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Same but Different? The impact of Research and Technology Organizations versus Universities on firms' innovation

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Abstract

Research and Technology Organizations (RTOs) and universities are important elements of countries' innovation system. Due to their intermediate position in between science and industry, RTOs and universities are often blended together and considered as the same thing. However, many studies have stressed the differences between the two. In this paper, we compare the impact of RTOs and universities on firms' innovation type and performance. More specifically, we analyze what kind of innovation firms which work with RTOs versus universities are more likely to develop. Our study is based on statistical analysis of Community Innovation Survey available micro-data (CIS 2012). Our results suggest that firms which work with RTOs versus universities have different innovation outcomes. In particular, we find that companies that deem RTOs as more important sources of knowledge than universities have a higher probability to develop *service innovation*, have *less need to invest in internal R&D* but are *less likely to be innovative including new to the world innovation.* These results have important policy and management implications.

Keywords: Research and Technology Organizations (RTOs), Universities, Service Innovation, University-industry linkages, Open Innovation.

JEL Code: O31, O32, O33, O34

1. Introduction

It is well established that the innovation process has become increasingly open and includes the collaboration of many and diverse partners (Chesbrough 2003). More specifically, special attention has been given over the years in the relationship between academia and industry and its impact on the innovation outcomes (Caloghirou et al. 2001; Perkmann & Walsh 2007; D'Este & Perkmann 2011; Mowery et al., 2015). Public Research Organizations, facing the contemporary turbulent environment and the scarcity of public funds have been increasingly required by local governments to enlarge their activities beyond the traditional teaching and basic research and to assume a more active role in innovation by strengthening their interactions with industrial partners[1].

Yet, this stream of research on public research – industry relationships is very much focused on universities (Lundvall 1992; Mowery et al. 2005; Etzkowitz & Leydesdorff 2000; Etzkovitz & Goktepe 2005; Debackere & Veugelers 2005; Rasmussen 2008; Comacchio et al. 2012; Sharif & Baark 2011; Mowery et al., 2015). The public research landscape, though, does not only comprise universities. The Research and Technology Organisations (RTOs) are also an important part of the academic and public research world and a contributor in the current complex knowledge economies (Metcalfe 2010). In fact RTOs are a significant part of what is called the "extra-university research organizations" sector (Arnold et al. 2010). According to the European Association of Research and Technology Organizations (EARTO) there are 350 RTOs in Europe operating in 23 countries involving a network of 150.000 researchers, engineers and technicians. These organizations provide innovative solutions to 100 000 companies per year on diverse domains such as health, security, energy, transportation, materials, agriculture (to mention just a few) with an overall economic impact of 40 billion euros.

[1] A prominent example is the introduction of the Bayh-Dole Act in US, which gave incentives to American universities to actively seek revenues from their research outputs, for instance via patenting and licensing. A large stream of research has been dedicated to the consequences of this Act and on the impact of universities on innovation (Mowery et al. 2001, Howells et al. 2012, Nelson 2001, Grimaldi et al. 2001). Similarly, the European Framework programs have also been an important incentive for universities to engage in partnerships with several and diverse partners (Caloghirou et al.2001).

RTOs are not solely a European phenomenon. Renowned RTOs exist also in many other countries such as US, Canada, China, Brazil, India, etc. [2]

If in the literature we sometimes find different names for qualifying RTOs, such as public institutes, research institutes, technological institutes (Gulbrandsen 2011), the EARTO defines them as *"organizations which as their predominant activity provide research and development, technology and innovation services to enterprises, governments and other clients…"* (EURAB, 2005, p. 1). This is in line with Albors-Garrigos et al. (2010) who also define RTOs as organizations whose main business is R&D and their purpose being to enhance the innovative performance of their customers.

Like universities which are also largely different across countries, RTOs might have diverse inherent characteristics. They might be public, semi-public or private, some of them are technology-oriented while others provide services in social sciences or economics. The funding of RTOs is also a mix of public and private[3]. This leads Gulbrandsen (2011) to highlight the hybrid nature of RTOs as they operate between public and private organizations and they are at the boundary between the notion of Knowledge-Intensive Business Service Firm (KIBS) and academia. The innovation model of RTOs as described by the report of Arnold et al. (2010, p.10–11) comprises the following stages: (i) exploratory research and development to develop an area of capability or a technology platform; (ii) further work to refine and exploit that knowledge, often in collaboration projects with the industry; (iii) more routinized exploitation of this knowledge via consulting, licensing and spin-off company creation.

Despite the important presence of RTOs in the national innovation systems there is a lack of theoretical and empirical studies about them (Modrego-Rico et al. 2005; Gulbrandsen 2011). And when they are analyzed, RTOs are often blended together with universities (Perkmann & Walsh, 2007). Yet, RTOs and universities are distinct types of

[2] The interested reader can find more information about RTOs in an international context through the website of WAITRO http://www.waitro.org/index.php.

[3] RTOs rely on a mix including public and private funding, such as membership subscriptions, fee-for service activities, government core funding, contracts for public grant-funded research or competitive contracts from firms or governments, which is a result of their hybrid character (Berger & Hofer 2010).

organizations (Arnold et al. 2007; Readman et al. 2015; Barlatier et al. 2017). RTOs can "fulfill a different role in economy's knowledge ecology" (Metcalfe 2010, p. 22) and, in particular, companies may address RTOs for different reasons than they address universities (Arnold et al. 2007).

The objective of this paper is to fill in this gap in the literature by analyzing empirically the distinct role of RTOs versus universities regarding firms' innovation. More specifically, we study the impact of RTOs and universities on the kind of innovation firms introduce. Indeed since RTOs and universities have different skills, knowledge and business models, their impact on the nature of innovation which they contribute to develop should be different. Our study is based on statistical analysis of the 2012 Community Innovation Survey (CIS 2012) data from 8 European countries. Our results suggest that companies that deem RTOs as more important sources of knowledge than universities have a higher probability to develop *service innovation*, have *less need to invest in internal R&D* but are *less likely to develop new to the market or new to the world innovation.* These first empirical results are broadly in line with earlier theoretical analysis of the respective role of RTOs and universities as knowledge provider for firms' innovation (Tann et al. 2002; Preissl 2006; Arnold et al. 2007; Arnold et al. 2010; Albors-Garrigos et al. 2010; Readman et al. 2015). They generate important insights both from a policy and a managerial perspective.

