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A Triple Helix Model of Doctoral Education: A Case Study of an Industrial Doctorate

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Abstract: The knowledge economy requires a revolution in doctoral education. This article generalizes a triple helix model of doctoral education based on the existing literature. Further, it conducts a case study of a Center for Doctoral Training sponsored by the Engineering and Physical Sciences Research Council in the United Kingdom. This research adopts document and observation studies as instruments to examine the roles of university, industry, and government, and their interactions, in doctoral education. Through document and observation analyses, it finds that universities provide disciplinary, interdisciplinary, and professional training to doctoral students; industry offers research and training opportunities, research grants, and placements; and governments stimulate the cooperation between universities and industry through support policies and grants. Universities, industry, and governments benefit from these interactions, and these benefits reinforce their interactions. In the meantime, university autonomy is compromised by the involvement of industry and governments in doctoral education, although the rigor of the doctorates is not compromised because universities dominate the assessment. The curriculum, supervision, matching of research projects from industry with the research interests of doctoral students, and research outcomes, which are in the boundary spaces of the triple helix model of doctoral education, should be further developed for the development of industrial doctorates.

Keywords: knowledge economy; doctoral education; engineering education; industrial doctorate; triple helix; university–industry–government relations

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1. Introduction

Knowledge is becoming the driver of economic growth. It is not only an output of the economy but also an input of the economy, which is why economic development depends heavily on knowledge. Knowledge can be distinguished into disciplinary knowledge, produced at universities, and transdisciplinary knowledge, created outside universities, which are Mode 1 and Mode 2 knowledge in the knowledge typology [1]. Universities are the leading producers of knowledge and knowledge creators, such as doctoral students. Doctoral students, who possess the highest academic credentials in the educational system, play a significant role in academia and industry.

Knowledge, knowledge economy, and doctoral education are linked by the process of knowledge creation and consumption. Universities, which are primary producers of Mode 1 knowledge, are instruments for economic and liberal personal development [2]. However, the knowledge economy demands a lot of knowledge workers equipped with professional knowledge to apply their capacities for innovation and entrepreneurship to practice [3]. It becomes a challenge for universities as Mode 1 knowledge producers to cultivate doctoral graduates with Mode 2 knowledge demanded by the knowledge economy. Therefore, there is a necessity for a revolution in doctoral education. The revolution of doctoral education has two directions. One is to modify the traditional PhD to accommodate more practical forms of research; the other is to develop new doctoral models [4]. Even, the subjects of doctoral education are necessary to be reconfigured if the above revolution is not enough [5].

In response to the necessity for a revolution in doctoral education, a number of new types of doctorates have arisen. In the United Kingdom, the traditional PhD still dominates doctoral education, which primarily prepares academic staff for academia. It is commonly criticized for cultivating graduates without skills required by industry [6]. The Professional Doctorate (ProfDoc), as one type of doctorate, develops doctoral students' capabilities to work in professional contexts to meet the specific demands of a professional group outside of universities while meeting the criteria for the award of doctoral degrees by universities [7]. Therefore, it benefits both individuals and organizations. An individual can benefit from personal development and an organization can benefit from practitioner research and original knowledge generation at workplaces. However, it can only benefit a few professions because of the large number of professions and the emergence and disappearance of some professions. Further, it closes the door for students with less experience because working experience is usually an entrance prerequisite of ProfDoc. Moreover, it generally follows the taught component plus thesis model, which has no significant difference from the part-time PhD [8]. The industrial doctorate is another type of doctorate that students work on research projects from industry. It better fulfills the demands of the knowledge economy development for it is equally rooted in academia and industry [9].

Big initiatives of university–industry collaborative doctoral education at the national level have been developed all over the world [10]. The university–industry collaborative doctoral education should be evaluated for further development. Despite a large number of studies on university–industry interactions [11], a limited number of studies on university–industry collaboration in doctoral education [12,13], of which most are case studies, have been conducted in different countries. A couple of articles touch upon one or more aspects of the doctoral education process, such as the motivations and benefits of participants, curriculum and training, research topics, supervision, research outcomes, and employability. There is a lack of a comprehensive examination of the tripartite relationships among universities, industry, and governments. To fill this gap, this research aims to examine the university–industry–government partnership in doctoral education. It will address the following research questions:

(1) What are the roles of university, industry, and government in doctoral education?
(2) What are the dynamic interactions among the institutional spheres of university, industry, and government in doctoral education?

