R&D MANAGEMENT

Intellectual capital and R&D performance improvement: the case of Italian public universities

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This paper aims to develop a model to analyse and improve the performance of R&D activities in Italian public universities through the intellectual capital (IC) perspective. The extant literature includes several models for R&D analysis, but none quantify the link between IC and universities' research activity performance. This research attempts to fill a gap in knowledge by explicitly focusing on the relationship between IC according to its dimensions and universities' research activity performance. To achieve this aim, we develop a theoretical model and test the model using secondary data from all the Italian public universities through the structural equation modelling method. The findings show that small universities with a good level of relations with external organisations, a good level of internationalisation and solid infrastructure have a higher level of scientific productivity than larger universities that are less internationalised and invest less in infrastructure.

1. Introduction

In the university ecosystem, evaluating Research and Development (R&D) activities has become a topic of growing importance in many countries (Abramo and D'Angelo, 2015). These efforts lead to scientific research that results in new ideas, procedures and products that benefit society. According to Faizal Omar et al. (2019), university research can become a resource for the national community as well as for the university system itself. Indeed, statistics on a country's R&D expenditure levels are frequently used in high-level national policy debates and science and innovation regulations (Tijssen and Winnink, 2017). For countries with high levels of gross domestic product, R&D activities, technological development and competencies of public bodies are of primary importance for productivity (Schwab, 2017). The public research and innovation system, which includes higher education institutions and other public R&D entities, is critical in developing and promoting the knowledge and skills that innovative enterprises need to expand their R&D operations. This growing relevance of R&D activities has prompted many countries to conduct university R&D evaluation. In particular, in several European countries, the introduction of new modalities of managing public sector performance reporting has posed new challenges for universities. For example, the Bologna Declaration, like other policy activities implemented at the European level, aims to achieve greater compatibility and comparison in the higher education and research sector (Marra, 2018). These new public policies push universities to create and execute new management models, influencing how they are governed and managed while also giving them more decision-making autonomy. Universities and higher education institutions must introduce new R&D activities' measurement mechanisms with inherent production and performance orientation logic based on new key performance indicators (KPIs).

Furthermore, as universities are mainly publicly funded organisations, they are faced with a growing demand for information related to transparency regarding the use and results (social and economic) obtained with these funds (Inauen and Schenker-Wicki, 2011). These political and managerial challenges require implementing new university management and relationship systems. Nonetheless, this emerging trend, studies on measuring the performance of R&D activities are much more frequent in the private sector; fewer studies are concerned with the public sector (e.g. Coccia, 2004; Leitner and Warden, 2004; Secundo et al., 2010; Agostino et al., 2012; De Matos Pedro et al., 2022). In addition, the university's R&D performance has a multidimensional nature, and its assessment requires appropriate metrics. Therefore, some studies have begun to focus on using different KPIs for evaluating R&D results in the public sector (Grimaldi et al., 2013; Asiaei et al., 2018). In the literature, we can distinguish universities' R&D indicators according to different components. First of all, some authors focus on the creation of knowledge through the generation and exploitation of patents and licences (Wu et al., 2012; Chen and Chen, 2013). Another part of the literature is linked to the third mission of universities (Pedro et al., 2020; Kulikova et al., 2019). A further research branch on universities' performance considers the didactic scope (Ramirez et al., 2016; Iacoviello et al., 2019). Finally, few contributions consider indicators capable of enhancing the scientific production of universities (Kulikova et al., 2019; Pedro et al., 2019). Furthermore, another part of research adopted novel assessment models to enhance intangible resources of universities. One of the most known approaches is that of intellectual capital (IC) (Edvinsson and Malone, 1997; Stewart, 1997). In their literature review, Bellucci et al. (2021) found that numerous previous studies have adopted IC related to university performance measurement systems (PMS). In particular, Veltri and Puntillo (2020) investigated whether the PMS of universities consider the administration of IC as a criterion for evaluating their managers. In addition, Secundo and Elia (2014) proposed a PMS for academic entrepreneurship. Finally, Martin-Sardesai and Guthrie (2018) used case studies from Australian public universities to add to the IC literature in education by exploring the relationship between PMS and academic human capital.