The remainder of the paper is structured as follows. First, we build our theoretical hypotheses regarding the impact of RTOs versus universities on firm's innovation (Section 2). Then we present the empirical design of our study (Section 3). Section 4 summarizes our main results. Finally, a discussion of these results and their research implications for practitioners and policy makers conclude the paper (Section 5).

2. Formulation of research hypotheses

2.1 The effects on firms' innovation performance

The effects of open innovation on innovative performance have been largely debated this last decade. It has been shown in general that the appropriate use of external knowledge has a positive impact on the firm's innovation performance (Laursen & Salter 2006). Laursen and Salter (2006) also argue that the search for external knowledge in the context of open innovation should be reasonable and that over-search (both in terms of breadth and depth) may hinder innovative performance. In general, it is recommended that managers should use diverse types of knowledge providers which complement each other (Tether & Tajar 2008) while maintaining the right balance in order not to get lost in too many search channels (Laursen & Salter 2006).

Given this context, and given the fact that universities and RTOs develop skills and knowledge largely complement to those held by firms, one can expect that the relationship should be mutually beneficial. In the case of RTOs, a consultation carried out by the "Association of Donors for the German Economy" in 2006 showed that cooperation between enterprises and RTOs is considered as highly beneficial for both parties. In particular, interacting with RTOs might enable firms to more easily and efficiently transferring and assimilating new technologies from academia (Readman et al. 2015).

Cooperating with universities is also positive for companies as it does not merely contribute to the innovation process by delivering inventions but it also offers creative ways of solving problems, opportunities to access human capital (e.g. students) and to gaining "windows" on emerging technologies and knowledge for specific innovations (Perkmann & Walsh 2007; D'Este & Perkmann 2011). Jaffe (1989) found that university research has significant positive effects on firms' innovative activities (as measured by patents). Cohen et al. (2002) also found that university research is critical to industrial R&D, especially for manufacturing firms.

Therefore, we can argue that both the collaboration with RTOs and universities have a positive effect on the innovative performance of firms. Nevertheless, the proficiency of RTOs in a variety of technologies and services, coupled with a focus on tangible outcomes (Tann et al. 2002), shows a greater propensity to impact on pragmatic innovation outcomes. RTOs were created with the explicit purpose to support the firms' innovation activities (Arnold et al. 2007; Arnold et al. 2010). Their core activity as it is evident from their definition is to perform applied research and commercialize them together with their industrial partners (Arnold et al. 2010), while for universities this is only their third mission after teaching and basic research (Etzkowitz & Leydesdorff 2000). Furthermore, the cognitive proximity of RTOs and industry (as RTOs lie in the interface between academia and industry) makes it easier to understand and translate business needs and scientific knowledge into pragmatic innovation output. This is not always possible with universities, where the different culture with their industrial partners has often been mentioned as a barrier in the developments of collaborative innovation projects (Siegel et al. 2007). Therefore, we can formulate our first hypothesis:

Hypothesis 1a: Companies that deem RTOs as more important sources of knowledge than universities develop more innovation (irrespectively of their type and impact)

While RTOs proficiency in translating scientific research into a pragmatic output has been acknowledged by the relevant literature, little has been said regarding the contribution of RTOs to breakthrough-radical innovations. On the contrary, Caloghirou et al. (2001) have shown that when collaborating with universities, firms primarily aim at keeping up with major technological developments, achieving research synergies and reducing R&D costs. In fact, in this case it is universities that are praised to contribute to world class innovation. Evidence is provided by many scientific domains such as pharmaceuticals or software engineering and aerodynamics (Feller 1990; D’Este & Perkmann 2011; Perkmann et al. 2013). This is normal if we consider the fact that universities are more concerned with basic and more experimental research that is more likely to generate breakthrough, first in the world innovations (Caloghirou et al. 2001; Perkmann et al. 2013; Feller 1990). Therefore, our second hypothesis:

Hypothesis 1b: Companies that deem RTOs as more important sources of knowledge than universities are less likely to develop world-class innovations.

2.2 The effects on the type of innovation: RTOs proficiency in service innovation

Another difference that can be expected between RTOs and universities concerns the type of innovation (service versus goods) they induce in the economy. The main mission of

RTOs is to support the local economies by providing innovation services (Tann et al. 2002; EURAB 2005; Arnold et al. 2007). Firms expect from RTOs to be able to offer them knowledge-based services in order to make up for the knowledge that they do not possess and are not willing to invest in (Mrinalini & Nath 2008). Therefore, RTOs have to be able to make their service offering compatible with new knowledge generation (Modrego-Rico et al. 2005).

The growth of the tertiary sector has raised the attention on services; for instance the importance of knowledge intensive services has been emphasized in the literature as being a strategic tool for companies for developing new markets, new process and new products (Metcalfe & Miles 2000; Gonzalez-Moreono & Saez-Martinez 2009). Moreover, scholars have identified the importance of innovation in services separately from goods (Gallouj & Weinstein 1997; Evangelista 2000; Hipp 2010). Service innovation is highly abstract due to the inherent characteristics of services and it is often considered as complementary to goods innovation (Gallouj & Weinstein 1997; Gallouj & Savona 2011). From this perspective, Toivonen and Tuominen (2009, p.899) argue that "innovation in services shows some specific features which cannot be deeply understood if the models developed in the manufacturing context are applied".

Furthermore, service innovation capabilities have very recently started to be discussed from academics but most of the contributions remain theoretical (e.g. den Hertog et al. 2010). One of the most prominent frameworks about the development of service innovation capabilities was developed by Froehle and Roth (2007) which is based on the interplay between resources and process. This framework was further refined and studied in the context of RTOs empirically (Giannopoulou et al. 2011; Giannopoulou et al. 2012; Gryszkiewicz et al. 2013a; Gryszkiewicz et al. 2013b). The results showed that RTOs have distinct service innovation capabilities mainly because of their unique human capital as they have the opportunity to employ diverse profile of highly qualified people (Mrinalini & Nath 2000). Furthermore, the relational capital of RTOs with various stakeholders such as industry, government and academia (Arnold et al. 2007; Arnold et al. 2010) provides them also with an important asset on service innovation capabilities development. Finally, RTOs were shown to also have unique capabilities in fostering creativity in service innovation thanks to their highly stimulating and dynamic working environment (Giannopoulou et al. 2014). This is in line with Gadrey et al. (1995) who argue that human, technological, organizational related capabilities are at the heart of a service offering.