The findings are useful for policymakers, practitioners, and researchers. First, they may provide guidance to the policymakers to stimulate cooperation among universities, industry, and governments on doctoral education. Second, they may guide practitioners in universities to design doctoral programs. Third, they may also guide business leaders to advance the knowledge economy development. Forth, they may contribute a new model of doctoral education to the academic community.

2. University–Industry–Government Collaboration in Doctoral Education

Doctoral students are at the core of knowledge creation, knowledge transfer, and the establishment and maintenance of relationships between universities and industry [12,14]. The increasing demand for collaborative research and knowledge exchange drives university–industry collaboration in doctoral education [15].

To fulfill the demands of the knowledge economy, doctoral programs with a partnership between universities and industry have been promoted by governments. Innovation Fund Denmark funds the Industrial Researcher Program where a doctoral student is employed by a private company, enrolled in a university, and funded by Innovation Fund Denmark. The French Ministry for Higher Education, Research, and Innovation finances the Industrial Agreements for Training through Research (Cifre) program where a doctoral student is employed by one company, local authority, or association, and works towards a doctoral degree in an academic research laboratory. The European Marie Skłodowska-Curie Innovative Training Networks involve both academic and non-academic sectors in doctoral education so that doctoral graduates' skills better match the demands of public and private sectors. In Australia, the Department of Education, Skills, and Employment sponsors the National Industry PhD Program, which aims to add over 1800 industrial PhDs over 10 years. The Engineering and Physical Sciences Research Council (EPSRC) of the United Kingdom launched the Center for Doctoral Training (CDT) scheme to support university–industry collaboration in doctoral education.

These initiatives have attracted researchers' attention. This research mainly concerns the doctoral education process, including purpose, selection, curriculum, learning and supervision, assessment, and outcome. An entrance prerequisite of an EngD program sponsored by the EPSRC in the UK is a first or an upper-second-class honors degree or a master's degree in engineering in a relevant area. The applications are reviewed by both industrial sponsors and academic supervisors. Then, the shortlisted applicants are invited for interviews [16]. However, in the literature, it is unknown whether the industrial sponsors attend the interviews or not.

It is important to consider curriculum when judging whether doctoral programs cultivate graduates with the skills demanded by industry. A comparative case study of two Science and Technology Parks in Sweden and Spain suggested a three-step process to adapt doctoral-level skills to the needs of local industrial employers: creating a supportive innovation ecosystem, maintaining university–industry collaboration, and cultivating doctoral students to meet the non-academic demands. This process can be self-reinforcing in that each step reinforces the previous one [17]. Both studies in the United Kingdom and Spain demonstrated that industrial doctoral students took both technical and generic-skills modules to support their future research [16,18] and they spent 50% of their time in industry to acquire these skills [18]. In Portugal, industrial doctoral programs benefited from the curriculum jointly designed by universities and their industrial partners [19]. Doctoral students were interested in these programs because they may acquire the skills required by industry [20,21]; also, they believed that optional modules relating to their research topics or having a practical orientation are more valuable than compulsory modules [22].

Research project is the most important component of doctoral education. In most cases, research topics are selected by negotiation between universities and industrial partners [15]. For example, doctoral students in an EngD program funded by the EPSRC and industrial partners had to work on research projects agreed between the university and its industrial partners [16]. Further, the focuses of these research projects were industry-specific technical problems, specifications, and prototypes, rather than high-risk concepts and knowledge in the subject areas [23]. Therefore, industrial doctoral students do not have much freedom to choose their research projects.

Industrial doctoral students are usually supervised by supervisors from both academia and industry [16,18]. From the student's perspective, their experiences were affected by the commitment and availability of industrial supervisors. Genuine joint supervision and supervisors' good individual personal skills can bring positive experiences [24]. From the supervisor's perspective, a study in Australia found that their experiences were positive, although expectations about procedures, progress, and outcomes sometimes needed further clarification [25]. However, in the literature, the respective responsibilities of supervisors from academia and industry are not clear.

