even without the Industrial PhD qualification it is still possible for the programmes to establish other agreements to collaborate with companies that carry out R&D

[1] PON refers to an Italian National Operational Program (PON) that foster economic growth, social cohesion, and regional development utilizing European Union funding sources, specifically the European Social Fund (FSE) and the European Regional Development Fund (FESR). FSE supports projects related to social inclusion, employment, education, and skills development, while FESR finances infrastructure, innovation, and economic development projects, particularly in less-developed regions.

activities without all the requirements above, or even other agreements with any company aiming at scholarship funding. Starting from 2022 these latter kinds of agreements have increased significantly due to the introduction of a co-financing framework within the PNNR (Recovery and Resilience Plan, i.e. the implementation tool, in Italy, for the Next Generation EU program).
This framework produces a three-type classification of the collaborations, as defined in Table 1:

Table 1. Collaboration between PhD programmes and companies' classification.

Collaboration scope	Company requisites	Specificity
Scholarship founding	None	
Associated PhD with companies	Demonstrable coherent and functional R&D activity	- the associated company must finance at least one scholarship for the PhD programme, co-financing can be supported both by the associated company and by external parties (based on specific agreements)
Industrial PhD	- Demonstrable coherent and functional R&D activity, coherent and functional - At least one company member included in the PhD Steering Committee - Outline of a specific scientific project, consistent with the programme * For each company involved	- the company must finance at least one scholarship for the PhD programme, co-financing can be supported both by the company and by external parties (based on specific agreements) - specific requirements can be provided for the research activities (interdisciplinarity, intersectorality) - a portion of the available places for the PhD programme can be reserved to company employees engaged in highly qualified activitieS

Italy's approach to Industrial PhDs aligns with broader European efforts to strengthen academia-industry collaboration. Indeed, since 2011 European Union has included industrial doctorates in its policy agenda for research, innovation and employment. However there are notable differences in implementation across countries, of which have extensive and long-lasting experience in this field. Among the main European experiences, we can certainly mention those of Germany, the UK, France and the Nordic countries, which have developed industrial PhD models with distinct characteristics and diverse approaches to university-business collaboration.
In Germany, Industrial PhD programs function as a collaboration between universities and companies, allowing doctoral students to conduct research while being integrated into an industrial environment. These programs typically involve a contractual agreement where the PhD candidate is employed by a company while

being supervised by both academic and industry mentors. The students divide their time between dissertation research and company-related tasks, gaining hands-on experience in a corporate setting.

In some cases, companies also support PhD students working within university faculties on joint research projects to enhance cooperation between academia and industry. Another common model involves professionals who pursue a PhD while maintaining their regular job in a company, with academic supervision remaining independent. These programs aim to bridge the gap between theoretical research and practical application, fostering knowledge transfer and innovation while equipping students with industry-relevant skills (Grimm, 2018).

In the UK, the main initiative is the Industrial CASE Studentships program, which supports collaboration between academia and industry through industrial PhD opportunities. Established in 1994, the program is administered by UK Research and Innovation (UKRI) and its constituent research councils, such as the Engineering and Physical Sciences Research Council (EPSRC) and the Science and Technology Facilities Council (STFC). The program aims to enhance innovation and equip PhD graduates with skills that meet both academic and industry needs. However, the proportion of PhD scholarships funded by Industrial CASE varies depending on the research council's priorities, available funding, and the level of industry engagement in specific research areas. Under the Industrial CASE scheme, PhD candidates work on projects co-designed by a university and an industrial partner, addressing real-world challenges. The program provides four years of funding, combining academic research with practical industry exposure. The funding includes tuition fee coverage, a stipend (often higher than standard UKRI stipends due to industry contributions), and research costs. Additionally, students are required to spend a minimum of three months working directly with the industrial partner, promoting knowledge transfer and building valuable professional networks. Collaboration models in Industrial CASE include joint knowledge development, applied research to improve products or processes, or exploratory research into emerging technologies[2]. The scheme is distinguished by its integration of academic and practical training, which ensures that PhD graduates are well prepared for careers in both academia and industry, often providing advantages in the private sector (Lee & Miozzo, 2015).The CIFRE (Convention Industrielle de Formation par la Recherche) program in France is a state-supported initiative that fosters collaboration between academia and industry through industrial PhD programs. Managed by the National Association for Research and Technology (ANRT), it has been in place since 1981 with the goal of strengthening university-industry exchanges while enhancing the professional integration of PhD graduates. The program provides three-year funding for PhD candidates employed by companies, requiring a formal agreement between the firm and a public research laboratory. The state grants a scholarship over three years, while the company offers a minimum annual salary. Collaboration models under CIFRE include knowledge transfer from academia to industry, joint knowledge co-

[2]https://www.ukri.org/what-we-do/developing-people-and-skills/stfc/training/types-of-training/industrial-case-studentships/ (last access on April 10th 2025)

development, or outsourcing of research to universities. Research strategies vary from product/process improvement, to developing new scientific competences, or exploring high-risk innovation areas. The program covers approximately 9% of funded PhDs in France and is particularly attractive to firms, including SMEs, as it helps de-risk R&D investments while providing access to academic expertise. Compared to similar European schemes, CIFRE is distinguished by its formalized agreements, structured collaboration, and emphasis on long-term engagement. It is recognized as a key mechanism in bridging scientific research and industrial application, facilitating innovation, and ensuring highly skilled workforce integration into industry (Plantec et al., 2019).

