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Research centres and universities' intellectual capital: a quantitative empirical study of PhD holders' contributions

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This study investigates the mechanisms of intellectual capital (IC) in knowledge-intensive research centres and universities in the Minalogic cluster of Grenoble, France. We use structural equation modelling to analyse responses from 248 PhD holders. Our results show a positive relationship among human, relational, structural, and intellectual capital outcomes. We first contribute to the early understanding of IC mechanisms in research centres and universities by conducting a quantitative empirical study, which is novel to IC. We support the relation between knowledge-based human capital and relational alliances capital and highlight the importance of employing PhD holders. Second, unlike past studies, we offer empirical support that (a) relational alliances capital relates to structural innovation capital and (b) knowledge-based human capital relates to structural innovation capital. We suggest that research centres and universities should develop an alliance portfolio for innovations. Third, we uncover that structural innovation capital relates to IC outcomes, contributing to the assessment of the economic and social role of public research centres and universities. This study presents managerial implications for policymakers and practitioners engaged in research centres and universities by highlighting the importance of key components of IC.

1. Introduction

In the current knowledge-based economy (Tseng and Goo, 2005), firms source external knowledge from universities to stay ahead in the competition (Lipsey, 2001; Cohen et al., 2003; Balconi and Laboranti, 2006). Thus, university-industry R&D cooperation increases companies' abilities to create high-impact technologies and bring new products to the market (Faems et al., 2003; Belderbos et al., 2004; Cassiman et al., 2008). Therefore, effectively acquiring scientific knowledge through research cooperation with university scientists positively affects

a company's innovation performance (Zucker and Darby, 2001; George et al., 2002; Zucker et al., 2002; Cassiman et al., 2008) and competitive advantage (Nahapiet and Ghoshal, 1998; Subramaniam and Youndt, 2005; Crupi et al., 2020).

Due to an increasing interest in the role of knowledge and intellectual capital (IC) (Petty and Guthrie, 2000; Kianto et al., 2010), IC has been examined as being related to listed firms (M.C. Chen et al., 2005; Firer and Williams, 2003), SMEs (Hermans and Kauranen, 2005; McDowell et al., 2018; Mahmood and Mubarik, 2020), new ventures (Hayton, 2005), family businesses (Grimaldi et

al., 2016), and high- and low-tech firms (Tseng and Goo, 2005; Delgado-Verde et al., 2016; Buenechea-Elberdin et al., 2018). However, few studies have investigated IC with a focus on universities, education, and the public sector (Bellucci et al., 2021); therefore, studies on universities and research centres are scarce (Del Rocío Martínez-Torres, 2013; Dabić et al., 2021). Lately, universities, higher education schools, and research centres have received a 'third mission' – acting as a game changer – in addition to teaching and research duties, which are achievements in themselves. Therefore, studying IC in these institutions is an urgent and important need to realise this new objective. Universities should take on the challenging economic and social roles of contributing to communities and territories (Compagnucci and Spigarelli, 2020), possibly leading to the economically and socially significant role of IC in mobilising intangible resources (Bisogno et al., 2018).

Hence, there is increasing interest in the IC found in higher education institutions (HEIs). Universities' IC impactfully catalyses the attractiveness of a region, matters to the knowledge-based society (Bisogno et al., 2018), and fulfils universities' third mission (Compagnucci and Spigarelli, 2020). Therefore, further research in the education sector that facilitates the growth of social capital within a community is needed (Mowery and Sampat, 2005). Indeed, studying HEIs augments the ties between local communities and industries by strengthening relational capital (RC). However, although some empirical studies have focused on how improved teachers' abilities enhance human capital (HC) growth in HEIs (Oliver, 2013), the role of PhD holders in universities and research centres remains unknown. Such understanding is needed to manage the IC of these refined workforces better. In line with HEIs' third mission, IC matters in universities and research centres because it attracts researchers and PhD students to join these institutions.

An increasing number of European universities provide evidence of the measurement of key performance indicators to assess IC and its social and economic impacts (Scaringella and Chanaron, 2015); however, other universities do not conduct studies on the outcomes of IC. Therefore, we lack studies on IC outcomes for universities and research centres' stakeholders (Compagnucci and Spigarelli, 2020) to complement past studies on IC measurement (Siboni et al., 2013; Veltri et al., 2014) and IC disclosure (Leitner, 2004; Cañibano and Paloma Sánchez, 2009). Studies on IC outcomes, which identify the demonstrated impacts of IC, are vital for attracting funders to invest in local ecosystems (Scaringella and Radziwon, 2018). However, this

aspect is missing for both universities and research centres.

Particularly, we lack the quantitative studies necessary to draw further policymaking implications (Bisogno et al., 2018) related to IC outcomes. For example, few studies have investigated the voluntary IC disclosure in Italian (Sangiorgi and Siboni, 2017) or South African universities (Veltri and Silvestri, 2015). However, some have examined the measurement of IC components (Ramirez and Gordillo, 2014), development of dashboards for university IC to monitor tangible and intangible assets (Secundo et al., 2016), creation of reporting models (Sánchez et al., 2009), and university performance (Cricelli et al., 2018).

Nevertheless, past studies on IC in education do not distinguish between universities and research centres, which is needed to uncover the similarities and differences between these organisations because their management and disclosure of IC might significantly differ (Bisogno et al., 2018). We identified four papers only that used a single-case study research design when studying IC in research centres. Therefore, we have a limited understanding of the role of public-sector research and development organisations (Kim and Kumar, 2009), besides a dashboard of IC metrics development (Secundo et al., 2010), spin-off creations (Carayannis et al., 2014), and incubations (Loyarte et al., 2018). Studying both universities and research centres is important because they have complementary roles, can develop synergetic activities, and offer job mobility across organisations that reinforce IC at the regional level. While investigations have been conducted in many countries (Bisogno et al., 2018), no empirical research has been conducted in France. We address this gap by investigating the IC from research centres and universities in the Minalogic cluster of Grenoble, France.