Assessment is important for doctoral education regarding the rigor of doctoral programs. Despite the involvement of industry, universities maintain the rigor of the degrees so that the academic standards do not need to be compromised [15,26]. This can be explained by that knowledge-intensive industrial partners employ staff with research qualifications, in most cases have long-time interactions with universities, rarely have very high stakes in the research carried out by the doctoral students, and the supervisors from academia are experienced in collaborative research [26].

Research outcome is critical to distinguish different types of doctorates. A survey in a research-based university in the United Kingdom found that research projects with industrial involvement produced fewer journal publications [23]. This can be explained by the contradiction that universities would like to disseminate knowledge via the publication of articles, while industry would like to keep data confidential [15,24].

The collaboration in doctoral education among universities, industry, and governments has benefited these participants. Universities directly benefit from the collaboration in different dimensions: research grants, access to research facilities and data, application of research to real issues, exposure to different disciplinary areas of research, and inclusion of employability skills in doctoral education [25,27]. Supervisors may benefit from the advantages of greater access to research sites and researchable data, the value of research being applied to complex, real-life issues, and exposure to different disciplinary areas of research [25]. Doctoral students may benefit from greater exposure to industry and the reputation of the collaborative scheme that funds their research [15,28]. Thus, doctoral graduates can easily transfer to careers in industry [13,23,28].

Industry benefits from new knowledge, state-of-the-art research, and qualified doctoral graduates [13,29]. The research projects carried out by doctoral students are important for industrial partners, and their industry-relevance strongly depends on co-financing, joint supervision, joint formulation of the research projects, and structured placements [29]. In the meantime, industrial R&D employees can familiarize themselves with research and education, which facilitates them to cross the boundary between university and industry [13].

Governments do not directly benefit from the university–industry collaboration in doctoral education, while benefits from the economic and social development, which are advanced by university–industry interactions that promote innovation, entrepreneurship, and social responsibility, integrate industrial input within university research, acquire the awareness of the technological challenges of industry, and contribute to sustainable funding for research [15].

However, there are challenges in university–industry–government partnership in doctoral education. First, there is a debate about the domination of research projects and the use of data by doctoral students [25]. Universities need to disseminate knowledge via the publication of articles, while industry needs to keep data confidential [24]. Second, doctoral students may not have much interaction with industrial partners as expected, which suggests that a systematic approach is necessary to include them in strategic and meaningful interactions [24,28]. Even though they have the opportunities to access industrial environments and data, these opportunities do not always translate into a positive learning experience. They need to reflect upon, process, and apply these experiences to their research work and emerging identities [28]. Even, these collaborative programs may distract doctoral students by other tasks and neglect their research [24]. Further, it is a challenge for doctoral students to deal with several supervisors and satisfy the requirements of universities and industry, including reporting systems, coursework, and research topics [15]. Moreover, doctoral graduates confer advantages to careers in the private sector, but disadvantages to careers in academia and public research organizations [23]. Third, despite the positive experiences of supervisors, the effectiveness of the collaborative research should be further developed, particularly in the following dimensions: improved methods for discussing academic standards, industrial demands, research ethics, clarification of the responsibilities and timelines of the doctoral education process, and improved processes for negotiating and managing university–industry relationships [25].