This background, therefore, highlights two separate approaches to evaluating the university's R&D performance. On the one hand, the first approach is oriented to the use of specific metrics linked above all to the exploitation of patents and the evaluation of the activities of the third mission. On the other hand, the second use IC models to enhance the intangible resources present in universities. This study aims to close the circle and jointly consider these two areas of research. Indeed, to date, there is a lack of studies focused on analysing the R&D performance of universities, evaluated through scientific research, and how the different components of the IC impact R&D performance. According to Bisogno et al. (2018), IC research in the education sector is still in its infancy, with most studies focusing on IC in European contexts utilising a case study approach. The authors called for additional research that addresses a variety of educational, methodological and geographic circumstances. This paper aims to respond to this call and analyse the relationships between IC according to its dimensions, human capital (HC), structural capital (SC) and relational capital (RC), and the performance of universities' research activity, identified as scientific productivity. Several hypotheses were formulated, and a conceptual model was then developed. The model has been tested on a sample of secondary data from Italian public universities using the structural equation modelling (SEM) approach. Italian universities were chosen because, following Decree No. 150/2009, they were required to issue a 3-year evaluation report aimed at optimising labour productivity and the efficiency and transparency of their research activities. The empirical results stress the main aspects in which universities can intervene to improve their productivity.

The remainder of this paper is organised as follows. Section 2 defines the theoretical background and hypotheses of the research model. Section 3 includes the statistical analysis and hypothesis testing. Results are discussed in Section 4. Finally, Section 5 reports the conclusions, implications and future research directions.

2. Theoretical background and hypothesis development

Among public institutions, the role of universities and research institutions has major relevance for the economy of countries and regions as it has a considerable weight in terms of an educated workforce and greater entrepreneurship within the country (Secundo et al., 2018). University systems are immersed in an intense transformation process triggered by the need to make universities more flexible, transparent, competitive and comparable (Sánchez et al., 2009). To meet these challenges, higher education institutions must consciously manage the processes of creating their R&D performance and recognise the importance of their role in society and the value they can create. Knowledge resources are the foundation of the core competencies of any organisation. Therefore, they play a key strategic role and must be measured in a clear and detailed way using ad hoc metrics. The universities that adopt a strategic approach to manage the intellectual components have the opportunity to improve their reputation. In this vein, Feng et al. (2004) believe the key factor that will increase universities' strength is the efficient internal management of R&D activities.

Two branches of research have implemented different solutions to respond to these new challenges. On the one hand, the extant literature has focused on the measurements of university R&D performance. Johnes and Yu (2008) examined the relative efficiency of Chinese universities' research using data envelopment analysis (DEA). Foltz et al. (2011) looked at efficiency and technical development in US institutions to see if there was a pattern that could be linked to patent commercialisation. Qin and Du (2018) employed a multi-perspective network DEA approach to measure Chinese universities' R&D efficiency.

On the other hand, several authors have concentrated on IC models, a well-known concept in literature, however, associating it with a new context such as the university one. Indeed, the concept of IC can be dated back to 1969; Galbraith was the first who introduced this topic as a bundle of intangible resources that companies could exploit to gain a competitive advantage and sustain it (Matricano, 2020). The extant literature on IC focuses on different characteristics of this construct, but the most adopted method analyses IC according to three different dimensions: HC, SC and RC (Stewart, 1997). HC represents the value that human resources provide to the company through their skills and know-how. SC represents the support infrastructure of the organisation that enables HC to function. RC represents the organisation's external relations as its primary success factor (Secundo et al., 2010). Numerous previous contributions identified theoretical frameworks defining the main variables used to describe IC in university and the possible relationships among them (e.g. Boedker et al., 2005; Demartini and Paoloni, 2013; Grimaldi et al., 2013; Asiaei et al., 2018). Secundo et al. (2010) identify a dashboard of indicators related to IC in the university field and present a single university case using the dashboard without valuing the link with the performance. Karami and Vafaei (2014) perform a case study analysis on IC reporting models of eight Australian universities. Secundo et al. (2017) proposed an IC-based conceptual framework to measure the third mission activities of universities.