Industrial doctorates in Nordic countries, particularly in Norway and Sweden, have gained prominence as a mechanism to bridge the gap between academia and industry. These programs, often funded or co-hosted by companies, provide doctoral candidates with direct exposure to industrial research environments, fostering collaboration and facilitating smoother transitions into non-academic careers. Unlike traditional PhD paths, industrial doctorates emphasize applied research, aligning doctoral training with industry needs and enhancing employability.

Despite their advantages, the effectiveness of industrial PhDs varies by country. In Sweden, exposure to industry is high, often through structured collaborations, while in Norway, prior industry experience before entering a PhD program plays a more significant role in shaping career transitions. However, the transition to industry is not always automatic, as skill mismatches persist, requiring graduates to actively build networks during their PhD. While university-industry partnerships provide opportunities, personal networking remains crucial in securing industry positions.

Ultimately, industrial doctorates contribute to bridging academia and industry, yet their success depends on the strength of university-industry ties and the ability of doctoral candidates to leverage these connections. The Nordic model highlights the potential of structured collaborations but also underscores the need for stronger institutional support in facilitating career transitions. (Germain-Alamartine et al., 2021).At the European level, in 2014, the Marie Skłodowska-Curie Actions (MSCA) introduced the Industrial Doctoral Programmes flagship initiative, designed to foster PhD training through partnerships between universities, companies, and other socio-economic stakeholders. Funded by the European Union's Horizon Europe program, MSCA provides substantial financial support, covering salaries, research costs, and mobility allowances. This funding directly supports both the PhD candidate and the host organizations, incentivizing international collaboration. The MSCA initiative stands out for its global outlook, interdisciplinary scope, and comprehensive support for mobility and training, setting it apart from more localized and industry-specific national industrial PhD programs. A central feature of MSCA programs is the emphasis on international, intersectoral, and interdisciplinary mobility. PhD candidates are required to work in multiple countries and often across academia and industry, fostering global collaboration. Consequently, MSCA programs are

particularly attractive for building international networks and preparing PhD graduates for global careers in both academia and industry[3].
All Industrial PhD schemes typically involve shared funding between an agency, a university, and a company, with the company applying for the grant. The PhD student, enrolled in a regular program, is jointly supervised by both institutions and splits their time between the university and the firm (Thune & Børing, 2015).
Italy has developed a structured system for industrial PhDs, overall its regulatory approach is more prescriptive compared to the company-driven models in Germany or the flexible, incentive-based schemes in France and the UK. The introduction of PNRR funds has significantly expanded industry-academia collaborations, but challenges remain in ensuring long-term private sector engagement beyond co-financing mechanisms.2.

Data and methodology

This explorative research on Italian Industrial PhD programs was conducted over a two-year period (2022-2023) and all the scientific disciplines. Since 2013, the Italian National Agency for the Evaluation of Universities and Research Institutes (ANVUR) has been entrusted with conducting the initial accreditation and annual verification of PhD programmes. ANVUR therefore verifies that PhD programs meet specific requirements, the evaluation procedure is mainly based on a set of ex-ante indicators focused on the quality of the PhD Steering Committee and of the Scientific Coordinator, the teaching activities, the financial sustainability, the availability of scholarships, the research infrastructures, and the overall coherence of the research project.
Table 2 underscores the regional disparities in the availability and uptake of doctoral education in Italy, with larger and more populous regions generally hosting more extensive programs and enrollments. It presents in detail the distribution of PhD programs and students at the NUTS 2 level across Italian regions for the academic years 2022 (XXXVIII cycle) and 2023 (XXXIV cycle). It highlights both regional and national trends in higher education, reflecting the heterogeneity of doctoral education in Italy. The number of the accredited PhD programs and students for 2022 (XXXVIII cycle) and 2023 (XXXIX cycle) is reported in Table 2. The data was derived from the public website of ANVUR[4] and from the Portal of Higher Education Data of the Italian Ministry of University and Research[5].

[3] https://marie-sklodowska-curie-actions.ec.europa.eu/actions/doctoral-networks (last access on April 10th 2025)
[4] www.anvur.it (last access on November 09th, 2024)
[5] https://ustat.mur.gov.it/ (last access on November 09th, 2024)

Table 2. Number of universities, PhD programs and PhD students in 2022 and 2023, by NUTS 2 level.

NUTS 2 level	Number of universities	2022 (XXXVIII cycle)		2023 (XXXIV cycle)	
		PhD programs	PhD Students	PhD programs	PhD Students
Piedmont	4	56	1024	56	1039
Aosta Valley	1	0	0	0	0
Liguria	1	30	480	31	491
Lombardy	15	162	2790	171	2937
Abruzzo	5	38	393	41	402
Molise	1	7	62	7	56
Campania	10	102	1490	113	1785
Apulia	5	57	841	64	777
Basilicata	1	5	82	5	40
Calabria	4	27	288	31	243
Sicily	4	70	768	71	931
Sardinia	2	25	276	28	214
Autonomous Province of Bolzano/Bozen	1	8	105	7	65
Autonomous Province of Trento	1	18	290	18	333
Veneto	4	72	1029	74	1246
Friuli Venezia Giulia	3	36	389	37	393
Emilia-Romagna	4	98	2552	101	1508
Tuscany	8	96	1310	106	1354
Umbria	2	23	202	25	224
Marche	4	28	383	29	380
Lazio	20	194	2495	204	2458
Italy	**100**	**1152**	**17249**	**1219**	**16876**

In 2022, there were 1,152 PhD programs nationwide with 17,249 enrolled students, while in 2023, these numbers shifted slightly to 1,219 courses and 16,876 students. This indicates an increase in the number of PhD programs but a slight decrease in overall student enrollment. The regional distribution shows notable differences: Lombardy, with its 15 universities, leads in both years, offering 162 courses to 2,790 students in 2022 and increasing to 171 courses for 2,937 students in 2023. Lazio follows with 20 universities, offering 194 courses with 2,495 students in 2022 and 204 courses with 2,458 students in 2023. Both regions account for a significant portion of Italy's doctoral education system.