3. Conceptual Framework

The triple helix model [30] has become an important framework for researching the three institutional spheres of university, industry, and government, and their dynamic interactions, in innovation and entrepreneurship [31]. It is increasing in national, regional, and multinational innovation systems. The balanced triple helix model is a recursive overlay of communications and negotiations among the institutional spheres of university, industry, and government. It generates a knowledge infrastructure that each of the overlapping institutional spheres takes the role of the other, and hybrid organizations emerge at the interfaces of these institutional spheres. The communications and negotiations among the institutional spheres operate on a roughly equal basis [32]. Traditionally, industries and governments advance industrial development. Nowadays, universities are also contributing to industrial development because more activities in both governments and industry rely on advances in knowledge. Due to the increasing complexity of tasks and rapid technical advances, there is more crossover and cooperation within and across institutional spheres [33]. Universities are not only knowledge producers but also institutions composed of research groups, incubators, and science parks, where economic development takes place [34,35]. It seems that "entrepreneurial university" becomes a global phenomenon with an isomorphic path of development [33]. Industry somewhat operates in academic modes. Industry is transforming and raising its technological level that becomes a little closer to what universities do in adopting educational modes and in sharing knowledge among industry [36]. Governments encourage this transition as an economic development strategy that reflects changes in the relationship between knowledge producers and users [33].

The triple helix model has provided a variety of means and methods of collaboration for doctoral education [29]. Based on the existing literature, a triple helix model of doctoral education is proposed, as seen in Figure 1. Universities, industry, and governments take their own roles within their institutional spheres, interact with each other in their boundary spaces, and overlap in their boundary spaces.

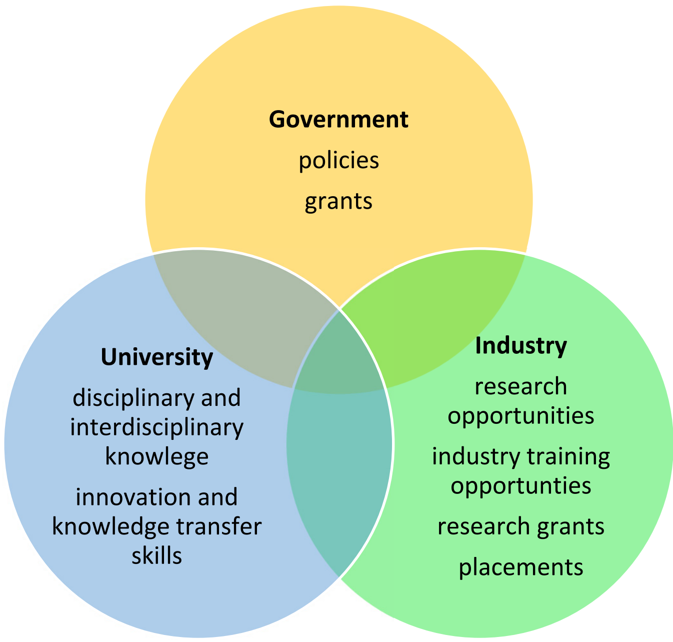

Figure 1. A triple helix model of doctoral education.

Figure 1 describes how universities, industry, and governments work together to cultivate doctoral students for the knowledge economy. Today, universities emphasize entrepreneurial values and skills and exposure to real-life problems [26]. They provide research training and supervision to industrial doctoral students. The research training includes not only disciplinary and interdisciplinary training but also innovation and knowledge transfer skills [9].

Industry demands more workers with broader sets of skills [26]. It provides supervision, funding, placements, and data, and facilitates networking. Such placements widen the experience and employability of doctoral students. They help doctoral candidates to better understand research problems and industrial culture by using facilities, involving industry business, and interactions with staff, which may foster knowledge transfer in both directions [15]. For example, a case study in Portugal showed that industrial partners expanded their skills, influenced research topics, provided research environments and research conditions, and sometimes employment opportunities [14].

Governments stimulate new types of researcher training, promote policies that focus on broader sets of skills of research training, and encourage cultivating doctoral researchers for industry [26]. Governments and their funding bodies are becoming active in shaping research and doctoral education in universities. In the United Kingdom, the Economic and Social Research Council (ESRC) has successfully increased its influence over university doctoral education policies through its sponsorship of CDTs, which is leading to a shift in disciplinary culture and structural changes within universities. Training collaborations and studentship competitions are threading the autonomy of academia, which leads to a rethinking of boundaries. The ESRC would like to extend and develop the engagement with universities through its sponsorship. Individual academics and universities are increasingly excluded from this dialogue if they choose not to become actors [37].