Therefore, although these previous contributions analysed the issue of IC and the measurement of R&D performance in universities, to date, there is a lack of studies that link these two stems of research and empirically test the relation among IC components and their impact on the R&D performance of universities. Furthermore, we have formulated hypotheses for the relationship between IC components and universities' R&D performance starting from these premises.

Secundo et al. (2016) assessed that HC and RC have a bidirectional link. Indeed, the authors stated that the human component of IC develops the processes and structures that connect the university with enterprises and institutions. RC generates value for all university members and builds effect for the university's stakeholders. In addition, several previous studies reinforced this concept, identifying a positive relationship between the different components of capital (Bontis, 1998; Sveiby, 2001; Marr and Starovic, 2003). These premises allow us to formulate the following hypotheses:

H1 There is a positive correlation between the HC and RC.

H2 There is a positive correlation between the HC and SC.

H3 There is a positive correlation between the RC and SC.

As for the link between IC and universities' performance, we based our hypotheses on several previous contributions. Cricelli et al. (2018) looked at a sample of 31 Colombian public universities to see if there was a link between IC and overall performance. They showed that the top-performing universities also had greater IC levels, whereas the bottom-performing universities lacked several IC resources. Pedro et al. (2020) examined 738 students and 587 lecturers/researchers from seven Portuguese public institutions and found a link between structural and relational capital and university performance. These contributions derive from consolidated analyses in the context of private companies. Several authors assessed that IC contributes significantly towards firm performance, or firm performance relies on more than just physical capital (Barney, 1991; Edvinsson and Malone, 1997; Goh, 2005; Schiuma and Lerro, 2008). IC is crucial to business success and performance: high IC indicates a higher performance (Abdullah and Sofian, 2012). This background allows us to formulate the following hypotheses:

H4 HC of the year n positively affects the performance of year $n+1$.

H5 RC of the year n positively affects the performance of year $n+1$.

H6 SC of the year n positively affects the performance of year $n+1$.

Specifically, we consider 1 year of delay between IC components and the performance because, according to Björk and Solomon (2013), this represents the average total publication delay of scientific contributions. Figure 1 summarises the conceptual model developed based on the hypotheses mentioned above. This conceptual model was developed to understand how IC components affect university R&D success. On the one hand, we have proposed a direct and unidirectional link between IC components and R&D results. On the other hand, we believe the three IC components are connected in a direct and bidirectional link.

3. Methodology

3.1. Data collection

The above hypotheses were tested on a dataset of Italian public universities. The choice fell on Italian universities since, following the issue of legislative decree n° 150/2009, they were obliged to issue a 3-year reporting document. For this reason, since 2011, every Italian public university has been required to produce and disseminate a performance evaluation report. Thus, efficiently identifying the relationships between IC and performance will facilitate universities in building reports and improving performance based on which universities will obtain funding. What is more, we focused on scientific performance because the National Agency for the Evaluation of the University and Research System (ANVUR) has launched the new Research Quality Assessment (VQR) exercise for 2015–2019 with decrees 1110/2019 and 444/2020. The VQR aims to evaluate the results of scientific research and third mission activities of the 2015–2019 period by universities, public research bodies supervised by the MUR and other public and private entities that carry out research activities. These new decrees provide that for evaluating the quality of the research, each university/research centre must submit for the evaluation several 'products', that is three times the number of members. In this way, the constraint of the previous VQRs where each researcher was required to present a fixed number of research products is removed. This new criterion helps prevent improper use of the VQR and the publication of profiles in relation only to scientific areas. In fact, the previous evaluation systems have also published the profiles and marks for the single scientific disciplinary sectors, thus getting closer to individual evaluations or small groups of researchers. On the contrary, today's system provides a global assessment of universities.