In contrast, smaller regions like Aosta Valley, Molise, and Basilicata have minimal or no representation in doctoral education, with Valle d'Aosta reporting no PhD programs or students in either year. Regions like Emilia Romagna and Tuscany also demonstrate strong participation, with substantial numbers of courses and students, though Emilia Romagna shows a marked decline in student enrollment from 2,552 in 2022 to 1,508 in 2023, despite a slight increase in courses offered.

Southern regions such as Campania and Apulia show a growing number of courses but varying trends in student enrollment, with Campania experiencing a significant rise in students from 1,490 in 2022 to 1,785 in 2023, while Puglia sees a reduction from 841 to 777. Sicily, on the other hand, reflects consistent growth, increasing both courses and student numbers between the two years.

The data also emphasizes the contributions of autonomous provinces like Autonomous Provinces of Trento and Bolzano, which, despite their smaller size, maintain a consistent presence in doctoral education. Trento, for instance, reported stable course offerings at 18 but increased student enrollment from 290 in 2022 to 333 in 2023.

The subsequent section of this study will delve into the mapping of PhD programs specifically characterized as industrial doctorates for the academic years 2022 and 2023. To analyze these programs, text analysis techniques, particularly Latent Dirichlet Allocation (LDA), will be applied to the titles of the industrial PhD programs. This methodology will allow for the identification of key thematic areas addressed by these programs, shedding light on the specific industrial and technological challenges they aim to tackle. By clustering and categorizing topics, this analysis will highlight trends, such as the prevalence of themes related to digital transformation, sustainability, or advanced manufacturing, providing a clearer understanding of the strategic focus of these doctoral initiatives.

In addition, potential relationships between the geographical distribution of industrial PhDs and specific territorial characteristics will be explored thought spatial descriptive statistics. The main aim is to investigate whether the presence and concentration of industrial PhD programs are linked to the region's innovation performance.

Results and discussion

Geographic distribution of industrial PhD programs

Table 3 provides an overview of the distribution of industrial PhD programs in Italy at the NUTS 2 level for the XXXVIII (2022) and XXXIV (2023) cycles, highlighting an overall growth both in absolute and relative terms. The total number of industrial PhD programs increased from 49 (4.3% of the total PhD programs) in 2022 to 83 (6.8%) in 2023. This growth reflects an expanding emphasis on the alignment between doctoral education and industrial needs, in line with broader European trends promoting university-industry collaboration (Etzkowitz & Leydesdorff, 2000). Regionally, the data reveal significant disparities. Liguria shows a remarkable increase in industrial PhD programs, rising from 23.3% to 41.9% of the total PhDs in the region, positioning it as a leader in integrating doctoral training with industrial applications. Similarly, regions such as Abruzzo (18.4% to 22%) and Umbria (21.7% to 36%) demonstrate significant relative growth, reflecting targeted regional initiatives. Conversely, several regions, including Basilicata, Calabria, Sardinia, and Veneto, report no industrial PhD programs, underscoring persistent challenges in fostering such programs in less industrialized or peripheral areas.

The data also underline the prominence of certain industrial and academic hubs, such as Lombardia and Lazio, which exhibit modest relative growth but play critical roles due to their overall academic and industrial capacity. Notably, Molise shows a decline in the relative share of industrial PhD programs (from 57.1% to 28.6%), which may warrant further investigation into the underlying causes. The increasing proportion of industrial PhD programs at the national level (from 4.3% to 6.8%)

signals a growing recognition of their strategic importance for enhancing research and innovation ecosystems.

Table 3. Number and percentage of industrial PhD programs in 2022 and 2023, by NUTS 2 level.

NUTS 2 level	Number of Industrial PhD programs (percentage in brackets)	
	2022 (XXXVIII cycle)	2023 (XXXIV cycle)
Piedmont	1 (1.8)	1 (1.8)
Aosta Valley	0 (0)	0 (0)
Liguria	7 (23.3)	13 (41.9)
Lombardy	1 (0.6)	5 (2.9)
Abruzzo	7 (18.4)	9 (22)
Molise	4 (57.1)	2 (28.6)
Campania	9 (8.8)	10 (8.8)
Apulia	1 (1.8)	2 (3.1)
Basilicata	0 (0)	0 (0)
Calabria	0 (0)	0 (0)
Sicily	3 (4.3)	8 (11.3)
Sardinia	0 (0)	0 (0)
Autonomous Province of Bolzano/Bozen	0 (0)	0 (0)
Autonomous Province of Trento	1 (5.6)	1 (5.6)
Veneto	0 (0)	0 (0)
Friuli Venezia Giulia	1 (2.8)	5 (13.5)
Emilia-Romagna	1 (1)	5 (5)
Tuscany	2 (2.1)	3 (2.8)
Umbria	5 (21.7)	9 (36)
Marche	0 (0)	0 (0)
Lazio	6 (3.1)	10 (4.9)
Italy	49 (4.3)	83 (6.8)

The maps reported in Figure 1 complement the data presented in Table 3 by offering a geographic visualization of the distribution of industrial PhD programs across Italian regions at the NUTS 2 level for the XXXVIII (2022) and XXXIV (2023) cycles. They highlight the persistence of significant regional disparities in the adoption of industrial PhDs, with marked differences between northern, central, and southern Italy.