Therefore, our study investigates the following research question: *What are the IC mechanisms in research centres and universities?*

The study's expected contributions are three-fold. First, in response to the calls made by Bellucci et al. (2021), Bisogno et al. (2018), and Del Rocío Martínez-Torres (2013), this study aims to be the first quantitative empirical study investigating IC in research centres and universities by targeting PhD holders – a solid base of HC – from internationally recognised research centres and universities in Grenoble. Second, it enriches the existing mixed-results in IC literature (Buenechea-Elberdin et al., 2018; Salinas-Ávila et al., 2020; Guerrero et al., 2021) by considering the debates on whether RC relates positively to structural capital (SC). This research is meaningful to policymakers and practitioners engaged in research

centres and universities because it can provide further evidence of the relation between RC and SC as an essential mechanism of IC. Third, to contribute to Guerrero et al.'s (2021) and Schiavone et al.'s (2022) findings, we investigate not only the main components of IC, such as HC, RC, and SC, but also the outcomes of IC from research centres and universities. We also offer insights to organisations about the benefits of strengthening their RC by engaging PhD holders who can catalyse the SC of research centres and universities.

2. Theoretical background

John Kenneth Galbraith coined the term IC in 1969. However, Stewart started IC more practically after a series of *Fortune* articles and his 1997 book *Intellectual Capital: The New Wealth of Organizations*. Stewart (1997) defined intellectual capital as 'the intellectual material – knowledge, information, intellectual property, experience – that can be used to create wealth' (p. 12). Stewart considered HC, SC, and customer capital (later replaced by RC, which is broader) as the three components of IC.

While IC in firms has been the primary focus in IC research, IC in universities and research centres is now receiving due attention (Del Rocío Martínez-Torres, 2013; Dabić et al., 2021). It is essential for knowledge-intensive industries that companies work directly with universities to obtain state-of-the-art knowledge and expertise (Zucker and Darby, 2001; Zucker et al., 2002; Cassiman et al., 2008). Hence, the importance of working directly with universities is especially emphasised in the industry-scientific literature (Cohen et al., 2003).

Several scholars have promoted the value of focussing universities' IC on spin-off creations. First, Villanueva-Flores et al. (2022) argued that IC is key to universities' competitive advantage and value creation, and academic entrepreneurs' HC and RC affect their international orientation, including during the COVID-19 pandemic (Paoloni et al., 2021). Second, Coad et al. (2021) maintained that HC is important because it influences the economically and socially vital spin-off capabilities developed by university employees. Third, Prencipe et al. (2022) contended that the gender ratio in boards of directors matters. However, the relation between the components of universities' IC remains unclear.

For universities, HC comprises teaching and researching skills as well as personal relationships (Del Rocío Martínez-Torres, 2013). Martin-Sardesai and Guthrie (2018) investigated the link between academic HC and performance measurement

systems derived from case studies conducted in the Australian public sector. Extending that research, Bongiovanni et al. (2020) added faculty members, students, PhD students, professional staff, and research fellows. Bisogno et al. (2018) defined HC as a 'set of explicit and tacit knowledge of the universities' personnel acquired through formal and informal educational and actualisation processes embodied in their activities' (p. 22). HC has been considered based on the nature of knowledge, both tacit and explicit (Bontis, 1998; Bisogno et al., 2018), and the types of knowledge, know-how and know-what (Edvinsson and Sullivan, 1996; Nahapiet and Ghoshal, 1998). However, no research in IC has considered knowledge divisibility, based on the seminal work of Cristiano Antonelli. Our study considers HC by referring to knowledge divisibility that is characterised by four main features: (1) knowledge complementarity (Arrow, 1975; Milgrom and Roberts, 1995; Antonelli, 1999), (2) knowledge cumulability (Arrow, 1972, 1969; Antonelli, 1999; Antonelli and Teubal, 2006), (3) knowledge compositeness (Antonelli and Calderini, 2008; Antonelli et al., 2010; Kafouros and Forsans, 2012), and (4) knowledge fungibility (Lipsev et al., 1998; Antonelli, 2003).

Barrena-Martínez et al. (2020) argued that 'relational capital represents the relations and knowledge exchanges with the organization's external stakeholders' (p. 261). RC in universities comprises research application and diffusion, contacts and relationships, and image (Del Rocío Martínez-Torres, 2013). Bongiovanni et al. (2020) defined the RC of universities based on the following activities: 'relations with regional, national, and international commissions; associations and scientific societies; spin-offs; non-affiliated academics in universities; social context; and volunteering sector' (p. 485). Further, Bisogno et al. (2018) argued that 'relational capital gathers the wide set of economic, political, and institutional relationships developed and maintained by universities' (p. 23).

Past research has discussed different aspects of RC; however, the role of strategic alliances in RC requires further investigation. This may be because R&D alliances are created with other companies, not with universities and research institutes (Stuart et al., 2007; Almeida et al., 2011). Furthermore, responses from interviews conducted by Almeida et al. (2011) suggest that, because of their formal nature, R&D partnerships might not attract scientists' attention, decreasing the alliances' efficiency. Therefore, few studies have considered the cooperation between research labs and universities in pursuing technology exploration (e.g., George et al., 2002) or strategic

alliances between universities and firms to develop a critical flow of technical knowledge (e.g., Mowery and Shane, 2002), such as R&D alliances with universities (Gittelman and Kogut, 2003; Bercovitz and Feldman, 2007). Belderbos et al. (2016) argued that research institutes and universities are a primary source of the latest knowledge. They often offer access to new ideas and concepts involving fundamental knowledge (Baum et al., 2000; George et al., 2001). Thus, studying the RC in universities and research centres provides insight into how they accomplish their third mission (Compagnucci and Spigarelli, 2020).