Vice versa, industrial doctoral programs reinforce university–industry partnerships via doctoral students and doctoral graduates, who work across academia and industry. A case study in Portugal has shown that doctoral students can enhance university–industry collaboration through their research that can positively influence knowledge transfer and knowledge sharing [14]. Another case study in Finland has found that collaborative programs in doctoral education train both industrial actors and academics through boundary-spanning activities. These programs facilitated and motivated doctoral students and graduates to work in industry that a majority of the graduates continued their careers in industry [13].

4. Materials and Methods

In order to examine the institutional spheres of university, industry, and government, and their interactions, in doctoral education, preliminary information was gained by looking at the CDT scheme sponsored by the EPSRC. This CDT scheme aims to gather diverse areas of expertise together from universities, industry, and associations to cultivate scientists and engineers with the knowledge and skills to tackle evolving issues. In 2013, the EPSRC invested about GBP 500 million and attracted over GBP 450 million matched funding from universities and industry to support 115 CDTs across 49 British universities, which involve over 1000 universities, companies, and other partners to train over 7000 doctoral students [38]. In 2019, the EPSRC invested about GBP 446 million and attracted over GBP 508 million matched funding to fund 75 CDTs across 48 British universities, which involve over 1400 project partners, to train over 4600 students [39].

This CDT scheme may be the largest university–industry collaborative doctoral education initiative supported by government funding body in the world. It represents a typical model of university–industry–government partnership in doctoral education, which may answer the research questions. This research was based on a case study carried out in a CDT of energy technologies in England. A case study approach can provide an insight into the research issue. The selection of this CDT was based on the following criteria: First, this CDT has reached its maturity as it is sponsored by the EPSRC from 2009 to 2024. Second, like most CDTs, this CDT is hosted by a research-intensive university. Third, energy technology involves chemical engineering and mechanical engineering, which are the main engineering disciplines, and it is an active research area for the rapid development of renewable energy and the cleaner use of traditional energy. Fourth, the author was the manager of the chosen CDT, so it is possible to access the data of this CDT.

Document and observation studies were adopted as the instruments to collect data. As a limitation of formal documents regarding CDTs [40], insider research provides the opportunity to access documents and observe the doctoral education process in the chosen CDT. Therefore, document and observation studies are appropriate for this research. The documents include the websites, regulations, and reports of the EPSRC, the degree-awarding university, and this CDT. As manager of the CDT, the author can access the documents and involve in the process of doctoral education. An unstructured observation was conducted and recorded in the author's field notes. Under the guidance of the triple helix model of doctoral education in Figure 1, document and observation analyses were conducted to analyze the collected data. The mixture of document and observation studies provides data triangulation. Following the analytic procedure of document analysis [41], the author found, selected, appraised, and synthesized the data contained in the documents into the themes of purpose, selection, curriculum, learning and supervision, assessment, and outcome. The author also transcribed, coded, and themed the observed data in the field notes into the same themes.

5. Results

Through document and observation analyses, this section describes the industrial doctoral education process, which includes purpose, selection, curriculum, learning and supervision, assessment, and outcome, as well as the roles of universities, industry, and governments, and their interactions. The roles of university, industry, and government are presented in Table 1.

Table 1. The roles of university, industry, and government in doctoral education.

	University	Industry	Government
Purpose	a. Cultivate doctoral students b. Enhance research collaboration	a. Enhance research collaboration	a. Create a supportive environment and new working cultures b. Establish links between universities and between universities and with industry c. Cultivate scientists and engineers to tackle real-world challenges. d. Conduct evaluation
Selection	a. Set entry requirements b. Conduct selection interviews	a. Match research projects and research interests	a. Conduct evaluation
Curriculum	a. Provide disciplinary training b. Provide interdisciplinary training c. Provide professional skills training	a. Provide in-company training b. Provide placements	a. Require technical and transferrable skills b. Conduct evaluation
Learning and supervision	a. Mentor learning b. Provide academic supervisor	a. Provide industrial supervisor	a. Conduct evaluation
Assessment	a. Conduct annual review b. Conduct final assessment	a. Monitor project progression	a. Conduct evaluation
Outcome	a. Require research outcome that can be publication, technical report, or research thesis	a. Require project report	a. Conduct evaluation