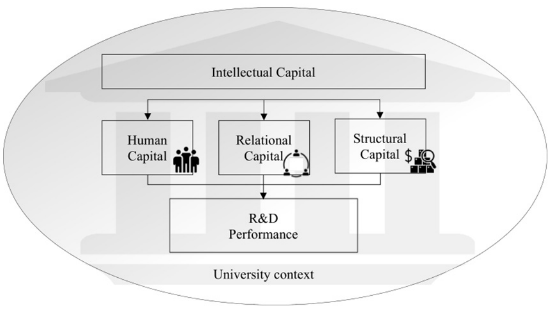

Figure 1. Conceptual model.

We collected data from several national and international official sources, including Scopus, universities' websites and the Ministry of University and Research (MUR) website. Specifically, the R&D performance data of each university were obtained through the Scopus platform. The data relating to the IC capital components were obtained from the MUR in the section relating to the statistical surveys of the universities. On the other hand, some data (relating to the SC) were obtained starting from the annual financial statements of each university. The data refer to the entire population of Italian public universities. Universities with special status were excluded from the sampling because these universities are regulated differently, and this would generate an inconsistency in the comparison between different variables. Specifically, we collected data for 3 years, from 2016 to 2018. This data collection was figured out as a database consisting of 13 variables for each of the 61 Italian public universities. Variables were divided into three sections corresponding to the three latent estimated variables (HC; RC; SC). Based on the literature, we chose what kind of variables to acquire and how each IC component explained these variables. Table 1 presents the database in detail. As

Table 1. Database adopted

IC components	Indicators	References
Human capital (HC)	HC1. Number of full professors	Iacoviello et al. (2019)
	HC2. Number of associate professors	Iacoviello et al. (2019)
	HC3. Number of full time researchers	Iacoviello et al. (2019)
	HC4. Number of part-time researchers	Iacoviello et al. (2019)
	HC5. Number of PhD students	Ramirez et al. (2016), Manes Rossi et al. (2018)
Relational capital (RC)	RC1. Number of scholarships agreements financed by public bodies	Pedro et al. (2019)
	RC2. Number of scholarships agreements financed by private bodies	Secundo and Elia (2014), Iacoviello et al. (2019), Feng et al. (2012)
	RC3. Number of PhD students abroad	Leitner (2004)
Structural capital (SC)	SC1. Number of post-doctoral scholarships agreements	Secundo and Elia (2014), Kinsella and McBrierty (1997)
	SC2. Amount of reward fee of the Ordinary Financing Fund (OFF)	Sánchez et al. (2009)
	SC3. Amount of scientific equipment	Leitner (2004), Manes Rossi et al. (2018), Feng et al. (2012), Kulikova et al. (2019)
	SC4. Competitive financing	Leitner (2004)

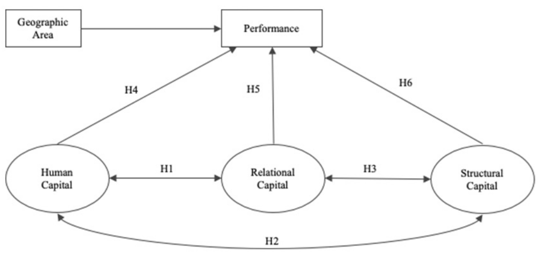

Figure 2. Structural model.

for the performance variable, according to several previous contributions (e.g. Feng et al., 2012; Wu et al., 2012; Manes Rossi et al., 2018; Kulikova et al., 2019; Pedro et al., 2019), we consider the scientific productivity defined as the ratio between the total amount of documents published (e.g. journal articles, book chapters, conference proceedings) and the total number of employees. The total number of employees is obtained as the sum of the HC variables. In particular, we have chosen to consider productivity, not production (total number of documents published), as a high intensity of HC characterises this item, and it would have biased the results in favour of HC. Finally, we assumed the geographic area as a control variable because Italy is characterised by different demographic features based on the geographic area. This assumption allows us to highlight differences between universities. Based on the hypotheses of the previous section, two models were identified:

1. Model relating to the biennium 2016/2017, in which the HC, RC and SC of 2016 exert a direct effect on the performance of 2017.
2. Model relating to the biennium 2017/2018, in which the HC, RC and SC of 2017 exert a direct effect on the performance of 2018.