While RTOs can be considered as more focused towards service innovations, this is not the case for universities. In particular, Tether and Tajar (2008) show that universities are more focused towards industrial problems and tend to provide firms with product and process innovation. Therefore, our third hypothesis:

Hypothesis 2: Firms that deem RTOs as more important sources of knowledge than universities are more likely to develop service innovation.

2.3 The effects on the need to invest in internal R&D

Internal R&D does not only generate innovations, but it also helps the firm to develop the ability to identify, assimilate, and exploit knowledge from the environment-what is called a firm's 'learning' or 'absorptive' capacity (Cohen & Levinthal, 1989; 1990). Consequently, open innovation and more specifically the use of external sources of knowledge is often considered to be a complement of internal R&D rather than a substitute (Lichtenthaler & Ernst 2008). Following this reasoning, Vanhaverbeke et al. (2008) argue that internal and external sources should be combined and in this perspective internal R&D is very important to effectively exploit external knowledge. However, Laursen and Salter (2006) found that open innovation is often a substitute rather than a complement to internal R&D.

When it comes to public research in particular, Cohen and Levinthal (1998) have shown that there is a direct link between the firm’s R&D activities and the use of public research. More specifically, the two authors argue that companies are investing in internal R&D not only for generating innovations but also to be able to develop the absorptive capacity to identify important external knowledge such as coming from public research of universities or government laboratories. Moreover, it has been shown that the R&D

intensity of the firm is positively correlated with the use of external knowledge from universities (Mohnen & Hoareau 2003; Laursen & Salter 2004).

As compared to universities RTOs are more focused on applied research. Universities' core activity (together with teaching) is to perform basic research, but "fundamental knowledge is too abstract in many cases to map easily onto practical problems in firms, and a translational or development gap usually needs to be bridged" (Metcalfe 2010, p.23). Jensen and Thursby (2001) found that an important share of university inventions are still embryonic, i.e. cannot be used as such by firms. The latter must still massively invest in R&D in order to make these embryonic inventions valuable. Therefore, since ideas coming from universities are more premature and require more work until they reach the stage of commercialization, it follows that firms which collaborate with universities need to invest in internal R&D in order to reuse knowledge stemming out of university labs (Rogers 2003).

RTOs, on the other hand, can cover this need with their specific innovation capabilities (Gryszkiewicz et al. 2013a). RTOs are more than merely intermediaries that convert the science-based knowledge from the universities into applied knowledge that can be absorbed more easily by the SMEs (Goduscheit & Knudsen 2015). They are important knowledge co-creators that are actively involved in the innovation process and can provide much more than mere technology transfer (Barlatier et al. 2017). The capability of RTOs to manage effectively the innovation process from the idea to the commercialization stage is therefore an asset in the collaboration projects, since it might reduce firms' need to invest in internal R&D. Thus we propose that:

Hypothesis 3: Companies that deem RTOs as more important sources of knowledge than universities exhibit a lower need to invest in internal R&D.

3. Empirical design

3.1 Data collection

The data that we use in order to test the above mentioned hypotheses come from the 2012 Community Innovation Survey (CIS) which is administered by Eurostat[4]. The CIS aims at collecting information regarding the innovation activity, namely type of innovation, funding, sources of knowledge, performance etc., of European enterprises. The main methodology and concepts are based on the Oslo Manual.

Taking into account the purpose of this research project and the constraints of data availability and confidentiality we focus on the results of the CIS 2012 from eight countries, namely Belgium, Spain, Italy, Luxembourg, Portugal, Finland, Sweden and Norway. These countries have long history in public research. In particular, they:

(i) Host important active RTOs according to EARTO (European Association of RTOs);
(ii) Host important and renowned universities;
(iii) Have a proven innovation record.

Our sample consists of 31,255 enterprises in total, of all sizes (ranging from SMEs to MNEs) and economic sectors.

3.2 Econometric treatment

Model 1 – Hypothesis 1a. In order to test our four hypotheses we rely on four different models. To test hypothesis 1a we use two different proxies of the innovative performance of the firm. First, we use a dependent variable which takes the value 1 if the firm reports having introduced at least one innovation which is new to the market during the considered period (NEWMKT- Figure 1). Since we are dealing with a binary dependent variable the most appropriate choice is a logit model.

[4] http://ec.europa.eu/eurostat/web/microdata/community-innovation-survey

Figure 1: CIS questions to proxy the innovation performance

2.3 Were any of your product innovations (goods or services) during the three years 2010 to 2012:

		Yes	No	
		1	*0*	
New to your market?	Your enterprise introduced a new or significantly improved product onto your market before your competitors (it may have already been available in other markets)	☐	☐	*NEWMKT*
Only new to your firm?	Your enterprise introduced a new or significantly improved product that was already available from your competitors in your market	☐	☐	*NEWFRM*

Using the definitions above, please give the percentage of your total turnover[5] in 2012 from:

New or significantly improved products introduced during the three years 2010 to 2012 that were **new to your market**	*TURNMAR*	%
New or significantly improved products introduced during the three years 2010 to 2012 that were **only new to your firm**	*TURNIN*	%
Products that were **unchanged or only marginally modified** during the three years 2010 to 2012 (include the resale of new products purchased from other enterprises)	*TURNUNG*	%
Total turnover in 2012	1 0 0	%

2.4 To the best of your knowledge, were any of your product innovations during the three years 2010 to 2012:

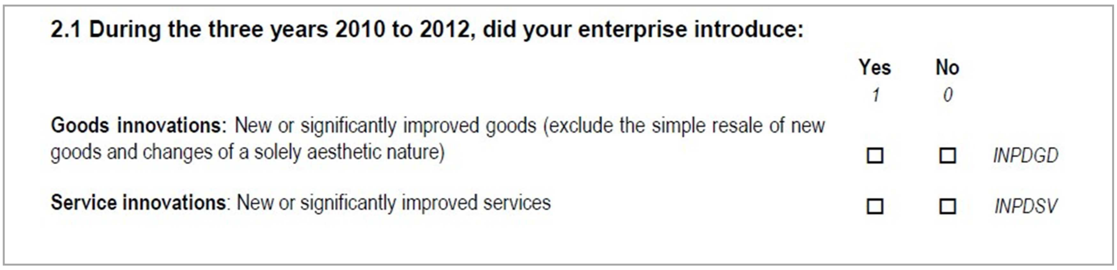
	Yes	No	Don't know	
	1	*0*	*2*	
A first in [your country]	☐	☐	☐	*INPDFC*
A first in Europe*	☐	☐	☐	*INPDFE*
A world first	☐	☐	☐	*INPDFW*

In addition to this logit model we also use an alternative dependent variable, namely the share of turnover that comes from new to the market products (variable TURNMAR- Figure 1) instead of the binary variable NEWMKT. In this case we are dealing with a double censored regression model (left censored at 0 and right censored at 1) (Wooldridge 2009).