The EPSRC determines the priority sponsor areas by consulting experts from universities and industry. The sponsored CDTs were selected based on the reviews by the panels of the different themes, composed of members from universities, industry, etc. These CDTs have to partner with industry and contribute to the priority sponsor areas determined by the EPSRC. The research area of the chosen CDT falls into the energy theme of the

EPSRC. The EPSRC provided about GBP 6.8 million in 2009 and around GBP 3.5 million in 2014 to the chosen CDT. These grants have provided sufficient scholarships for EngD students. Each EngD student is waived of tuition fee and receives about GBP 19,000 as a stipend per year for four years. Moreover, there is an additional budget for their travels for international conferences, workshops, etc. It is noted that the stipend is higher than that of traditional Ph.D. students at the same university. This CDT has established partnerships with over 43 partners from industry and academia throughout the world. Most of the industrial partners are large energy corporates.

The purpose of the CDT prescribed by the EPSRC and clearly stated by this CDT is strongly linked to industry. According to the EPSRC, the CDT scheme aims to create supportive environments for students, provide new working cultures, establish links between teams within universities, and build lasting relationships with industry to cultivate scientists and engineers to tackle real-world challenges [39]. This CDT stated that the EngD program is developed for students, called "Research Engineers", to train future leaders to tackle the major challenges at the national and international levels. The collaboration in doctoral education may further enhance their research collaborations. It was observed that most of the industrial partners have long-term research collaborations with this university. They collaborate with this university for doctoral education as part of their collaborative research.

It was observed that the selection of the EngD students is primarily controlled by the degree-awarding university. A bachelor's degree with a first or upper-second-class honors or a master's degree with distinction in a relevant field is an entrance prerequisite while working experience is not a prerequisite. The industrial partners play a key role in the selection process. They examine the matching of applications with their research projects through an additional interview that the shortlisted candidates are invited for interviews to discuss the research projects in more details with them.

According to the EPSRC, the curricula of the four-year doctoral programs in these CDTs include training related to technical and transferrable skills and a research element [38]. The curriculum of this EngD program is regulated by the Quality Manual of the degree-awarding university and further developed by this CDT. The Quality Manual shows that the curriculum has up to 180 credits of modules, which are normally completed in the first two years of the program. The curriculum of this CDT has shown that this EngD program incorporates a taught component, which is identical to 25% of the program duration, and a research project from industry. The taught component includes modules of contextual, advanced technical, and technology management skills to prepare for both doctoral research and a career within industry. These modules are up to 180 credits, including 120 credits of compulsory modules and 60 credits of optional modules. It was observed that, besides the taught component, the industrial partners provide in-company training opportunities to the EngD students, which are aligned with their research projects.

In this CDT, it was observed that a mentor from the partner universities is appointed to each EngD student at the taught stage of the program. The mentor provides support to the EngD student, such as identifying training needs and advising on optional module choice, to ensure they are appropriate to the student's future career development. The Quality Manual advises that an individual EngD student is supervised by a supervisory team and that each EngD student has at least two academic supervisors and one industrial supervisor. In this CDT, it was observed that each EngD student is assigned two academic supervisors from the partner universities and one non-academic supervisor from the industrial partners at the end of the first academic year. The non-academic supervisor coordinates daily support for the students because the EngD students conduct research projects based on industrial partners.

The Quality Manual advises that the conferment of the EngD degree requires that EngD candidates should have successfully obtained all credits of the taught modules for graduation and be examined in the form of a viva voce by an external examiner who is knowledgeable and experienced in the same area at the end of each academic year. In this

CDT, it was observed that the annual review is dominated by the university, although, sometimes, external examiners are from industry. Finally, the research outcome is examined by a panel composed of an internal examiner and an external examiner, who are usually from academia. As both the annual review and examination of the final research outcome are dominated by the university, the industrial partners do have not much impact on the assessment.

The Quality Manual has shown that the outcome of the EngD program is a portfolio composed of research projects with a common theme carried out in industry and supervised by academic supervisors from the partner universities. The EngD candidates shall submit a portfolio thesis, which could be publications, technical reports, or a research thesis, for assessment in accordance with the requirements of the CDT. The research outcomes deposited in the repository of the university from 2019 to 2021 have shown that all EngD graduates submitted research theses for graduation, although publications and technical reports may replace research theses in the university policy.