Figure 2 shows the structural model built based on the hypotheses defined.

3.2. *Structural model and hypothesis testing*

The SEM analysis was performed to assess the research framework and test the research hypotheses. This method is the most appropriate to impute relationships between unobserved constructs (latent variables) and observable variables (Hancock, 2003). Latent constructs can be exogenous, not influenced by any variable present within the hypothesised model, or *vice versa* endogenous. The endogenous variables are random, while the exogenous variables can also be assumed as deterministic; the respective observed endogenous and exogenous indicators are classified similarly, but by convention, they are considered stochastic (Parrini et al., 2010). The choice fell on the SEM approach because it allows for testing complex models that imply direct and indirect effects. There is a direct link between a predictor variable and a dependent variable in the first case. In the second case, the relationship between the two variables is mediated by one or more intervening variables. Indeed, a variable can appear both as a dependent and independent variable simultaneously, prompting the use of new terms such as those of exogenous and endogenous variables. This assumption allows us to reflect better on the nature of the phenomenon under investigation through the construction of theoretical–analytical models that consider the vast articulation of reality.

The model was implemented through the Stata 13© software using the maximum likelihood with missing value (MLMV) method as missing values characterise the database. Following Barbaranelli and Ingoglia (2013), the measured variables have been normalised before implementing the methodology to avoid inaccurate results. Furthermore, the variable geographic area has been considered a factor variable because it assumes only three values (North, South, Centre). Thus, it has been necessary to encode this variable as a combination of two dummy variables (Table 2).

According to the encoding defined, we assume the North as a basis of comparison. The models' estimated parameters related to the geographical area will quantify the deviation of the South and the Centre from the North in defining productivity. We have analysed the models' adaptability to verify the goodness of fit. Following Byrne (1994), we consider the Tucker–Lewis index (TLI) and comparative fit index (CFI). Their value should be >0.90. Tables 3 and 4 highlight CLI and TLI's values for each biennium.

Table 2. Encoding of the variable geographic area

	North/South	North/Centre
North	0	0
Centre	0	1
South	1	0

Table 3. Indicators of the goodness of fit for the biennium 2016/2017

Fit statistic	Value	Description
Baseline comparison		
CFI	0.847	Comparative fit index
TLI	0.814	Tucker–Lewis index

Table 4. Indicators of the goodness of fit for the biennium 2017/2018

Fit statistic	Value	Description
Baseline comparison		
CFI	0.836	Comparative fit index
TLI	0.800	Tucker–Lewis index

The TLI and CLI are below the acceptance threshold. This result means that the models have no statistical significance. In that, we need to subject the two models to a fitting process. The fitting process involves making changes to the model suggested by the modification indices to increase the model's adaptability. According to Furr and Bacharach (2013), the variables measured with factor loadings <0.30 were removed to improve the goodness of fit. In particular, in the model 2016/2017, we remove only the variable SC4. As for the biennium 2017/2018, the variables RC1 and SC4 were excluded. The estimated parameters after the fitting process reported by each model are summarised in Tables 5–12.

Table 5. Estimated factor loadings for the biennium 2016/2017

Measured variable	HC	RC	SC
HC1	0.99	–	–
HC2	1	–	–
HC3	0.90	–	–
HC4	0.94	–	–
HC5	0.91	–	–
RC1	–	0.59	–
RC2	–	0.66	–
RC3	–	0.32	–
SC1	–	–	0.29
SC2	–	–	0.96
SC3	–	–	0.60
SC4	–	–	–

Table 6. Estimated correlation for the biennium 2016/2017

	HC	RC	SC
HC	1		
RC	0.77	1	
SC	0.98	0.82	1

Table 7. Estimated regression coefficients for the biennium 2016/2017

IC component	Performance
HC	−0.076
RC	0.13
SC	0.35

Table 8. Estimated parameters for the geographical area variable for the biennium 2016/2017