The SC of universities entails teaching improvement, internal collaboration, research management, and organisation management (Del Rocío Martínez-Torres, 2013). Bongiovanni et al. (2020) defined the SC of universities as 'research outputs (publications and patents); knowledge creation processes and projects (seminars and research projects); impact and artifacts of scientific research (best practices, integrated research centres, guidelines and protocols, records, and databases); outputs of teaching (training); and educational outputs' (p. 485). Following the distinction tree presented by Lövingsson et al. (2000), our study focuses on innovation capabilities (InnoC) (Chen et al., 2004; Tseng and Goo, 2005; Wang and Chang, 2005). We aim to complement J. Chen et al. (2004), who illustrated InnoC using Skandia Navigator as an example. In Section 3, we further elaborate on InnoC, defined as SC, based on Schumpeter's (1934) seminal definition. Edquist et al. (2001) supported Schumpeter's (1934) view on innovation. Tavassoli and Karlsson (2015) argued that the Schumpeterian definition of innovation, as a process, product, organisational, and marketing innovation, remains important today.

In university–industry collaborations, Al-Tabbaa and Ankrah (2019) argued that there is a lack of studies on the micro-foundations of technology transfer, using the lens of social capital. Yet, in the knowledge-based economy (KBE), universities are important stakeholders who produce knowledge and train skilled HC, such as PhD graduates (Hancock et al., 2017). PhD holders are essential to IC (Caparrós-Ruiz, 2019; Djuric et al., 2020; Pretorius and Macaulay, 2021) and constitute the *human capital stock* of society (Schwabe, 2011). Indeed, PhD holders contribute to the development of high-value HC that catalyses economic growth by creating and applying scientific knowledge (Hancock et al., 2017) and creating new ventures that strengthen the university–industry linkages (Muscio and Ramaciotti, 2019). However, PhD holders, a scarce resource, are important and should be preserved and

studied. In France, less than 1% of 25- to 64-year-old university graduates have PhDs (OECD, 2019). Therefore, Hancock et al. (2017) encouraged further research to investigate the role of doctoral scientists in the KBE.

While PhD holders are a rare HC, they are in jeopardy because their doctoral education has failed to provide adequate training to match the current job market's needs. Such misalignments cause inefficiencies in the current educational system and hinder the future development of such HC (Servage, 2009; Schwabe, 2011). Pretorius and Macaulay (2021) studied HC related to PhD students' expectations when building their academic identity. They argued that PhD students are marginalised and have a sense of disempowerment that hinders the development of HC. Therefore, our study also aims to investigate the role of PhD holders in universities and research centres' IC.

3. Hypothesis development

3.1. Human capital and relational capital

A critical part of new scientific knowledge – as part of HC – is often not transmitted through publications, but only through close interactions among people, university teams, and company scientists by mean of a direct cooperation (Gulati, 1995; Belderbos et al., 2016), trust (Gilsing et al., 2008), and an efficient RC (Zucker et al., 1998, 2002; Cassiman et al., 2008). In addition to tacit knowledge, leading academic laboratories produce codified knowledge based on know-what and analytical knowledge (Cooke, 2006).

According to previous research, HC and CC in businesses are positively related to each other. For instance, Bontis (1998)'s original model supported this relation between HC and CC. Based on a study of 289 senior executives from large Taiwanese firms, Tseng and Goo (2005) argued that HC and RC relate positively. Furthermore, Mention and Bontis (2013) supported the relation between HC and RC in the banking system in Luxembourg and Belgium. Finally, Kianto et al.'s (2017) empirical study of 180 Spanish companies suggested that HC and RC relate positively, and, in a similar empirical context, both external and internal RC relate positively to HC, according to Buenechea-Elberdin et al. (2018). However, empirical studies on universities are rare; for example, Salinas-Ávila et al. (2020) support the relation between HC and RC in Colombian public universities. However, research centres have not been studied.

Mertens and Rübken (2013) argued that doctorate holders strengthen HC as, compared to graduates

with master's degrees, they tend to work for longer hours. Liu et al. (2020) contended that PhD creativity is part of the scientific and technical HC. Furthermore, Yamaguchi et al. (2021) maintained that organisations with a greater number of PhD holders benefit from a stronger HC, which is a determinant of R&D outsourcing. These findings support that PhD holders are vital contributors to organisations and policymaking.

Heitor et al. (2014) proposed that regions and countries should acquire knowledge from PhD holders to drive economic and social development. Furthermore, Roh (2015) concluded that PhD holders migrating to the United States contribute to countries' brain drain, affecting a nation's HC. Hence, we derive the following hypothesis:

H1 Human capital relates positively to relational capital.

3.2. Relational capital and structural capital

Zhang et al. (2022) argued that little research has been done on RC, particularly on the impact of university-industry alliance portfolio depth and breath, except the few studies conducted at the dyadic level (Scandura, 2016; Fischer et al., 2018). They argued that alliance portfolio depth negatively effects firms' growths, while alliance portfolio breath positively impacts firms' growths. Furthermore, Østergaard and Drejer (2022) argued that the persistence of RC within university-industry collaborations is rather high. Such sustained SC is due to the collaboration of a wide range of partner types. Therefore, the breadth of knowledge is key to the persistence of university-industry RC.

However, in Bontis's (1998) early model, the relation between CC and SC was not significant. Contrastingly, Mention and Bontis (2013) later found that SC and RC are related in a dissimilar empirical context. This is similar to Salinas-Ávila et al. (2020)'s study of Columbian universities. Subramaniam and Youndt (2005) found that 'anticipated, organizational capital positively influenced incremental innovative capability' (p. 450). Tseng and Goo (2005) argued that RC and InnoC relate positively. Kianto et al. (2017) determined that RC and innovation performance relate positively. However, Buenechea-Elberdin et al. (2018) did not find external RC and managerial innovation performance as significant in their study. Therefore, results on the relation between RC and InnoC are mixed.

From their longitudinal study on Portuguese HEI covering four decades, Heitor et al. (2014) suggest a

co-evolution of RC formation and research-capacity building. They found that alliances and partnerships between HEI and firms are important in catalysing RC. Similarly, Guerrero et al. (2021) investigated how IC is affected by partners' behaviours in industry-university collaborations. Thus, we derive the following hypothesis:

H2 Relational capital relates positively to structural capital.