Model 1b– Hypothesis 1b. In this second model, aimed at testing hypothesis 1b, the dependent variable is a binary variable that we construct based on the answer to the question 2.4 of the survey regarding the degree of novelty of the innovation (WORLD_FIRST- see Figure 1). In this case our dependent variable takes the value 1 if the INPDFW (world first product innovation) variable takes the value 1 (yes answer) and 0 otherwise. This is therefore again a logit model.

Model 2 – Hypothesis 2. In order to test hypothesis 2, we use as the dependent variable the answer to the question of the CIS questionnaire regarding the development of service innovation, which is expressed by the binary variable INPDSV (Figure 2). In model 2 the dependent variable is therefore a dummy variable which takes the value 1 if the firm reports having introduced service innovation (0 otherwise), which again leads to a logit model.

Figure 2: CIS question to proxy the type of innovation (service versus product)


2.1 During the three years 2010 to 2012, did your enterprise introduce:

	Yes 1	No 0	
Goods innovations: New or significantly improved goods (exclude the simple resale of new goods and changes of a solely aesthetic nature)	☐	☐	*INPDGD*
Service innovations: New or significantly improved services	☐	☐	*INPDSV*

Model 3– Hypothesis 3. In the last model which aimed at testing hypothesis 3, the dependent variable is the fraction of internal R&D expenditures to the firm's turnover (INT_RD_P – see Table 1). In the 2012 CIS questionnaire, the expenditures on R&D are requested under the question displayed in Figure 3. The figure we retain corresponds therefore to the variable RRDINX, i.e. the total amount of in-house R&D performed by the firm (therefore excluding external R&D). In this case, since the dependent variable is the fraction of internal R&D expenditures to the firm's turnover, only positive values are possible. Moreover, there is no upper limit (as the expenditure on R&D can exceed the turnover of the company).We use, therefore, a censored regression Tobit model (Wooldridge, 2009).

Figure 3: CIS question to proxy the intensity of R&D investments

5.2 How much did your enterprise spend on each of the following innovation activities in 2012 only?
Innovation activities are defined in question 5.1 above. Include current expenditures (including labour costs, contracted-out activities, and other related costs) as well as capital expenditures on buildings and equipment.[7]

Please fill in '0' if your enterprise had no expenditures for an activity in 2012
With a lack of precise accounting data please use estimates

In-house R&D (Include current expenditures including labour costs and capital expenditures on buildings and equipment specifically for R&D)	RRDINX
External R&D	RRDEXX
Acquisition of machinery, equipment, software & buildings (Exclude expenditures on these items that are for R&D)	RMACX
Acquisition of existing knowledge from other enterprises or organisations	ROEKX
All other innovation activities including design, training, marketing, and other relevant activities	ROTRX
Total expenditures on innovation activities (Sum of expenditures for all types of innovation activities)	RALLX

3.3 Description of the independent and control variables

The main independent variable we rely on is the relative importance of RTOs vs universities as a knowledge source for respondents. For this we use two existing variables in the CIS questionnaire, namely the SUNI and SGMT ones. These two variables are extracted from the response to the question of how important the respondents find several sources of innovation (Figure 4). We take SUNI variable as the indicator of the importance of universities and SGMT variable as the best proxy of RTOs' importance in the innovation process.

Then, in order to synthetize the relative importance of RTOs versus universities into one single variable we subtract these two variable in order to create a new variable RTOVSUNI such that RTOVSUNI= SGMT-SUNI. This new variable takes values from -3 to 3 (since variables SUNI and SGMT takes values from 0 to 3). Positive values of the new constructed variable mean that the respondent firm reports RTOs as more important source of innovation than universities while negative values mean the opposite.

Figure 4: CIS question to proxy the importance of knowledge coming from RTOs versus universities

6.1 During the three years 2010 to 2012, how important to your enterprise's innovation activities were each of the following information sources? Include information sources that provided information for new innovation projects or contributed to the completion of existing projects.

	Information source	**High** 3	**Medium** 2	**Low** 1	**Not used** 0	
		Degree of importance *Tick 'not used' if no information was obtained from a source.*				
Internal	Within your enterprise or enterprise group	☐	☐	☐	☐	*SENTG*
Market sources	Suppliers of equipment, materials, components, or software	☐	☐	☐	☐	*SSUP*
	Clients or customers from the private sector	☐	☐	☐	☐	*SCLPR*
	Clients or customers from the public sector*	☐	☐	☐	☐	*SCLPU*
	Competitors or other enterprises in your industry	☐	☐	☐	☐	*SCOM*
	Consultants and commercial labs	☐	☐	☐	☐	*SINS*
Education & research institutes	Universities or other higher education institutions	☐	☐	☐	☐	*SUNI*
	Government, public or private research institutes	☐	☐	☐	☐	*SGMT*
Other sources	Conferences, trade fairs, exhibitions	☐	☐	☐	☐	*SCON*
	Scientific journals and trade/technical publications	☐	☐	☐	☐	*SJOU*
	Professional and industry associations	☐	☐	☐	☐	*SPRO*

In addition, we rely on several control variables based on relevant literature. First we control for some general characteristics such as the size of the enterprise which is expressed by the log of number of employees, the country where the company operates and the NACE activity. Also, we control for whether or not the firm has cooperation with other organizations, belongs to a group or is present in other markets than its national one, since previous studies have shown that these variables might affect the innovative dimension of a firm. Furthermore, since it has widely been shown in the relevant literature that the R&D investment of a firm is important for the innovation outcome we also control for the R&D intensity of the enterprise which is expressed as the fraction of expenditures in R&D to the number of employees (Asikainen & Mangiarotti 2016).