Geographic area	Performance
North/Center	−0.35
North/South	−0.20

Table 9. Estimated factor loadings for the biennium 2017/2018

Variable	HC	RC	SC
HC1	0.99	–	–
HC2	0.99	–	–
HC3	0.90	–	–
HC4	0.96	–	–
HC5	0.89	–	–
RC1	–	–	–
RC2	–	0.77	–
RC3	–	0.50	–
SC1	–	–	0.41
SC2	–	–	0.99
SC3	–	–	0.72
SC4	–	–	–

Table 10. Estimated correlation for the biennium 2017/2018

	HC	RC	SC
HC	1		
RC	0.59	1	
SC	0.98	0.62	1

Table 11. Estimated regression coefficients for the biennium 2017/2018

IC component	Performance
HC	–0.75
RC	0.33
SC	0.76

Table 12. Estimated parameters for the geographical area variable for the biennium 2017/2018

Geographic area	Performance
North/Center	0.52
North/South	0.44

Based on the results obtained, we must analyse the models' adaptability again to verify that the indicators related to the goodness of fit are above the acceptance threshold of 0.90. Tables 13 and 14 show the goodness of fit indicators for the two models after the fitting process.

As depicted in the tables, the indexes TLI and CFI are above the acceptance threshold of 0.90. Thus, the two models present acceptable data adequacy. Figures 3 and 4 depict the final models to be analysed in the following section.

Table 13. Indicators of the goodness of fit for the biennium 2016/2017 after the fitting process

Fit statistic	Value	Description
Baseline comparison		
CFI	0.929	Comparative fit index
TLI	0.909	Tucker–Lewis index

Table 14. Indicators of the goodness of fit for the biennium 2017/2018 after the fitting process

Fit statistic	Value	Description
Baseline comparison		
CFI	0.934	Comparative fit index
TLI	0.912	Tucker–Lewis index

4. Analysis of the results

The conceptual and structural models responded to the need to understand how IC components influence the R&D performance of universities. On the one hand, we have hypothesised a direct and unidirectional link between the IC components and the R&D performance. On the other hand, we have hypothesised a direct and bidirectional link between the three IC components. First of all, our results show that the level of HC, RC and SC play a key role in the productivity of Italian state universities. However, common elements and some differences characterise the two models presented. In particular, concerning the link between latent and measured variables, as shown in Tables 5 and 9, the values of the estimated factor loadings are all above the acceptance threshold of 0.3. As far as the common elements are concerned, moving on to analyse the consistency of Hypothesis 1, which stated a positive correlation between HC and RC, this hypothesis is supported in both models.

Indeed, the correlation coefficients are respectively 0.77 for the biennium 2016/2017 and 0.59 for the biennium 2017/2018. Similarly, Hypothesis 2, imposing a positive correlation between HC and SC, is supported in both models with a correlation value of 0.98 for both biennia. Finally, the last Hypothesis 3, regarding the positive correlation between SC and RC, is also supported with a value of 0.82 for the biennium 2016/2017 and 0.62 for the biennium 2017/2018. These results are not surprising, as numerous studies had theorised a positive correlation between the components of IC (Sveiby, 2001; Marr and Starovic, 2003; Low et al., 2015; Secundo et al., 2016; Sangiorgi and Siboni, 2017). It is, therefore, concluded that there is a strong synergy between the