3.3. Human capital and structural capital

Gretsch et al. (2019) encouraged the collaboration between science-based and market-based partners to leverage the complementarity of resources, expertise, and HC to innovate and strengthen their SC. The cooperation with universities enables firms to acquire specific knowledge, find new ways to solve problems, capture opportunities for HC, and identify promising windows for emerging technologies (Perkmann and Walsh, 2007; D'Este and Perkmann, 2011). Similarly, Giannopoulou et al. (2019) demonstrated that companies strengthen their SC by innovating more and launching a larger number of new products when benefiting from HC from universities.

Bontis (1998) argued that the relationship between HC and SC is positive and significant. Mention and Bontis (2013) confirmed that HC and SC relate positively in the banking sector. Using a qualitative index system, J. Chen et al. (2004) found that HC and InnoC relate positively. Likewise, from their study of Spanish firms, Tseng and Goo (2005) posited that HC and InnoC relate positively. Additionally, Wang and Chang (2005) determined that HC affects InnoC, based on their empirical studies on Taiwanese firms in the IT industry.

However, based on their study of 180 Spanish firms, Kianto et al. (2017)'s findings did not support the relationship between HC and innovation performance. Moreover, Subramaniam and Youndt (2005) argued that 'human capital, by itself, was negatively associated with radical innovative capability' (p. 450). As mentioned above, studies on universities are infrequent. We can only refer to Salinas-Ávila et al.'s (2020) research that investigates 209 researchers from eight Colombian universities, supporting the relation between HC and SC. However, studies on the relation between HC and InnoC, from a research centre or university perspective, are scarce. Therefore, we pose the following hypothesis:

H3 Human capital relates positively to structural capital.

3.4. Structural capital and intellectual capital outcomes

Bontis (1998) supported the positive relation between SC and performance. Existing studies, including Chen et al.'s (2005) study on Taiwanese listed companies and the public's value added intellectual coefficient, confirmed that IC and firms' market value/financial performance relate. Firer and Williams (2003) also investigated the impact of IC on firm performance and included profitability, productivity, and market valuation in their empirical study of 75 publicly traded firms in South Africa. Likewise, from their study of Taiwanese IC design companies, Wu et al. (2006) argued that IC affects competitive advantage. Furthermore, Kehoe and Tzabbar's (2015) examination and analysis of 456 biotechnology firms, from 1973 to 2003, showed that star employees have a substantial and positive effect on a firm's productivity and are also drivers for other innovative leaders in an organisation. Therefore, they provided insights into how HC, as part of the IC, may be a competitive advantage in an organisation.

In their study on industry-university partnerships, Guerrero et al. (2021) were interested not only in the efforts of IC but also in the outputs and the outcomes of subsidised projects. Findings from their study on Mexican subsidised industry-university partnerships indicate that opportunistic behaviours affect IC impacts (performance) and returns to society (job creation); therefore, they offer subsequent socio-economic returns. However, Andrews et al.'s (2021) investigations into how universities catalyse the commercialisation and distribution of technical knowledge through technology transfer offices revealed some limitations, such as communication issues between academics and industry partners. Narzary and Palo (2021) argued that HC, RC, and SC have positive outcomes, such as fostering employees' innovative behaviour. However, they also raised potential negative consequences of IC. They found that placing too much pressure on the innovative outcomes of IC could lead to counterproductive effects, such as loss of motivation leading to burn-out. In addition to Guerrero et al. (2021), Andrews et al. (2021), Narzary and Palo (2021), and Schiavone et al. (2022) called for further quantitative research

to measure the outcomes of IC, such as those related to overall efficiency improvement, specialisation in a particular market segment, new client acquisition, cost reduction, future goals determination, and image and processes improvement (Birchall et al., 2011). Consequently, we develop the following hypothesis:

H4 Structural capital relates positively to intellectual capital outcomes.

Our study investigates the research model shown in Figure 1, which is derived from the literature on IC, knowledge management, strategic management, and innovation management.

4. Methodology

4.1. Questionnaire development

Our questionnaire was developed through a multi-stage process (Churchill, 1979; Anderson and Gerbing, 1988; Hazan and Shaver, 1994; Hazan and Zeifman, 1999). We conducted a qualitative preliminary study by interviewing 36 experts (including 9 PhD holders) in the field: 25 IC managers in firms, 6 researchers in universities, and 5 researchers in research centres. Thereafter, we adapted scales from the literature to build our draft questionnaire, which was subsequently evaluated by (a) four academic experts in innovation management and IC, (b) two practitioners, and (c) an individual from the Minalogic cluster of Grenoble. Based on the critical evaluation of the questionnaire, we simplified some items in our constructs for a quicker answering process.

We measured four constructs comprising 31 items. HC was assessed using a 4-item adapted scale from Backmann et al. (2015)'s seven-point Likert scale. RC was measured as a binary variable, using a 15-item scale adapted from Simonin (1999) and Schilke and Goerzen (2010). SC was computed using a five-item scale adapted from Calantone et al. (2006), Nielsen and Nielsen (2009), and Tavassoli and Karlsson (2015)'s seven-point Likert scale. intellectual capital outcomes was calculated using a seven-item scale from Birchall et al. (2011). We used six control variables: gender, age, job type, department,

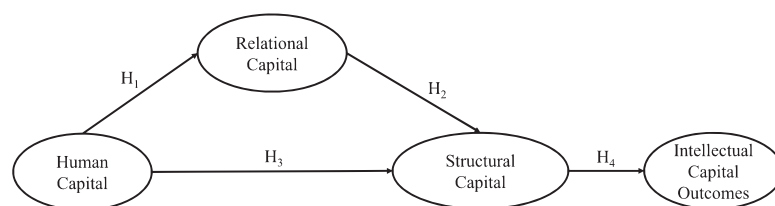


Figure 1. Research model.

number of subordinates, and log of the organisation's size. The questionnaire was translated into French and back translated into English by an independent translator who was not familiar with the original questionnaire. The two questionnaires were then compared to ensure that the content remained unchanged.