In 2022, central regions such as Umbria and Abruzzo emerged as leaders in industrial PhD adoption, while northern and southern regions generally showed lower percentages. In 2023, Liguria demonstrated a notable increase, positioning itself alongside Umbria as a leader in integrating industrial PhD programs. However, several southern regions, including Basilicata, Calabria, and Sardinia, remain largely excluded from this trend, reflecting ongoing challenges in fostering university-industry collaboration in less industrialized or peripheral areas.

The maps visually emphasize the growing polarization, with industrial PhD programs concentrating in specific academic and industrial hubs. This uneven geographic distribution highlights the need for targeted policies to support

underrepresented regions, enabling broader national alignment with the European agenda for university-industry collaboration.

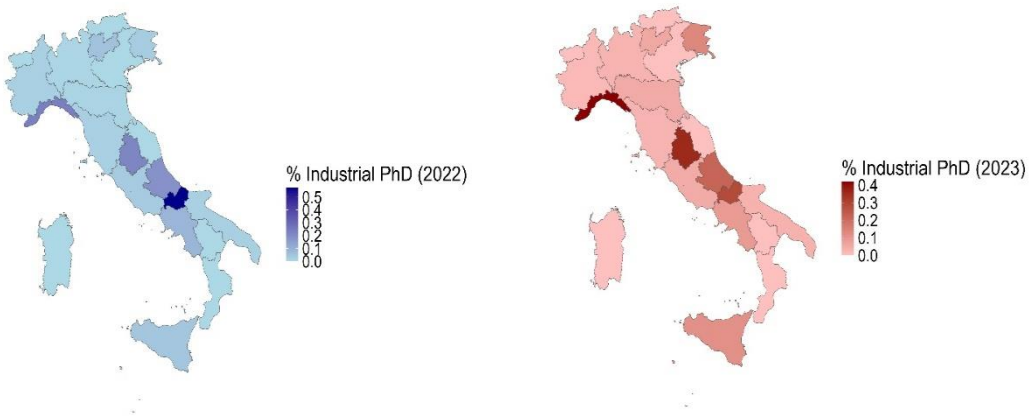

Figure 1. Percentage of 2022 and 2023 Industrial PhD program.

Thematic distribution of Industrial PhD programs

Figure 2 illustrates the application of Latent Dirichlet Allocation (LDA) to identify the main terms extracted from the titles of industrial PhD programs in Italy for the years 2022 and 2023. The analysis was performed on filtered datasets containing only industrial PhD programs, and the titles were translated into English to ensure consistency.

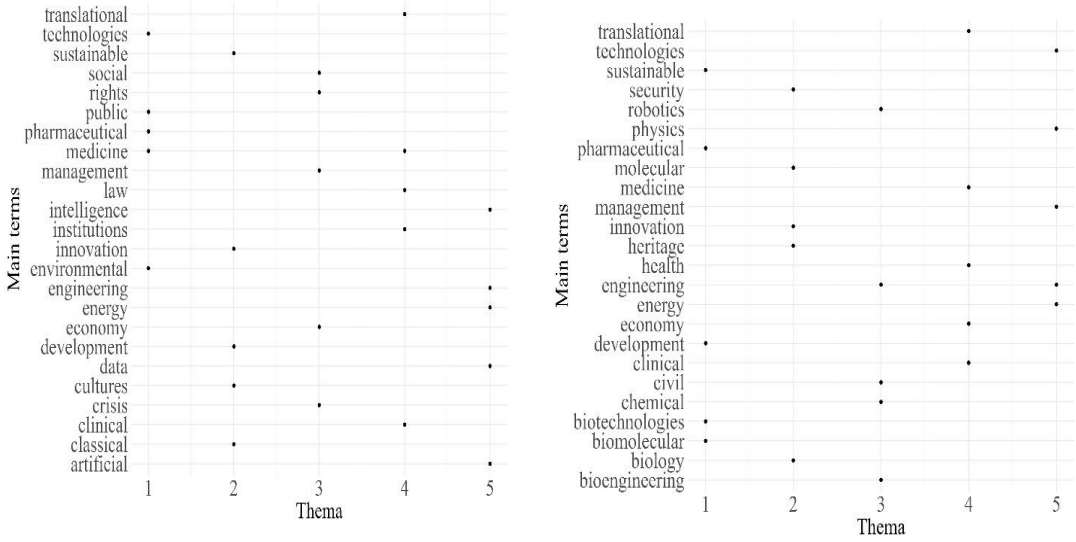

Figure 2. LDA analysis for 2022 and 2023 Industrial PhD programs.

In 2022, the thematic distribution highlights a strong emphasis on interdisciplinarity and sustainability, with terms such as "translational", "sustainable", "engineering", and "management" prominently represented. The presence of keywords such as "medicine", "pharmaceutical", and "environmental" suggests that healthcare, pharmaceutical research, and environmental studies played a significant role in shaping industrial PhD offerings. Furthermore, the inclusion of terms like "social" and "rights" points to an integration of social sciences, complementing the technical and scientific focus. The distribution of terms across the identified themes reflects a diverse approach to doctoral education, addressing a broad spectrum of societal and industrial challenges.