Finally, based on the work of Laursen and Salter (2006), we also control for search breadth, meaning the extent to which a company uses other sources of information in their innovation process (such as consultants, customers, etc., please see Figure 4) besides RTOs and universities. According to Laursen and Salter (2006) the squared term of this variable is also taken into account to account for diminishing returns. Similarly to search breadth, we also include in our controls the search depth which expresses the intensity of information source. In this case,we take into account how many sources the respondent firm reports as highly important.

A description of the dependent, independent and control variables is provided in Table 1 and Table 2.

Table 1: Description of dependent and independent variables for the econometric models: means, standard deviation, min and max values

H1a	H1b	H3	H4	Variable name	Variable code	Description	Mean	St. Dev.	Min	Max
				Dependent variables						
√				Turnover from new to the market products	TURNMAR	% of turnover coming from innovation that were new to the market	0.1	0.2	0.0	1.0
√				New to the market products	NEWMKT	Dummy, NEWMKT=1, if the enterprise has introduced a product new to the market	0.3	0.5	0.0	1.0
	√			New to the world products	WORLD_FIRST	Dummy, WORLD_FIRST=1, if the enterprise has introduced a world first innovation. Constructed variable WORLD_FIRST=1, if INPDFW=1	0.1	0.3	0.0	1.0
		√		Service innovation	INPDSV	Dummy, INPDSV=1, if the company has introduced onto the market a new or significantly improved service	0.1	0.3	0.0	1.0
			√	Investment in internal R&D	INT_RD_P	Fraction of in-house R&D investment to turnover. Constructed variable INT_RD_P = RRDINX/TURN12	0.2	18.1	0.0	3,493.0
				Independent variables						
√	√	√	√	Relative Importance of RTOs vs Universities as source of knowledge	RTOVSUNI	RTOVSUNI= {-3,-2,-1,0,1,2,3}, denotes the relative importance of RTOs vs universities as source of knowledge. Constructed variable: RTOVSUNI=SGMT-SUNI	-0.03	0.8	-3	3.0
√	√	√	√	RTOs as source of knowledge	SGMT	SGMT={0,1,2,3}, denotes the degree of importance of government or public research institutes as source of knowledge, 0= not used, 1=low,2=medium and 3=high	0.7	1.0	0.0	3.0
√	√	√	√	Universities as source of knowledge	SUNI	SUNI={0,1,2,3}, denotes the degree of importance of universities or other higher education institutes as source of knowledge, 0= not used, 1=low,2=medium and 3=high	0.8	1.0	0.0	3.0

Table 2: Description of the control variables for the econometric models: means, standard deviation, min and max values

H1a	H1b	H3	H4	Variable name	Variable code	Description	Mean	St. Dev.	Min	Max
				Control Variables						
√	√	√	√	Employees Nr	EMP12	Number of enterprise employees	141.6	1,002	0.0	C
√	√	√	√	Belonging to a group	GP	Dummy, GP=1, if the enterprise is part of a group	0.4	0.5	0.0	1.0
√	√	√	√	Presence in international Market	INT_MARKET	Dummy, INT_MARKET=1, if the enterprise is present in international market.	0.5	0.5	0.0	1.0
√	√	√		R&D capital intensity	RDINT_2	Fraction of R&D expenditures to number of employees. Constructed variable RDINT_2=RALLX/EMP1212	5,327.3	49,631.2	0.0	8,024,409.0
√	√	√	√	Cooperation	CO	CO=1, if the enterprise has cooperation arrangements on innovation activities	0.2	0.4	0.0	1.0
√	√	√	√	Cooperation breadth	CO_TOT	CO_TOT={0,1,2,…,38,39,40} Denotes the breadth of collaboration taking into account the collaboration with different actors in different locations.	0.6	2.3	0.0	40
√	√	√	√	Cooperation breadth Squared	CO_TOT_SQ	CO_TOT_SQ = {0,1,4,9,..., 1600}. Squared term of CO_TOT variable	5.7	39.1	0.0	1,600
√	√	√	√	Search breadth	SEARCH_ADJ	SEARCH_ADJ= {0, 1, 2, 3, 4, 5, 6, 7}. Denotes the search breadth taking into account the sources of external knowledge used irrespectively of the intensity (except Universities (SUNI) and RTOs (SGMT)).	4.7	2.4	0.0	7.0

H1a	H1b	H3	H4	Variable name	Variable code	Description	Mean	St. Dev.	Min	Max
				Control Variables						
						SINS_ADJ+SCON_ADJ+SJOU_ADJ+SPRO_ADJ				
	√	√	√	Search breadth squared	SEARCH_ADJ_SQ	SEARCH_ADJ_SQ= {0,1,4,9,16,25,36,49}. Squared term of SEARCH_ADJ variable	27.5	18.9	0.0	49
√	√	√	√	Search depth	DEPTH_ADJ	DEPTH_ADJ= {0,1,2,3,4,5,6,7}. Denotes the search depth taking into account the sources of external knowledge that are highly used (except Universities (SUNI) and RTOs (SGMT)).	0.9	1.2	0.0	7.0
√	√	√	√	Search depth squared	DEPTH_ADJ_SQ	DEPTH_ADJ_SQ= {0,1,4,9,16,25,36,49}. Squared term of DEPTH_ADJ variable	2.4	5.6	0.0	49
			√	Rest of R&D intensity	REST_RD_P	Fraction of R&D expenditures (except of in-house R&D) to number of employees.	0.1	3.7	0.0	568.0
√	√	√	√	NACE dummies	NACE_CORE[16]	Adjusted NACE CORE, NACE={NACE-EWG, NACE-Financial and insurance, NACE-Information and Communication, NACE-Manufacturing, NACE-Mining and QUARRYING, NACE-Transportation and Storage, NACE-Wholesale and Retail Trade, NACE-Other}				
√	√	√	√	Country dummies	NUTS	Country code, NUTS = {Belgium, Spain, Italy, Luxembourg, Portugal, Finland, Sweden, Norway}				

4. Results

4.1 RTOs, universities and firms' probability to innovate (H1a-H1b)

The first two models 1a and 1b deal with the innovative performance of the firm. The results of these two models can be found in Tables 3, 4 and 5, respectively. Whatever the proxy we use to measure firms' innovation performance (share of turnover coming from new to the market innovation or probability to introduce an innovation new to the market) we find that both RTOs and universities have a positive and significant impact on firms' innovation. Yet, the impact of universities is significantly more important, i.e. firms that see RTOs as more important sources of knowledge than universities have a significantly lower innovation performance. This goes against our hypothesis 1a. Moreover, as regard to world first innovation, we find that universities have a significantly more important impact than RTOs. Actually, only universities have a positive impact. Firms which see RTOs as important source of external information do not have a higher probability to introduce world first innovation. This is in line with hypothesis 1b.