Our study used the perceptual measurements of PhD holders from research centres and universities, who were part of the Minalogic cluster in Grenoble. A pre-test was performed on 32 researchers from research centres and universities in the Minalogic cluster in Grenoble. We used SPSS version 27 and AMOS to conduct the statistical analysis. We checked the reliability of our constructs with Cronbach's alpha; as our early statistics were satisfactory, the full survey was administered.

4.2. Data collection

First, we created a database by gathering 1761 researchers from research centres and universities that were part of the Minalogic cluster. The data included the name of the person and research centre/university as well as the person's function, email, and phone number, when available. Second, we sent 1761 individualised emails mentioning the person's name and position, the research centre's/university's name, the reasons for choosing the institution in our sample, the project's cover letter, and the link to our online survey. Third, we sent two email reminders at one-week intervals. We obtained 248 responses: 141 from research centres and 107 from universities (a 14.08% response rate) (Table 1). We used the organisation as our unit of analysis. Nine institutions were surveyed in the Minalogic cluster: the French Alternative Energies and Atomic Energy Commission (CEA), the French National Centre for Scientific Research (CNRS), European Synchrotron Radiation Facility (ESRF), Grenoble University, Joseph Fourier University (UJF), Pierre Mendès-France University (UPMF), Grenoble Institute of Technology (Grenoble INP), Polytech Grenoble, and Grenoble Ecole de Management (GEM). The test of early and late respondents was conducted to detect non-response bias (Armstrong and Overton, 1977). The average values of the first 10% and 20% of respondents were compared with those of the last 10% and 20% of the respondents. No significant difference was detected between earlier and later respondents.

5. Analysis

5.1. Validity

We executed multiple tests for content and construct validity. First, several academic experts

were consulted regarding content validity, and they all agreed that the measurement scales were appropriate for measuring the constructs. Second, content validity was evaluated based on the literature (Babbie, 2001). All measurement scales were adapted from these six top academic journals: *Journal of Product Innovation Management*, *Journal of International Business Studies*, *Journal of Management*, *Journal of Management Studies*, *Research Policy*, and *International Journal of Technology Management*. Third, reliability tests were used to assess content validity (Zwick, 1988; Rust and Cooil, 1994).

Construct reliability was examined using Cronbach's alpha, which exceeded 0.70 (Nunnally and Bernstein, 1994) for all factors, indicating acceptable consistency of the measurement items (Nunnally, 1978). We assessed the construct validity with convergent, discriminant, and nomological validity. Convergent validity was assessed by bivariate correlation, and it was higher than 0.3 for all constructs. We also assessed the convergence validity by considering the factor loadings. Based on our data analysis, all factors were significant with a loading greater than 0.5, which ensures a good convergence. We conducted pairwise correlations to check the discriminant validity (Anderson and Gerbing, 1988) (Table 2). Thereafter, we evaluated nomological validity by analysing two-by-two correlations and making assessments within the constructs. No items were excluded to avoid reducing the theoretical construct (Hair et al., 2006).

5.2. Normality and multicollinearity

We performed skewness and kurtosis tests to assess the normal distribution of our data. Two items exceeding a skew index higher than 3 (equity transfer 3.436 and cross equity 3.203) were identified. Further, all the kurtosis indexes were below 10 (Kline, 1998). We assessed the absence of multicollinearity using bivariate correlations and the variance inflation factor (VIF). In our empirical study, none of the bivariate correlations exceeded 0.85, and all the VIFs were below 3. Based on the bivariate correlation and VIF, we assessed the absence of multicollinearity in our data collection.

5.3. Confirmatory factor analysis

Confirmatory factor analysis (CFA) of the measurement model showed a good fit (CMIN/Df = 1.621; CFI = 0.896; IFI = 0.898; RMSEA = 0.036). The measurement model's results were favourable because all items significantly loaded on their corresponding

Table 1. Descriptive statistics

Dimension	Items	Research centres (<i>N</i> = 141)		Universities (<i>N</i> = 107)	
		Frequency	Percentage	Frequency	Percentage
Gender	Female	48	34.04	38	35.51
	Male	93	65.96	69	64.49
Age	18–24	1	0.71	0	0.00
	25–34	21	14.89	10	9.35
	35–44	45	31.91	43	41.19
	45–54	49	34.75	35	32.71
	55–64	25	17.73	11	10.28
Education	Doctorate degree	141	100.00	107	100.00
Job type	Executive, manager, superior intellectuals' profession	138	97.87	107	100.00
	Intermediate profession	3	2.13	0	0.00
Department	Head office and strategy	7	4.96	7	6.54
	Technological research and development	129	91.48	94	87.85
	Production and engineering	0	0.00	1	0.93
	Marketing	2	1.42	2	1.87
	Infrastructure and safety	1	0.71	0	0.00
	Information systems	1	0.71	1	0.93
	Quality and environment	1	0.71	2	1.87
Number of subordinates	0	59	41.84	44	41.12
	1–5	49	34.75	32	29.91
	6–10	13	9.22	12	11.21
	11–100	16	11.35	17	15.89
	101–600	4	2.84	2	1.87
Institution's size	101–250	0	0.00	1	0.93
	251–500	0	0.00	41	38.32
	501–1,000	14	9.93	23	21.49
	Above 1,001	127	90.07	42	39.25

N = 248.

Table 2. Means, standard deviations, and correlation

	Mean	Standard deviation	1	2	3
1. Human capital	4.78	1.380			
2. Relational capital	0.20	0.374	0.213**		
3. Structural capital	3.87	1.551	0.265***	0.316***	
4. Intellectual capital outcomes	4.75	1.468	0.184*	0.101 ns	0.319***

N = 248.

*Correlation is significant at the 0.05 level (two-tailed).