In 2023, the thematic landscape demonstrates a notable evolution, with an increasing emphasis on advanced technologies and specialized scientific domains. Terms such as "robotics", "physics", "biotechnologies", and "bioengineering" emerge as key elements, reflecting a shift towards cutting-edge fields with strong industrial applications. Despite this shift, the prominence of terms like "sustainable" and "innovation" indicates the continued prioritization of sustainability and the alignment of doctoral education with contemporary global challenges. Additionally, the emergence of terms such as "heritage" and "civil" suggests a growing recognition of cultural and infrastructural dimensions within industrial PhD programs.

A comparison of the two years reveals a dynamic evolution in the focus areas of industrial PhD programs in Italy. While the 2022 programs exhibit a broader thematic distribution, encompassing healthcare, sustainability, and social sciences, the 2023 programs signal a more targeted orientation towards technology-driven and specialized research fields. This shift underscores the responsiveness of doctoral education to emerging trends and evolving industry needs, reflecting the increasing integration of advanced technologies and interdisciplinary approaches. The consistent presence of sustainability and innovation as core themes highlights the strategic role of industrial PhD programs in fostering research and innovation ecosystems that address both industrial priorities and societal challenges.

Statistical analysis

The spatial distribution of 2022 and 2023 Industrial PhD programs can be effectively represented through Standard Deviational Ellipses. The Standard Deviational Ellipse is a graphical representation that shows the orientation, shape, and spatial dispersion of a set of points, its centre corresponds to the centroid (or barycentre) of the spatial distribution (for a more in-depth and technical disclosure see Wong & Lee, 2005; Brunsdon & Comber 2015). This representation can incorporate the weight of a variable by adjusting the size and orientation of the Ellipse based on the variance and distribution of that variable (i.e. the number of Industrial PhD programs), allowing it to reflect not only the spatial arrangement of points but also the intensity or significance of specific factors that influence the distribution. In this case, since all distributions consider the spatial centroids of the Italian regions as the set of points, the observable differences in the ellipses and the barycentre can be attributed merely to the weight of the variables considered.

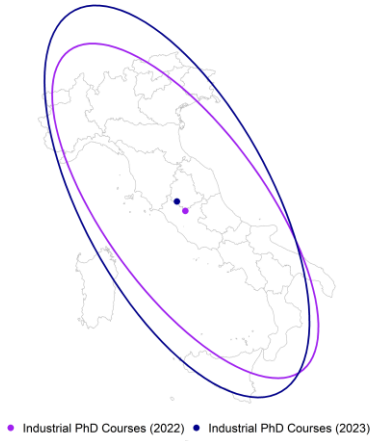

Figure 3. Standard Deviational Ellipses of 2022 and 2023 Industrial PhD programs.

The comparison of the Industrial PhD programs' Standard Deviational Ellipses for 2022 and 2023 (Figure 3) reinforces the key trend already highlighted in the discussion of Figure 1. Moreover, several noteworthy insights emerge when comparing the distribution of Industrial PhD programs with that of all PhD programs and universities.

While the 2022 ellipse for industrial PhD programs is notably narrower than that of all doctoral programs and universities, reflecting a higher concentration of industrial PhDs in a limited number of key hubs, the 2023 ellipse shows a significant shift. In 2023, the ellipse becomes more similar in size and orientation to those of the broader doctoral programs and university locations.

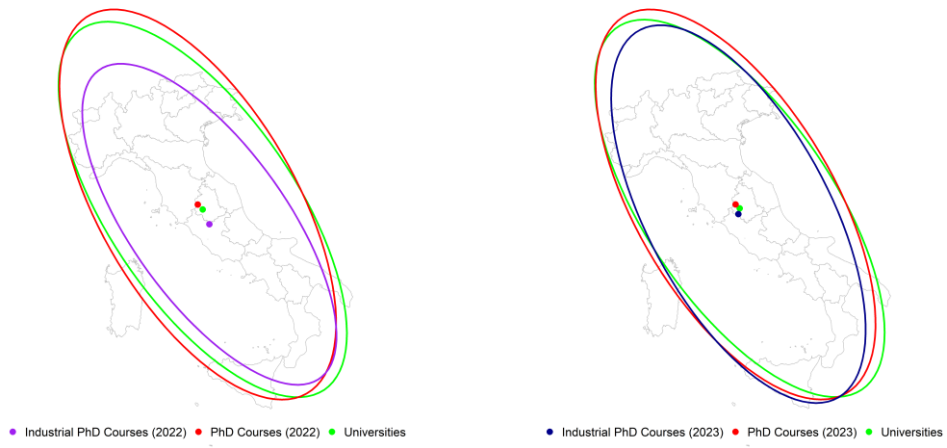

Figure 4. Standard Deviational Ellipses of 2022 and 2023 Universities, PhD programs and Industrial PhD programs.

A simple explanation could be found in the longer time elapsed for the for the XXXIV (2023) cycle since the formalization of the criteria for qualifying an

industrial PhD, revised by the relevant Italian Ministry in 2021 (thus maybe with short notice for the XXXIII cycle). Nevertheless, this change could also be attributed to a growing diversification in the institutions offering industrial PhD programs, possibly driven by policy initiatives aimed at fostering this kind of programs or the increased adoption of collaborative research models across a wider array of universities. Additionally, the expansion may reflect the alignment of local academic and industrial ecosystems with national and European funding priorities, which increasingly emphasize inclusive and distributed research excellence. As a result, the spatial footprint of industrial PhDs appears to be converging with the broader academic landscape, suggesting a gradual diffusion of opportunities beyond the traditional innovation hubs.

An analysis of industrial PhDs cannot ignore the characteristics of the educational and production systems in which they are embedded. For this purpose, the Regional Innovation Scoreboard (RIS) represents a shared and consolidated framework to characterize the territories at the NUTS 2 level in terms of innovation performance, enabling a comparative perspective and addressing various aspects of utmost importance for this study.