Table 3: Model 1a (Logit): Innovation performance (new to the market products) RTOs vs. Universities [5]

	Dependent variable:			
	New to the market products (=1)			
	(1)	(2)	(3)	(4)
Relative Importance of RTOs vs Universities	-0.037**	-0.038**		
	(0.018)	(0.018)		
RTOs as source of knowledge			0.059***	0.053**
			(0.021)	(0.021)
Universities as source of knowledge			0.124***	0.119***
			(0.020)	(0.020)
Employees Number (log)	0.071***	0.052***	0.059***	0.044***
	(0.012)	(0.012)	(0.012)	(0.013)
Belonging to a group (=1)	0.046	0.050	0.042	0.046
	(0.034)	(0.034)	(0.034)	(0.034)
Industry dummies	yes	yes	Yes	yes
Country dummies	yes	yes	Yes	yes
Presence in international markets (=1)	0.297***	0.285***	0.292***	0.281***
	(0.035)	(0.035)	(0.035)	(0.035)
R&D investment	5.908e-07***	5.489e-07 ***	5.502e-07 ***	5.246e-07***
	(6.476e-08)	(6.543e-08)	(6.478e-08)	(6.539e-08)
Cooperation (=1)	0.543***		0.462***	
	(0.033)		(0.034)	
Search Breadth	0.076***	0.037	0.047***	0.052*
	(0.007)	(0.029)	(0.008)	(0.029)
Search Breadth squared		0.004		-0.001
		(0.004)		(0.004)
Cooperation Breadth		0.127***		0.110***
		(0.009)		(0.009)
Cooperation Breadth squared		-0.003***		-0.002***
		(0.0005)		(0.001)
Search Depth		0.013		0.018
		(0.027)		(0.027)
Search Depth squared		-0.004		-0.008
		(0.006)		(0.006)
Constant	-1.026***	-0.834***	-0.953***	-0.845***
	(0.088)	(0.096)	(0.088)	(0.096)
Observations	21,335	21,345	21,335	21,345
Log Likelihood	-13,745.560	-13,715.290	-13,705.850	-13,682.760
Akaike Inf. Crit.	27,537.120	27,484.580	27,459.710	27,421.520
Note:	*p<0.1; **p<0.05; ***p<0.01			

[5] All regressions were implemented using the R statistical software.

Table 4: Model 1a (Tobit): Innovation performance (turnover share) RTOs vs. Universities

	Share of turnover from new to the market products			
	(1)	(2)	(3)	(4)
Relative Importance of RTOs vs Universities	-0.005*	-0.006*		
	(0.003)	(0.003)		
RTOs as source of knowledge			0.012***	0.011***
			(0.004)	(0.004)
Universities as source of knowledge			0.022***	0.021***
			(0.004)	(0.004)
Employees Number (log)	-0.008***	-0.011***	-0.010***	-0.012***
	(0.002)	(0.002)	(0.002)	(0.002)
Belonging to a group (=1)	0.007	0.007	0.006	0.006
	(0.006)	(0.006)	(0.006)	(0.006)
Presence in international markets (=1)	0.047***	0.046***	0.046***	0.045***
	(0.007)	(0.007)	(0.007)	(0.007)
Industry dummies	Yes	yes	yes	yes
Country dummies	Yes	yes	yes	yes
R&D investment	5.908e-07**	5.489e-07***	5.502e-07***	5.246e-07***
	(6.476e-08)	(6.543e-08)	(6.478e-08)	(6.539e-08)
Cooperation (=1)	0.075***		0.058***	
	(0.006)		(0.006)	
Search Breadth	0.010***	0.0001	0.005***	0.003
	(0.001)	(0.006)	(0.001)	(0.006)
Search Breadth squared		0.001*		0.0002
		(0.001)		(0.001)
Cooperation Breadth		0.017***		0.013***
		(0.001)		(0.002)
Cooperation Breadth Squared		-0.0005***		-0.0004***
		(0.0001)		(0.0001)
Search Depth		0.001		0.0004
		(0.001)		(0.001)
Search Depth squared		-0.002		-0.002
		(0.005)		(0.005)
logSigma	-1.051***	-1.052***	-1.053***	-1.054***
	(0.007)	(0.007)	(0.007)	(0.007)
Constant	-0.126***	-0.094***	-0.113***	-0.096***
	(0.016)	(0.018)	(0.016)	(0.018)
Observations	21,040	21,050	21,040	21,050
Log Likelihood	-10,376.240	-10,362.780	-10,334.740	-10,329.470
Akaike Inf. Crit.	20,800.470	20,781.560	20,719.470	20,716.940
Bayesian Inf. Crit.	20,991.370	21,004.290	20,918.330	20,947.630
Note:	**p<0.1; **p<0.05; ***p<0.01*			