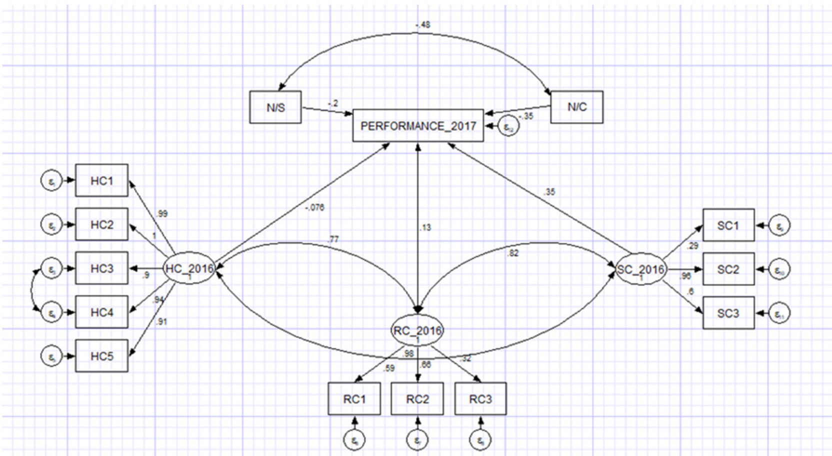

Figure 3. Model results for the biennium 2016/2017.

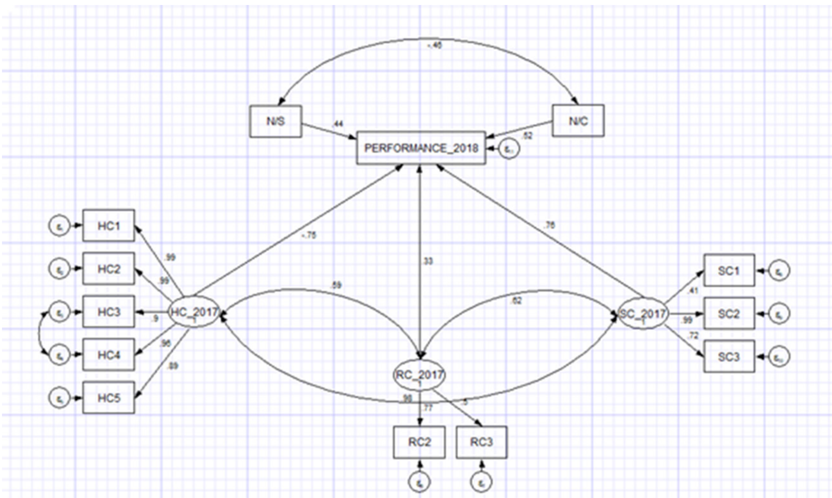

Figure 4. Model results for the biennium 2017/2018.

IC components of Italian universities, and there must be parallelism in the improvement and reporting of each component since these components are strongly correlated.

After analysing the first three hypotheses on the level of correlation between the IC components, we focused on the impact of each component on the performance. Specifically, Hypothesis 4, which states that the HC has a positive effect on the scientific productivity of Italian public universities, is not supported either in the biennium 2016/2017 or in the biennium 2017/2018. The regression coefficients turn out to be negative for each model ($\beta_{2016/2017} = -0.076$; $\beta_{2017/18} = -0.75$). This result seems counterintuitive when analysed individually, as an increase in HC would decrease scientific productivity. Indeed, as we will see later, this result is interesting when analysed in conjunction with evidence on the other components of IC. Turning then to Hypothesis 5, which claims that the higher RC better the scientific productivity, this is supported by both models ($\beta_{2016/2017} = 0.35$; $\beta_{2017/2018} = 0.76$). It can therefore be seen, in this case, that as the level of the university's relationship with external organisations increases, there is an improvement in the levels of scientific productivity. The last hypothesis, which states that the higher SC better the performance of Italian public universities, is supported in both models. The coefficients result as follows $\beta_{2016/2017} = 0.13$; $\beta_{2017/2018} = 0.33$. Therefore, a good infrastructural level has a positive impact on performance. A global analysis of the results obtained about the links between the IC components and the scientific productivity of Italian public universities shows that there are decreasing returns on productivity. This result means that small universities with a good level of relations with external organisations, a good level of internationalisation and solid infrastructure have a higher level of productivity than larger universities that are less internationalised and invest less in infrastructure. As for the contrasting elements between the two models, finally, we can analyse the estimated parameters for the geographic area. The values obtained for the biennium 2016/2017 define a trend favouring the North compared to the South and the Center. This trend indicates a significant impact from the northern universities in determining productivity compared to the South and the Centre universities. Instead, the values obtained for the biennium 2017/2018 define a significant trend favouring the South and the Centre compared with the North. This interesting result opens the way for further studies and insights into comparing the research activity of the universities of the North and those of the South and Centre.