The Regional Innovation Scoreboard (RIS) is a report published by the European Commission since 2009 to evaluate the innovation performance of European regions (complementing the European Innovation Scoreboard (EIS), which focuses on national performance). It aims to identify regional differences in innovation capabilities and highlight best practices; it is therefore a particularly fitting reference for this analysis.

The RIS provides a solid set of innovation indicators (including R&D investment, patents, entrepreneurial activities, and education) and following the same methodology of the EIS classifies the European's regions into four Innovation Performance groups according to their Regional Innovation Index (RII[6]):

1. Innovation Leaders (regions with above-average performance);
2. Strong Innovators (regions performing close to the EU average);
3. Moderate Innovators (below-average performers);
4. Emerging Innovators (lowest-performing regions).

[6] RII is calculated as the unweighted average of the normalised scores of 21 indicators. Since RIS uses fewer indicators (21 compared to 32 in the EIS), some with different definitions, and regional data are less timely than the country level data, it is necessary to align the country level results between RIS and AIS. The following correction is therefore applied to the composite indicator scores:

1) Calculate the ratios of the EIS 2023 Summary Innovation Index at country level with that of the EU: EIS_index_CTR / EIS_index_EU;

2) Calculate the ratios of the RIS 2023 Regional Innovation Index at country level with that of the EU: RIS_index_CTR / RIS_index_EU;

3) Calculate the correction factor by dividing the ratios 1) and 2).

These country correction factors are then multiplied with the RII for each region in the corresponding country to obtain final RII scores. Then relative performance scores are calculated by dividing the RII of the region by that of the EU and multiplying by 100. For trend performance, RIIs for all years are divided by that of the EU in 2016 (see the Regional Innovation Scoreboard 2023 – Methodology Report).

Italy is a Moderate Innovator within the EIS, but regional performance differences are high. Referring to the 2021 performance 12 of the 20 Italian regions were Moderate Innovators, but there were also seven Strong Innovators (see Figure 5) and two Emerging Innovators (Calabria and Aosta Valley).
Interestingly in 2023 RIS only three regions still result as Strong Innovators (Emilia-Romagna, Friuli-Venezia Giulia and Autonomous Province of Trento), and two as Emerging Innovators (Sicily and Sardinia), but RII indicator compares the regional performance to that of the EU in the same year. It is also noticeable that 2023 RIS highlights that Italian region performance has increased at a higher rate than that of the EU for all regions compared to 2014, and most strongly for Marche and Abruzzo (Figure 5).

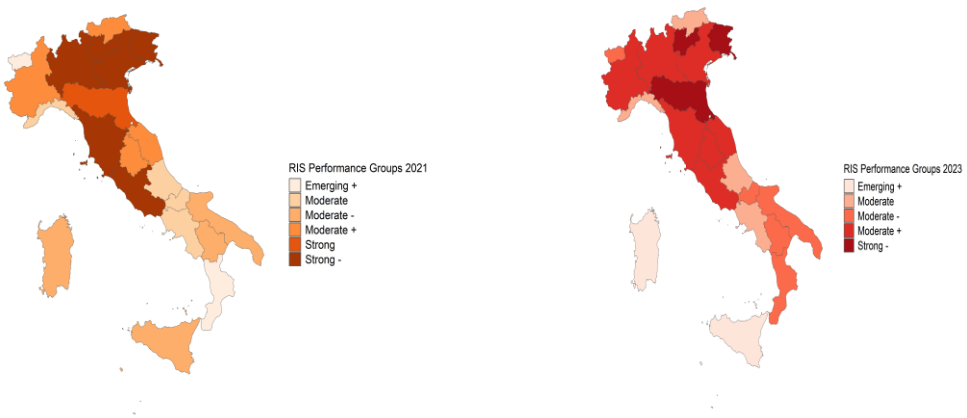

Figure 5. Innovation Performance groups (RIS 2021 and 2023).

In the following analysis, will be therefore considered the performance groups reported in the RIS 2021 and 2023 documents. However, to ensure data comparability, the detailed value of the Regional Innovation Index 2021 and 2022 presented in the 2023 RIS report will be used (see Figure 6).
Since the accreditation procedures for PhD programs occur during the academic year preceding their start, the RII 2021 values will be considered relevant for the XXXVIII cycle (starting in 2022), while the RII 2022 values will be considered relevant for the XXXIV cycle (starting in 2023).

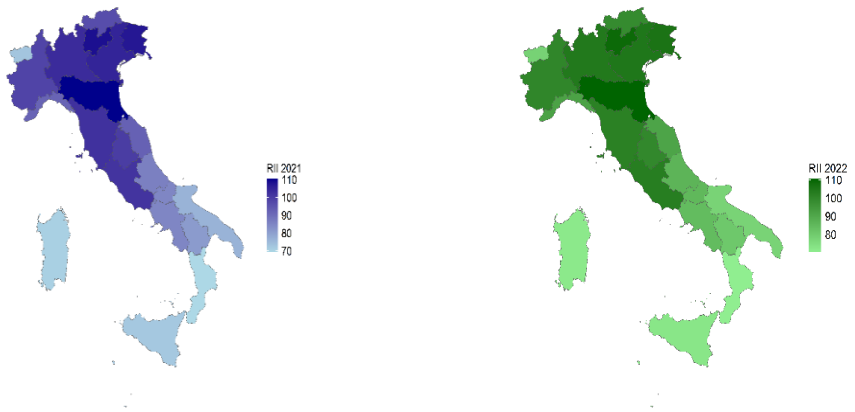

Figure 6. Regional Innovation Index – RII 2021 and RII 2022 (RIS 2023).