Despite the government and its funding bodies not being involved in the process of doctoral education at the institutional level, the EPSRC evaluates the sponsored CDTs. Each CDT has to submit an annual report to the EPSRC for monitoring. In addition, the EPSRC undertakes mid-term review exercises to evaluate the performance of these CDTs against their key targets and requirements. In 2016/2017, the EPSRC evaluated these CDTs from the following dimensions: objectives and operation, student attracted and student outcomes, value for money, taught component, impact on the wider community, and outputs [42].

6. Discussion

The findings have shown the whole process of doctoral education and the interactions of university, industry, and government in the chosen CDT. The government, represented by its funding body—the EPSRC—determined the priority research areas and facilitated the cooperation between universities and industry by offering grants. In the meantime, universities and industry engaged in the determination of priority research areas by providing expert advice.

The purpose of the CDT is consistent with that of the government, which is to cultivate scientists and engineers to tackle real-world challenges. Previous research found that university–industry collaboration in doctoral education was threading the autonomy of academia [37]. This research confirms previous findings that university autonomy is compromised through university–industry–government collaboration, which is pursued through the determination of the research areas, selection of students, negotiation of research topics, curriculum design, and joint supervision. Although universities have the freedom to participate in these activities, they will be excluded from this dialogue if they choose not to participate [37].

Universities, industry, and governments play critical roles in the whole process of doctoral education in the chosen CDT. First, the selection is dominated by universities, while industry can involve the selection of doctoral students as these doctoral students will conduct research in industry or on research projects from industry. Industry ensures that doctoral students' qualifications and research interests match the research projects. Second, the EngD program not only adds a taught component into the curriculum but also integrates industry engagement and practice research into the process of doctoral education. The taught component includes disciplinary, interdisciplinary, innovation, and knowledge transfer skills training. The industry-based training cannot be structured for the different research projects that doctoral students work on. The learning and research of the EngD students are under the guidance of the mentor and supervisors. Third, like the findings in prior studies [15,16,23], the EngD students do not have much freedom to choose their research projects. At the national level, the research priority areas were determined by the funding body. At the institutional level, the CDT has negotiated the research projects with its industrial partners before the recruitment of the doctoral students. Therefore, the research topics of the doctoral students are restricted to the research projects agreed between the CDT and its industrial partners. Thus, it is important that the EngD students' research interests match the research projects from industry at the selection stage. The involvement of industry at the selection stage has ensured the matching. Fourth, the EngD students may benefit from the arrangement of the supervision that each EngD student is assigned supervisors from academia and industry. However, the helpfulness of the industrial supervisors in this CDT may be doubted as they provide only administrative rather than academic support. Previous research has suggested that this may be improved by genuine joint supervision [24]. Fifth, the assessment of the EngD program is controlled by the university. This confirms that universities maintain academic standards to ensure the rigor of university–industry–government collaborative doctoral programs [15,26], although their autonomy is compromised. Sixth, the form of research outcome can be a portfolio thesis for this EngD program. Therefore, it is more flexible for the EngD students to meet the requirements of the university and its industrial partners. Despite the flexibility in the policy, all the EngD graduates chose to submit research theses for graduation. This is probably because both supervisors and students would like to defend the quality of the EngD program from the argument about the form of research outcome. Intellectual property is another aspect of research outcome. Although the university and its industrial partners have their own policies on intellectual properties in general, these policies are not or cannot be systematically developed to apply to both universities and industry. The supervisors have to discuss the ownership of intellectual properties with the industrial partners case by case because the contribution of grants and commitment to research from both parties vary with research project. Finally, although the government funding body does not involve in the operation of this CDT at the institutional level, it evaluates the performance of all CDTs at the national level.