Table 5: Model 1b (logit): RTOs vs Universities and new to the world products

	Dependent variable: New to the world products (=1)			
	(1)	(2)	(3)	(4)
Relative Importance of RTOs vs Universities	-0.096***	-0.116***		
	(0.033)	(0.034)		
RTOs as source of knowledge			-0.020	-0.052
			(0.039)	(0.041)
Universities as source of knowledge			0.153***	0.160***
			(0.037)	(0.037)
Employees Number (log)	0.137***	0.109***	0.126***	0.102***
	(0.022)	(0.023)	(0.022)	(0.023)
Belonging to a group (=1)	0.285***	0.295***	0.281***	0.293***
	(0.071)	(0.071)	(0.071)	(0.071)
Presence in international markets (=1)	1.477***	1.456***	1.468***	1.449***
	(0.095)	(0.095)	(0.095)	(0.095)
Industry Dummies	Yes	yes	yes	yes
Country dummies	Yes	yes	yes	yes
R&D investment	3.542e-06***	2.892e-06***	3.358e-06***	2.793e-06***
	(5.827e-07)	(5.722e-07)	(5.812e-07)	(5.696e-07)
Cooperation (=1)	0.693***		0.636***	
	(0.060)		(0.062)	
Cooperation Breadth		0.106***		0.098***
		(0.012)		(0.013)
Cooperation Breadth squared		-0.001**		-0.001**
		(0.001)		(0.001)
Search Breadth	0.074***	0.033	0.050***	0.046
	(0.016)	(0.068)	(0.017)	(0.069)
Search Breadth squared		0.003		-0.001
		(0.008)		(0.008)
Search Depth		0.058		0.061
		(0.050)		(0.050)
Search Depth squared		-0.010		-0.013
		(0.010)		(0.010)
Constant	-4.560***	-4.249***	-4.491***	-4.264***
	(0.173)	(0.205)	(0.174)	(0.205)
Observations	13,451	13,461	13,451	13,461
Log Likelihood	-4,414.931	-4,399.208	-4,408.409	-4,395.492
Akaike Inf. Crit.	8,869.862	8,846.415	8,858.819	8,840.983
Note:	*p<0.1; **p<0.05; ***p<0.01			

4.2 RTOs, universities and service innovations (H2)

The results of Model 2, which are presented in Table 6, tend to confirm hypothesis 2, as we indeed find a positive relationship between the probability of the firm to develop service innovation and the relative importance of RTOs vs. universities. This suggests as expressed by hypothesis 2 that, *ceteris paribus*, firms which see RTOs as more important source of knowledge than universities are more likely to introduce service innovation.

As far as the rest of the variables are concerned, we find a positive and statistically significant effect of the cooperation variable and the size of the firm, as well as for search breadth and a negative one for search breadth squared, as expected following recent literature. Nevertheless, we find a negative relationship between service innovation and the variables belonging to a group, presence in international markets and R&D intensity which is not in line with the relevant literature. This is not surprising though as we are dealing with service innovation which cannot be explained with the same measures as goods innovation (Hipp & Grupp 2005).

Table 6: Model 2 (logit): RTOs vs universities and service innovation

	Dependent Variable			
	Service Innovation=1			
	(1)	(2)	(3)	(4)
Relative Importance of RTOs vs Universities	0.030*	0.029*		
	(0.016)	(0.017)		
RTOs as source of knowledge			0.035*	0.019
			(0.019)	(0.019)
Universities as source of knowledge			-0.025	-0.037**
			(0.019)	(0.019)
Employees Nr(log)	0.086***	0.071***	0.086***	0.072***
	(0.011)	(0.011)	(0.011)	(0.011)
Belonging to a group(=1)	-0.132***	-0.126***	-0.132***	-0.126***
	(0.031)	(0.031)	(0.031)	(0.031)
Presence in international markets (=1)	-0.028	-0.04	-0.028	-0.039
	(0.031)	(0.031)	(0.031)	(0.031)
Country dummies	Yes	Yes	Yes	Yes
Industry dummies	Yes	Yes	Yes	Yes
R&D intensity	-4.342e-07	-9.213e-07**	-4.462e-07	-9.020e-07**
	(3.277e-07)	(3.780e-07)	(3.304e-07)	(0.01686)
Search Breadth	0.106***	0.130***	0.105***	0.128***
	(0.006)	(0.026)	(0.007)	(0.026)
Search Breadth squared		-0.005		-0.004
		(0.003)		(0.003)
Cooperation (=1)	0.426***		0.422***	
	(0.030)		(0.032)	
Cooperation Breadth		0.093***		0.095***
		(0.008)		(0.008)
Cooperation Breadth squared		-0.002***		-0.002***
		(0.0004)		(0.0004)
Search Depth		0.048*		0.047*
		(0.025)		(0.025)
Search Depth squared		0.001		0.001
		(0.005)		(0.005)
Intercept	-0.929***	-0.870***	-0.926***	-0.869***
	(0.082)	(0.089)	(0.082)	(0.089)
Observations	30,511	30,521	30,511	30,521
Log Likelihood	-16,906.880	-16,871.280	-16,906.760	-16,870.830
Akaike Inf. Crit.	33,859.760	33,796.560	33,861.520	33,797.660

*Note: *p<0.1; **p<0.05; ***p<0.01*

4.3 RTOs, universities and the need to invest in internal R&D (H3)

As regards to our third hypothesis, we find that companies that deem RTOs as more important sources of knowledge than universities have less need to invest in internal R&D (Table 7). This is in line with hypothesis 3, as RTOs are able not only to provide the research but also the development part to firms, meaning that they can to a certain extent cover part of firms' needs of performing internal R&D activities. Moreover, this is also a consistent result with the first hypothesis as we expect in the case of service innovation to have less need to invest in R&D as there is less need for special equipment, materials or labs for instance, as in the case of goods innovation. Service innovation requires more investment in human capital and idea generation processes.

Like in the previous example we also look into RTOs and universities separately and we see a positive sign in the relationship between these two sources of knowledge and the investment in internal R&D, supporting the common assumption that a level of internal R&D is always needed as absorptive capacity is highly important for the development of innovations. This result is also consistent with the results of (Gonzalez-Moreono & Saez-Martinez 2009) that have shown that investment in internal R&D is positively correlated with the probability of firms collaborating with universities and research institutes. This also proves that the negative relationship between the relative importance of RTOs vs universities and the need to invest in internal R&D does not only come from the service innovation effect; otherwise the coefficient between RTOs separately and investment in internal R&D would also be negative.

As for the rest of the control variables we see a positive relationship between cooperation and search breadth confirming that external sources of knowledge are rather a complement and not a substitute of R&D investment.