**Correlation is significant at the 0.01 level (two-tailed).

***Correlation is significant at the 0.001 level (two-tailed).

factor. All standardised factor loadings were over 0.5 and highly significant at a P -value $< .001$, which indicates good convergent validity among the instruments of each construct (Bagozzi and Yi, 1988). The modification indices in the CFA for omitted paths showed no significant cross-loading among the instruments, indicating good discriminant validity (Kline, 1998). All these results support the overall validity of constructs measured in the study. CFA was performed to assess the measurement model's reliability, convergent validity, and discriminant validity. Cronbach's alpha and composite reliability facilitated the assessment of the construct measures' reliability. The composite reliabilities of all constructs exceeded the 0.60 threshold (Bagozzi and Yi, 1988), ensuring the reliability of our constructs. The average variance extracted (AVE) exceeded .50 of the total variance; therefore, the convergent validity is established (Fornell and Larcker, 1981). The Fornell and Larcker (1981) criterion, which compares the square root of the construct AVEs with the construct correlations, was performed to assess the discriminant validity. The measurement model showed good discriminant validity for all constructs (Table 3). Considering the CFA results, we assess validity and reliability based on the recommendations from Fornell and Larcker (1981). By following Podsakoff and Organ (1986) and Podsakoff et al. (2003), our study limits the risk of common methods variance. Furthermore, Harman's single-factor test was employed (Podsakoff et al., 2003). In our empirical study, the factor explains 4.16% of the variance, which is below the 50% threshold. Therefore, the common method variance in our data is not substantial.

5.4. Structural equation model

Following past research on IC, we used structural equation modelling (Tseng and Goo, 2005; Wang and Chang, 2005; Mention and Bontis, 2013; Kianto et al., 2017; Buenechea-Elberdin et al., 2018; Shou et al., 2020; Wang et al., 2020). The model was over-identified ($df = 1,839$), observed variables were normally distributed, and latent constructs were normally distributed, and we obtained more than 90 observations (248 in our example). Thus, the maximum likelihood estimation is applicable in our model estimation. We assessed the measurement model validity, and the overall model fit was good. According to Hair et al. (2006), CMIN/Df should be below 2; our model's CMIN/Df is 1.531. The RMSEA should be less than 0.06, according to Hu and Bentler (1999); our model's RMSEA is 0.033. Standardised factor loadings were over 0.5

and significant at a P -value $< .001$, which indicates good convergent validity among the instruments of each construct (Bagozzi and Yi, 1988). Model 1 is our baseline model with control variables, while Model 2 provides the results of respondents from both research centres and universities (Table 4). We conducted group analysis between research centres and universities; however, none of the z scores was significant. Hence, we concluded that no significant difference exists.

5.5. Key results

Our analysis supports all four hypotheses. Our data support H_1 on PhD holders in research centres and universities: HC relates positively to RC (.020***). This indicates that how PhD holders manage knowledge is related to their engagement in R&D alliances, backward and forward alliances, licensing, and equity alliances. H_2 is supported: RC relates positively to SC (.305***). In particular, the involvement of research centres and universities in strategic alliances affects their organisational degree of innovation related to new production processes; new products; new materials, resources, and technologies; new markets; and new forms of organisations. Our data support H_3 : HC relates positively to SC (.069**). Therefore, PhD holders' knowledge management is intertwined with research centres' and universities' degrees of innovation. Lastly, our empirical study supports H_4 : SC relates positively to IC outcomes (.086**). This reveals that the degree of innovation relates to the organisational IC outcomes, such as overall efficiency improvement, specialisation in a market segment, acquisition of new clients, cost reduction, determination of future goals, and image and processes improvement. None of our six control variables were significant.

6. Discussion

6.1. Mechanism no. 1: knowledge-based human capital–relational alliances capital

In addition to the known advantages of employing PhD holders, such as greater work capacity, valuable creativity, and thoughtful strategic choice making (Mertens and Röbbken, 2013; Liu et al., 2020; Yamaguchi et al., 2021), our results suggest that PhD holders support the HC of research centres and universities that reinforce organisational RC, complementing Pretorius and Macaulay (2021) and Salinas-Ávila et al. (2020). To willingly collaborate with other

Table 3. Construct, items, reliability, and confirmatory factor analysis

Construct items	Factor loadings	AVE	CR	Cronbach's alpha
Human capital		0.524	0.810	0.816
By what method do you standardise knowledge to have complementarity between bits of knowledge from different origins? (Ex: Complementarity between software and hardware)	0.72***			
By what method do you grow rich step by step, module by module, technological brick by technological brick? (Ex: The mobile phone has several functions: phone, SMS, colour screen, pictures, video, mp3 player, internet, etc.)	0.90***			
By what method do you store bits of knowledge being spread? (Ex: To design a digital camera, it is necessary to mobilise various knowledge, such as optics, support of digital treatment, a battery, and a memory card, which can be localised in different geographical places.)	0.68***			
By what method do you use knowledge from one sector for other applications? (Ex: A performing captor initially developed for the automotive industry can be reused by the medical industry.)	0.54***			
Relational capital		0.602	0.883	0.885
Indicate in which strategic alliances you were involved last year. Tick the box 'not involved' if you were not involved in such agreements.				
Relational R&D alliance capital				
R&D Agreement (An organisation conducts a product's R&D.)	0.58***			
Technology transfer (An organisation develops a technology to be sold to another organisation.)	0.69***			
Cross-technology transfer (Two organisations develop distinctive technologies to proceed to a technological exchange.)	0.71***			
Relational backward alliance capital				
Supply agreement (An organisation provides goods for a buyer.)	0.62***			
Original equipment manufacturer (laptop, integrated circuit, etc.)	0.80***			
Manufacturing agreement (final product)	0.75***			
Relational forward alliance capital				
Marketing agreement (door-to-door selling, communication, promotion)	0.68***			
Value-added reseller agreement (services, training of end-users)	0.84***			
Relational licensing agreement capital				
Licensing agreement (The franchiser provides another organisation with its know-how, training, and permanent help against money.)	0.82***			
Exclusive licensing agreement (The organisation involved in a franchise uses only products and services from the franchisor.)	0.84***			
Cross-licensing agreement (Two organisations provide mutual assistance on know-how and training.)	0.74***			
Relational equity agreement capital				
Equity stake purchase (investment against shares)	0.71***			
Equity transfer (investment transfer from one organisation to another)	0.87***			