This CDT has shown the links among universities, industry, and governments, which can be analyzed with the triple helix model of doctoral education presented in Figure 1. The government facilitates the cooperation between university and industry through the launch of the CDT scheme. The government has influenced doctoral education by the determination of priority sponsor areas, selection of sponsored CDTs, allocation of funds, etc. These ensure that doctoral students' research meets the demands of the national and/or regional economy. Vice versa, both universities and industry are involved in the determination of priority sponsor areas, selection of sponsored CDTs, and allocation of funds by providing expert advice. Universities are changing their doctoral education in response to the demands of the knowledge economy. They are cultivating doctoral students with the skills required by industry because of the change in the labor market. These changes include providing disciplinary, interdisciplinary, and professional skills training to students and immersing students in industrial environments to understand industrial demands and operations. Therefore, doctoral graduates can be competitive in the industry job market. In the meantime, resources are critical for the development of universities so that universities are actively securing research grants from governments and industry. Industry also plays an important role in doctoral education through research collaboration, training, grants, and placement. First, industry has close research collaborations with universities; industry provides research opportunities based on industrial partners or universities for the EngD students. Second, industry provides opportunities for the EngD students to receive in-company training. Third, industry contributes research grants for doctoral education. Fourth, industry provides placements for the EngD students to work outside of universities. Industry may benefit from the research outcomes and qualified doctoral graduates. Therefore, they would like to support the schemes initiated by governments and strength their collaborations with universities.

In summary, governments promote the research directions and stimulates cooperation between universities and industry through policies and grants for doctoral education. Universities provide innovation and knowledge transfer skills training in addition to disciplinary and interdisciplinary knowledge to doctoral students and prepare them for careers in industry. Industry provides research and industry training opportunities, research grants, and placements to doctoral students. In the meantime, each actor of the triple helix model of doctoral education benefits from the interactions. These benefits reinforce their interactions to cultivate doctoral students. Universities, industry, and governments have taken their roles in doctoral education; however, their interactions should be enhanced in the boundary spaces presented in Figure 1, such as university autonomy, research projects determination, joint curriculum design, joint supervision, and research outcome.

7. Conclusions

Based on the existing literature, this article generalized a triple helix model of doctoral education, presented in Figure 1. Then, a practical example of the triple helix model of doctoral education was presented, which successfully showed the relations among universities, industry, and governments in doctoral education. Universities are changing their doctoral education in response to the demand of the knowledge economy by providing disciplinary, interdisciplinary, and professional training and conducting industry-relevant research. Industry works together with universities to cultivate doctoral students through collaborative research. Governments support the university–industry collaboration through policies and funding. Universities, industry, and governments benefit from their interactions, and these benefits reinforce their interactions. This theoretical innovation provides guidance for doctoral education to fulfill the demands of the knowledge economy, although the interactions in the boundary spaces need to be further developed.

The rigor of the industrial doctorate is not compromised because universities dominate the assessment, although university autonomy is compromised. However, the space for universities to compromise should be further explored. A structured curriculum jointly developed by universities and industry relating to industry can benefit students. The responsibilities of supervisors from academia and industry should be further clarified for genuine joint supervision and the interpersonal skills of these supervisors should be developed. Industrial doctoral students have to work on the research projects negotiated between universities and industry; therefore, it is important that their research interests match the research projects at the selection stage. Although industrial doctoral students may submit a portfolio thesis for graduation in the university policy, all EngD students still submitted research theses for graduation. It seems they would like to defend their quality by a research outcome that is commonly accepted in academia. For the different policies of universities and industry on intellectual properties and different contributions to the research projects, the share of intellectual properties varies with research project.

Although circumscribed to the British context, this article contributes to further knowledge on industrial doctorates—a topic on which research is still scarce. Although a mid-term review was conducted in 2016, its details, except for the review outcomes, are unknown. Thus, the success of industrial doctorates is unknown, which needs to be further tested in future studies and practice.

The triple helix model of doctoral education is useful for policymakers, business leaders, and education practitioners. This model clearly describes the roles of university, industry, and government, and their interactions, which may guide the practice of these stakeholders; it also provides a triple helix model of doctoral education to researchers for future research on university–industry–government collaboration in doctoral education. Further theoretical studies should be conducted to develop this model and empirical studies should be carried out to test and develop this model.

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