It is also possible to identify the key elements on which to intervene to improve the research activities of universities, considering the variables with the maximum value of factor loading in the two analysed models. These elements can be identified by the following measured variables:

- Number of full professors.
- Number of associate professors.
- Number of full-time researchers.
- Number of part-time researchers.
- Number of PhD students.
- Number of scholarships agreements financed by private bodies.
- Amount of reward fee of the Ordinary Financing Fund (OFF).

5. Conclusions and future research developments

During the last decade, great attention has been paid to the analysis of the IC components as a key driver of business competitive advantage. Less attention, instead, has been given to the IC in higher education. From this perspective, universities can play an important role as they are characterised by a high level of IC. Given the above, this study aimed to investigate the impact of IC components on performance in terms of scientific productivity. Considering that there are very few contributions in the literature that analyse the relationship between HC, RC, SC and universities' performance in terms of research productivity, this paper intends to fill this literature gap. A sample of secondary data from Italian public universities was collected to reach this aim. The data consider a period of 3 years from 2016 to 2018. As a result, the two models differ in terms of the impact of IC components on performance. Specifically, the following main findings come to light that emphasises the differences between the two biennia:

1. in 2016/2017, smaller northern universities characterised by good infrastructures and good relations with external bodies are more performing in terms of scientific productivity compared to southern and central universities characterised by a higher level of employees;
2. in 2017/2018, as in the previous year, smaller universities with a more solid infrastructure and good external relations have a positive, even though different, impact on productivity. In this case, the SC has a very significant incidence, as does the HC. These two components act predominantly on scientific productivity. On the contrary, compared to the previous biennium, it is possible to note a significant difference in productivity favouring the South and the Centre compared to the North.

5.1. *Implications and limitations*

As for implications, this paper represents a tool to guide universities' strategic choices. It emerges that the key elements to improve university research productivity are the university's personnel, the number of scholarships financed by private organisations, the amount of scientific equipment and the OFF since these variables present the maximum value of factor loading in the two analysed models. These results are relevant for both universities' managers and public policymakers. First, university managers could exploit new opportunities to reinforce HC by reducing the turnover levels of young researchers and increasing the offer for research doctorates. Furthermore, university managers should focus on strengthening the relationship with private entities and generating lasting collaborations over time that translate into scientific results that can benefit society and the university itself. As for policymakers, we have seen a negative impact of the human component of IC on the R&D performance, probably linked to the complicated evaluation system that has affected the daily life of universities. The new decrees, in some cases, have seriously distorted the free activity of research, causing insurmountable inequalities between the different research groups and the different scientific areas.

Furthermore, the new logic in the research evaluation system has imposed a publish or perish logic that has depressed the quality of scientific publications in favour of quantity. As a result, it has spread opportunistic practices in the academic community. Therefore, policymakers could enhance more aspects of RC, such as the level of internationalisation and SC understood as the ability to efficiently exploit resources to improve aspects such as sustainability and resilience. Concerning limitations, it may be useful to conduct further analysis in identifying additional variables regarding the definition of RC and SC. In addition, it may be interesting to define university performance through alternative variables (e.g. the number of research projects, the number of affiliated start-ups or the number of academies promoted by the university) or even to study the performance as a latent variable related to multiple measured variables. It could also be interesting to consider a larger time series or sample of European universities.

5.2. Future research directions

Future contributions could focus on the following objectives:

- Defining a framework useful for structuring and differentiating universities according to the approaches to developing the IC and the components that characterise it (HC, RC, SC).
- Carrying out studies aimed at analysing individual-specific metrics to evaluate IC components.
- Deepening the specialisation of the different contexts in which universities operate, studying the characteristic organisational structures and the different activities implemented internally to develop and improve the analysis of the IC.

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Data availability statement

Data derived from public domain resources.

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