The Standard Deviational Ellipses of the RII indicators for 2021 and 2022 are extremely close (almost overlapping, as seen in Figure 7), as are their centroids. It is only possible to highlight a slight widening of the ellipse in the northwest direction between the two years examined (it is important to highlight that much of the data used in the calculation of the RII is not updated annually, and as a result, the indicator inherently exhibits a certain level of stability between updates).

The comparison with the ellipses of the distribution of industrial PhD programs in 2022 and 2023 offers more points of interest. The first is that the centroids of the industrial PhD distributions (for both years under consideration) are located further south than those of the RII.

The second is that the ellipse of the industrial PhD distribution for 2023 has a width and directional orientation more similar to that of the innovative performance distribution, in line with what was expected based on the hypotheses outlined above.

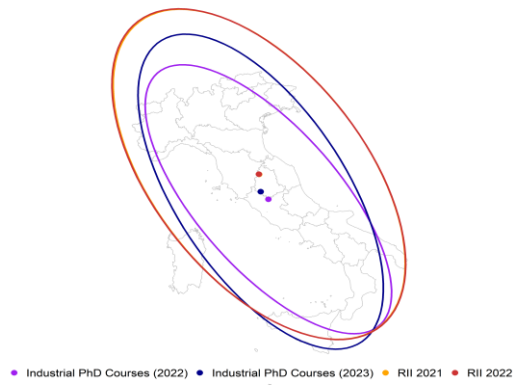

Figure 7. Regional Innovation Index – RII 2021 and RII 2022 (RIS 2023).

The fact that the centroids of the industrial PhD distributions for both 2022 and 2023 are located further south than those of the RII might suggest that industrial PhD programs are becoming more concentrated in southern regions. This could reflect a deliberate policy shift or a regional emphasis on developing innovation and industry-academic collaborations in areas traditionally less involved in these activities. It could also indicate a broader trend of industrial PhDs expanding outside the established innovation hubs, potentially due to regional development initiatives or universities seeking to align with national priorities.
The observation that the ellipse for the industrial PhD distribution in 2023 has a width and directional orientation more like that of the innovative performance distribution may indicate a closer alignment between industrial PhDs and the broader innovation landscape. This could suggest that the 2023 cohort of industrial PhDs is increasingly influenced by or integrated into areas of high innovative activity. Such a change in the shape and direction of the ellipse may also imply that industrial PhD programs are diversifying geographically and aligning more closely with regions that show stronger innovation performance, possibly driven by new funding policies or more strategic collaborations between universities and industries in these areas.

Conclusions

In a recent systematic literature review, Compagnucci and Spigarelli observed that research interest in industrial PhDs has grown rapidly since 2015, attributing this trend to both the emergence of the Third Mission of universities and policy factors, particularly in Europe. Also in the context of this growing attention Compagnucci and Spigarelli's analysis highlighted the marginality of quantitative studies, and pointed out the need for more structured studies, particularly those with a longitudinal perspective to estimate the impact of these types of programs.
This study represents a simple starting point for analysis in the Italian context; nevertheless, it highlights the evolving role of Industrial PhD programs in Italy as strategic tools for fostering collaboration between academia and industry and contributing to regional innovation dynamics. Besides, Italy represents a particularly interesting context, especially considering its regulatory model, more rigid and top-down compared to the industry-led approach in Germany or the more flexible, incentive-driven systems in France.
The analysis reveals significant findings related to the geographic and thematic distribution of these programs.
Between 2022 and 2023, the number of Industrial PhDs increased substantially, with their share rising from 4.3% to 6.8% of all doctoral programs. Regions like Liguria, Umbria, and Abruzzo demonstrated notable growth in industrial PhDs, while southern regions such as Basilicata, Calabria, and Sardinia lagged behind, underscoring persistent disparities. Thematic analysis using Latent Dirichlet Allocation (LDA) identified a shift in focus from broad themes like sustainability and interdisciplinarity in 2022 to more specialized domains such as robotics, biotechnologies, and advanced manufacturing in 2023.
The spatial distribution analysis suggests a growing alignment between Industrial PhD programs and regions with higher innovation performances, although the

centroids of their distribution are located further south compared to those of regional innovation indicators. This finding may indicate a deliberate policy shift to promote innovation in less-developed areas or an emerging trend of universities and industries in southern regions increasing their engagement in collaborative research. However, the persistence of regional disparities calls for broader policies to ensure equitable access to these programs and their benefits.

Future research should aim to evaluate the long-term impact of Industrial PhD programs on regional economic growth, workforce development, and the competitiveness of innovation ecosystems. In particular, the role of Italy's National Recovery and Resilience Plan (PNRR) in shaping the distribution, thematic focus, and effectiveness of these programs requires further exploration. The PNRR provides a unique opportunity to strengthen academic-industry collaboration through co-financed scholarships and investments in innovation-driven education. Assessing the extent to which these resources address regional and national priorities will be crucial to understanding their broader impact.