(Continues)

Table 3. (Continued)

Construct items	Factor loadings	AVE	CR	Cronbach's alpha
Cross-equity transfer (two organisations mutually invest funds in another organisation)	0.85***			
Joint venture (co-enterprise created by two or more organisations owning variable shares)	0.66***			
Structural capital		0.561	0.863	0.861
Please indicate the degree of innovation in the following domains within your organisation:				
New production processes	0.76***			
New products	0.86***			
New materials, resources, and technologies	0.68***			
New markets	0.70***			
New forms of organisations	0.67***			
Intellectual capital outcomes		0.533	0.887	0.890
Indicate your degree of agreement regarding positive output linked to interactions between your organisation and its partners:				
Interactions improve your company's overall efficiency	0.78***			
Interactions improve the specialisation of a particular market segment	0.56***			
Interactions lead to the acquisition of new clients	0.74***			
Interactions allow cost reduction	0.61***			
Interactions help in determining future goals	0.83***			
Interactions improve the organisation's image	0.79***			
Interactions improve processes	0.77***			

CMIN/Df = 1.621, CFI = .896, IFI = .898, RMSEA = .036. All the factor loadings are significant at *** level below 0.001. The bold values represent the constructs (human capital, relational capital, structural capital, and intellectual capital outcomes), and the sub constructs of relational capital (Relational R&D alliance capital, Relational backward alliance capital, etc.). AVE = average variance extracted; CR = composite reliability.

research centres, universities, and firms, knowledge complementarity is important. The scientific knowledge accumulated by researchers and faculty members offers greater knowledge depth that is valued in strategic alliances and allows complementary knowledge inputs to yield a higher degree of complexity. RC-engaging PhD holders from research centres and universities also require a high degree of diversity and knowledge breadth, which is enabled by knowledge compositeness – a blend of scientific and technological knowledge, including that from other industries – by reusing fungible knowledge. RC requires PhD holders to go beyond teaching and research activities and engage in socially impactful work with external stakeholders by utilising a broad range of strategic alliances, including R&D alliances, backward and forward alliances, and equity alliances and licensing.

6.2. Mechanism no. 2: relational alliances capital–structural innovation capital

Some studies support (Kianto et al., 2017; Salinas-Ávila et al., 2020; Guerrero et al., 2021), while

others do not support (Buenechea-Elberdin et al., 2018) the relation between RC and SC; however, our results support this relation in the specific case of research centres and universities. Our confirmatory research contradicts the findings of Almeida et al. (2011) on the engagement of scientists in R&D alliances. Our results show that scientists' interest in strengthening the RC catalyses their research centres' and universities' organisational SC to develop new methods, launch new products and services, access new resources, be better market oriented, and conduct organisational innovation. We argue that organisational objectives, like innovation stimulation, are not reached with one successful alliance, but rather through the combined influence of the overall alliance portfolio. Therefore, our results suggest that scientific collaboration enables different types of knowledge exchange to execute innovation. In considering the five types of innovation, we contribute to Dahlander et al.'s (2016) call for further research. By investigating the structural innovation capital of research centres and universities that are economically

Table 4. Estimates

	Model 1	Model 2	Model 3	Model 4
	Control	RC+ UNI	RC	UNI
Description of path				
H ₁	Human capital → Relational capital	0.020**	0.021 n.s.	0.034*
H ₂	Relational capital → Structural capital	0.305**	0.414*	0.457 n.s.
H ₃	Human capital → Structural capital	0.069**	0.082**	0.119 n.s.
H ₄	Structural capital → Intellectual capital outcomes	0.086***	0.126***	0.120*
Control variables				
	Age → Intellectual capital outcomes	0.008 n.s.	0.008 n.s.	0.010 n.s.
	Gender → Intellectual capital outcomes	0.154 n.s.	0.147 n.s.	0.216 n.s.
	Job type → Intellectual capital outcomes	0.323 n.s.	0.309 n.s.	0.537 n.s.
	Department → Intellectual capital outcomes	0.044 n.s.	0.042 n.s.	0.056 n.s.
	Number of subordinates → Intellectual capital outcomes	0.001 n.s.	0.001 n.s.	0.004 n.s.
	Log of organisation's size → Intellectual capital outcomes	0.183 n.s.	0.175 n.s.	0.230 n.s.
Model fit statistics				
	X ²	342,063	2816,000	2816,000
	df	189	1839	1839
	CMIN/Df	1.810	1.531	1.531
	GFI	0.906	0.780	0.780
	CFI	0.917	0.876	0.876
	RMSEA	0.041	0.033	0.033

n.s.: not significant.

* $P < .05$.** $P < .01$.*** $P < .001$.

and socially significant to the region (Bisogno et al., 2018), we further quantify HEIs' fulfilment of their third mission and, therefore, respond to the call by Compagnucci and Spigarelli (2020).