From a policy perspective, it is essential to address regional imbalances by introducing targeted funding mechanisms for less-developed areas, incentivizing companies to engage in collaborative research, and supporting universities in building capacity for industrial partnerships. Additionally, fostering interdisciplinary approaches and integrating sustainability into the design of Industrial PhDs will be critical to addressing complex societal and industrial challenges. Policymakers should also prioritize the development of robust performance monitoring frameworks to measure the effectiveness of these programs in delivering tangible benefits, including innovation outputs, economic development, and improved employability of graduates. By aligning national and regional policy goals with the strategic objectives of Industrial PhDs, Italy can maximize the potential of these programs as a cornerstone of its innovation and education policy framework, contributing to sustainable and inclusive economic growth. From an European perspective, a more coordinated initiative in the field of industrial PhDs would be highly desirable. Such an effort could help harmonize national systems, facilitate cross-border mobility of doctoral candidates, and promote shared standards for industry-academia collaboration. It would also support the development of a more integrated innovation ecosystem across the EU, strengthening the competitiveness of European research and industry in the global landscape.

References

Bernhard, I., & Olsson, A. K. (2020). University-industry collaboration in higher education: Exploring the informing flows framework in industrial PhD education. Informing Science, 23, 147.

Bienkowska, D., & Klofsten, M. (2012). Creating entrepreneurial networks: academic entrepreneurship, mobility and collaboration during PhD education. Higher Education, 64, 207-222.

Borrell-Damian, L., T. Brown, A. Dearing, J. Font, S. Hagen, J. Metcalfe, and J. Smith. 2010. "Collaborative Doctoral Education: University-Industry Partnerships for Enhancing Knowledge Exchange." Higher Education Policy 23 (4): 493–514. https://doi.org/10.1057/hep.2010.20.

Borrell-Damian, L., R. Morais, and J. H. Smith. 2015. Collaborative Doctoral Education in Europe: Research Partnerships and Employability for Researchers Report on Doc-Careers II Project. Brussels: European University Association.

Brunsdon, C., & Comber, L. (2015). "An Introduction to R for Spatial Analysis and Mapping." SAGE Publications.

Compagnucci, L., & Spigarelli, F. (2024). Industrial doctorates: a systematic literature review and future research agenda. Studies in Higher Education, 1–28.

Compagnucci, L., Spigarelli, F., Perugini, F., & Iacobucci, D. (2024). Industrial doctorates for regional development: the case of Le Marche Region. *Higher Education*, 1-21.

Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: from National Systems and "Mode 2" to a Triple Helix of university–industry–government relations. Research policy, 29(2), 109-123.

Germain-Alamartine, E., Ahoba-Sam, R., Moghadam-Saman, S., & Evers, G. (2021). Doctoral graduates' transition to industry: networks as a mechanism? Cases from Norway, Sweden and the UK. Studies in Higher Education, 46(12), 2680-2695.

Grimm, K. (2018). Assessing the Industrial PhD: Stakeholder Insights. Journal of Technology and Science Education, 8(4), 214-230.

Gustavsson, L., Nuur, C., & 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.

Haapakorpi, A. (2017). Doctorate holders outside the academy in Finland: Academic engagement and industry-specific competence. Journal of education and work, 30(1), 53-68. https://doi.org/10.1080/13639080.2015.1119257

Harman, K. M. 2008. "Challenging Traditional Research Training Culture: Industry-Oriented Doctoral Programs in Australian Cooperative Research Centres." In In Cultural Perspectives on Higher Education, edited by J. Välimaa and O. H. Ylijoki, 179–195. Dordrecht: Springer.

Lee, H. F., & Miozzo, M. (2015). How does working on university–industry collaborative projects affect science and engineering doctorates' careers? Evidence from a UK research-based university. The Journal of Technology Transfer, 40, 293-317.Leogrande, A., Costantiello, A., & Laureti, L. (2022). The Impact of New Doctorate Graduates on Innovation Systems in Europe. Available at SSRN 4209643.

Olsson, A.K. & Bernhard, I. (2023). Transforming doctoral education: Exploring industrial PhD collaboration in Sweden. International Journal of Work-Integrated Learning, 24(4), 523-536. https://www.ijwil.org/files/IJWIL_24_4_523_536.pdf

Plantec, Q., Cabanes, B., Le Masson, P., & Weil, B. (2019, June). Exploring practices in university-industry collaborations: the case of collaborative doctoral program in France. In R&D Management 2019.

Roolaht, T. (2015). Enhancing the industrial PhD programme as a policy tool for university—industry cooperation. Industry and Higher Education, 29(4), 257-269.

Santos, P., Veloso, L., & Urze, P. (2021). Students matter: The role of doctoral students in university–industry collaborations. Higher Education Research & Development, 40(7), 1530-1545.

Shin, J. C., Kehm, B. M., & Jones, G. A. (2018). The increasing importance, growth, and evolution of doctoral education. *Doctoral education for the knowledge society: Convergence or divergence in national approaches?*, 1-10.

Sjöö, K., & Hellström, T. (2019). University–industry collaboration: A literature review and synthesis. Industry and higher education, 33(4), 275-285.

Thune, T. (2009). Doctoral students on the university–industry interface: a review of the literature. Higher Education, 58, 637-651.
Thune, T. (2010). The training of "triple helix workers"? Doctoral students in university–industry–government collaborations. Minerva, 48, 463-483.
Thune, T., & Børing, P. (2015). Industry PhD schemes: Developing innovation competencies in firms?. Journal of the Knowledge Economy, 6, 385-401.
Thune, T., S. Kyvik, S. Sörlin, T. B. Olsen, A. Vabø, and C. Tømte. 2012. PhD Education in a Knowledge Society: An Evaluation of PhD Education in Norway. Nordic Institute for Studies in Innovation, Research and Education. Report 25/2012. ISBN 978-82-7218-846-6.
Wong, D. W., & Lee, J. (2005). Statistical Analysis of Geographic Information with ArcView GIS and ArcGIS. John Wiley & Sons.