6.3. Mechanism no. 3: knowledge-based human capital–structural innovation capital

Our empirical study also provides novel empirical findings germane to the existing debates on the relation between HC and SC by discussing if it is (a) significant and positive (e.g., Chen et al., 2004; Tseng and Goo, 2005; Wang and Chang, 2005), (b) not significant (e.g., Kianto et al., 2017), or (c) significant and negative (e.g., Subramaniam and Youndt, 2005). Therefore, our study further investigates the relation between HC and SC, not only in universities (e.g., Salinas-Ávila et al., 2020) but also in research centres. We support the relationship between HC and SC, finding that knowledge exchange through strategic

partnerships nurtures innovation. However, this relation is much weaker than the relation between RC and SC. Therefore, our study provides additional insights into the study by Barrena-Martínez et al. (2020), which highlights the intersection between IC and open innovation. We also add to Kuo et al.'s (2018) study on two, out of five, facets of SC. Our investigation of the SC in research centres and universities, in response to Tavassoli and Karlsson's (2015) calls for further research, surpasses the existing studies by types of innovation. Complementing Caparrós-Ruiz's (2019), Djuric et al.'s (2020), and Pretorius and Macaulay's (2021) recent studies, we argue that PhD holders are important to IC. However, given their rarity (OECD, 2019), developing HC stock based on PhD holders offers a limited contribution to structural innovation capital. Adding to past studies by Hancock et al. (2017), we argue that doctoral scientists have a limited role in the KBE, at least in terms of organisational innovation at research centres and the university level.

6.4. Mechanism no. 4: structural innovation capital–intellectual capital outcomes

Except for a few studies (e.g., Narzary and Palo, 2021), the outcomes of IC have not been well investigated (Schiafone et al., 2022), especially in universities and research centres (Dabić et al., 2021). We examined the IC outcomes of industry–university partnerships, which differ from regular socio-economic indicators such as performance and job creation, to address Guerrero et al.'s (2021) call. In contrast to past studies that point out the negative outcomes from industry–university partnerships (e.g., Andrews et al., 2021; Narzary and Palo, 2021), such as communication difficulties and counterproductive effects, our empirical study highlights a large range of positive results. Addressing Schiafone et al.'s (2022) recent call for further quantitative research on IC outcomes, our empirical study supports that research centres and universities' degrees of innovation are intertwined with various IC positive outcomes. For instance, structural innovation capital may lead to improved organisational efficiency, reduced costs, and other positive results, such as new clients, better image, improved processes, and enhanced strategic orientation to acquire new clients. Therefore, our study assesses that research centres and universities recognise the recently received third mission, considered as a salient challenge by Compagnucci and Spigarelli (2020). We provide empirical evidence that IC outcomes are economically and socially significant, not only for firms but also for research centres and universities.

7. Conclusion

7.1. Main contributions

We contribute to the literature on university–industry collaboration (Zucker and Darby, 2001; George et al., 2002; Zucker et al., 2002; Faems et al., 2003; Belderbos et al., 2004; Cassiman et al., 2008) by providing an in-depth understanding of IC mechanisms in research centres and universities. While the understanding of the benefits and challenges in the collaborations between science-based and market-based partners are well documented (Perkmann and Walsh, 2007; D'Este and Perkmann, 2011; Giannopoulou et al., 2019; Gretsche et al., 2019), we further characterise the interplay among HC, RC, SC, and IC outcomes – from a PhD holder's perspective – by addressing the call of Al-Tabbaa and Ankrah (2019) on the need for studies

on the micro-foundations of technology transfer in university–industry collaborations.

First, this study extends the discussion on IC in research centres and universities that play an increasing role in the knowledge-based economy. We conduct the first quantitative empirical study on both of these organisation types; therefore, we contribute to Bisogno et al. (2018). In particular, we elucidate four IC mechanisms in research centres and universities. Further, we contribute to Liu et al. (2020) and Yamaguchi et al. (2021) by characterising the advantage of employing PhD holders. Our empirical study supports the relation between knowledge-based HC and relational alliances capital.

Second, we contribute to the debates on the relation between RC and SC (Buenechea-Elberdin et al., 2018; Salinas-Ávila et al., 2020; Guerrero et al., 2021) by supporting the idea that relational alliance's capital relates to the structural innovation capital of research centres and universities. We encourage these scientific institutions to develop an alliance portfolio for innovations, instead of relying on a single alliance. Our study also expands the understanding of the relation between knowledge-based HC and structural innovation capital.

Third, our empirical study uncovers the relation between structural innovation capital and IC outcomes and, therefore, contributes to Guerrero et al. (2021) and Schiafone et al. (2022). In contrast to Andrews et al. (2021) and Narzary and Palo (2021), who presented the negative outcomes of industry–university partnerships, our study supports positive outcomes (efficiency, cost reduction, etc.) from IC that positively contribute to research centres' and universities' endeavours to successfully conduct their third mission.

7.2. Managerial implications

Our study has several implications for policymakers and practitioners overseeing research centres and universities. Most past studies have emphasised the importance of HC in such organisations; however, our study highlights the importance of the link between RC and SC. Indeed, PhD holders' knowledge depth and breadth are critical assets for these institutions, even though generating IC outcomes is challenging. First, it is essential to encourage scientists to collaborate with external partners to reinforce research centres' and universities' RC. Second, researchers and faculty members must be better informed on the existence of a wide range of strategic alliances (15 in our study), beyond the simple R&D alliance. Third, we encourage scientists to participate in multiple strategic alliances

because alliance portfolios fortify research centres' and universities' SC.

7.3. Limitations and paths for further studies

First, our study involved cross-sectional data collection, which prevented us from drawing causality. Still, we intended to authenticate the rationale of each link of the IC mechanisms to derive our research model to conclude our confirmatory analysis with solid theoretical foundations. We propose conducting longitudinal quantitative data analysis to assess the causality of the relationships between the components of the IC for further study.

Second, we considered RC as a dyadic relation between the research centres or universities and other partners. However, alliances do not exclusively occur between dyads; they could also be analysed between multiple firms: one-to-many and many-to-many matching frameworks. Thus, the ecosystem lenses (Scaringella and Radziwon, 2018; Prencipe et al., 2022) would be meaningful in investigating the IC between multiple players and their attributes.

Third, we studied university-industry collaborations from a micro-foundation lens. We encourage multilevel studies on technology transfer between firms and research partners, distinguishing HC at the individual level, social capital at the group level, and organisational capital at the organisational level (Fernandez-Perez de la Lastra et al., 2017). Such multilevel research could uncover the antecedents of IC's persistence in research centres and universities, as a follow up on the persistence of university-industry collaborations (Østergaard and Drejer, 2022).

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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