Table 7: Model 3 (Tobit): RTOs vs Universities and the need to invest in internal R&D

	Dependent variable: Investment in internal R&D			
	(1)	(2)	(3)	(4)
Relative Importance of RTOs vs Universities	-0.605^{***}	-0.585^{***}		
	(0.160)	(0.160)		
RTOs as source of knowledge			0.413^{**}	0.639^{***}
			(0.186)	(0.188)
Universities as source of knowledge			1.573^{***}	1.757^{***}
			(0.184)	(0.186)
Employees Number (log)	0.634^{***}	0.649^{***}	0.527^{***}	0.569^{***}
	(0.117)	(0.119)	(0.118)	(0.120)
Belonging to a group (=1)	0.085	0.211	0.053	0.174
	(0.330)	(0.330)	(0.330)	(0.330)
Country dummies	yes	yes	yes	yes
Industry dummies	yes	yes	yes	yes
Presence in international markets (=1)	3.246^{***}	3.159^{***}	3.175^{***}	3.099^{***}
	(0.343)	(0.343)	(0.343)	(0.344)
Rest of R&D intensity (except internal)	1.622^{***}	1.622^{***}	1.617^{***}	1.616^{***}
	(0.028)	(0.028)	(0.028)	(0.028)
Cooperation (=1)	4.439^{***}		3.438^{***}	
	(0.305)		(0.320)	
Search Breadth	1.360^{***}	2.902^{***}	1.027^{***}	3.042^{***}
	(0.067)	(0.275)	(0.074)	(0.276)
Search Breadth squared		-0.198^{***}		-0.262^{***}
		(0.033)		(0.034)
Cooperation Breadth		0.963^{***}		0.712^{***}
		(0.078)		(0.081)
Cooperation Breadth squared		-0.035^{***}		-0.029^{***}
		(0.004)		(0.004)
Search Depth		0.361		0.417
		(0.262)		(0.262)
Search Depth squared		-0.039		-0.100^{*}
		(0.056)		(0.056)
logSigma	3.028^{***}	3.027^{***}	3.027^{***}	3.027^{***}
	(0.006)	(0.006)	(0.006)	(0.006)
Constant	-15.722^{***}	-17.067^{***}	-15.110^{***}	-17.359^{***}
	(0.846)	(0.923)	(0.848)	(0.924)
Observations	29,821	29,831	29,821	29,831
Log Likelihood	-76,796.290	-76,830.290	-76,740.020	-76,753.610
Akaike Inf. Crit.	153,640.600	153,716.600	153,530.000	153,565.200
Bayesian Inf. Crit.	153,839.900	153,949.100	153,737.600	153,806.000
Note:	$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$			

5. Discussion and concluding remarks

The acquisition of external knowledge has become extremely important to firms (Dahlander & Gann 2010) and with the rise of the open innovation paradigm a lot of interest has been given by the academic community to understand the relationship of firms with external sources of knowledge.

RTOs are important actors in national innovation systems yet little is known about their special characteristics because most of the times they are studied together with universities. In order to address this gap we studied the specific impact of RTOs on firm's innovation compared to universities. This is an important contribution because it is generally admitted that comparisons between knowledge providers have seldom been done (Vivas & Barge-Gil 2015). Yet, the choice of the most suitable partner in innovation, and more specifically in open innovation, is not an easy one.

More precisely, we have shown that companies that place more importance to RTOs than universities as sources of knowledge are less likely to develop *new to the market or new to the world innovation* but are more likely to develop *service innovation* and have *less need to invest in internal R&D*. Our results illustrate a consistent description of RTOs (Tann et al. 2002; Preissl 2006; Arnold et al. 2007; Arnold et al. 2010; Albors-Garrigos et al. 2010; Readman et al. 2015). RTOs predominant activity is to provide innovation services to their industrial partners therefore we expect for them to be proficient in service innovation (Preissl 2006; Arnold et al. 2007; Arnold et al. 2010). Indeed previous literature shows that RTOs possess distinct service innovation capabilities (Gryszkiewicz et al. 2013a; Giannopoulou et al. 2014).

This proficiency of RTOs in service innovation has some further implications. Hypotheses 1a and 1b show that companies that deem RTOs as more important knowledge providers than universities are less likely to develop new to the market or new to the world products. This is a surprising result taking into account the main mission of RTOs which is to support the innovative process within organizations (Mrinalini & Nath 2000; Barge-Gil & Modrego-Rico 2008; Gulbrandsen 2011; Sharif & Baark 2011). But it could be explained by the fact that most radical innovations come vastly from goods innovation. Radical service innovation is very rare (von Hippel et al. 1999; Jones & Samalionis 2010). Most of the time, it is related to process improvements or modification of existing services. Moreover, sometimes it is even difficult to understand that a new service represents a radical innovation due to the intangibility of services and to the very rare patent applications (Sundbo 1997). Nevertheless, if there is radical service innovation this is very likely be created through co-creation (Perks et al. 2012), therefore the role of RTOs in this perspective is very important as RTOs could lead the development of radical service innovations.

Sundbo (1997), in his seminal work, was wondering if there exists innovation in services and how does it looks like. The author concludes that innovation in services does exist but it is an unsystematic process that has different characteristics than innovation in goods. Indeed, Hipp and Grupp (2005) show in their research that innovation process in services does not only take place in the R&D departments known from the manufacturing companies but covers a number of functional units of the firm. In fact this is reflected in the low internal R&D intensity of service companies from the traditional R&D statistics' point of view (Hipp et al. 2003).This is consistent with our results in the sense that we already noticed the negative relationship between the service innovation development and the R&D intensity of the firm in Model 2.

Moreover, we have also shown that the relative importance of RTOs to universities is negatively correlated to the internal R&D investment. This indicates that RTOs cover a need of both research and development for the companies supporting the view that RTOs are not only service but also knowledge providers (Barlatier et al. 2017). The specific innovation capabilities of RTOs are indeed an important asset in the collaboration with the industry as RTOs can cover the whole spectrum of the innovation process form idea generation to development and commercialization. On the other hand universities' research, being more embryonic and basic, addresses lower levels of technological readiness and therefore needs more refinement before not only reaching the commercialization stage (Rogers 2003; Metcalfe 2010) but also in order to be understood and assimilated by enterprises.

Our research has several implications for practitioners, as well as policy makers. First of all, firms can understand the benefits that they can reap by collaborating with RTOs and make an informed choice between RTOs and universities. RTOs can not only be seen as simple service providers but have a potential for service innovation that may still be unexploited. Consistently, RTOs management should also invest more on advertising the unique capabilities of RTOs in innovation especially compared to universities addressing the need for a clearer and more proactive marketing approach (Arnold et al. 2007). RTOs should therefore insist on the fact that they are not only knowledge transfer organizations but unique knowledge co-creators.

Finally, policy makers should give more importance to the special role of RTOs in open, networked and globalized innovation systems. If RTOs are indeed the new "open innovation" organizations as Chesbrough (2015) points out then the support of the government is indispensable, though available funding or structural supporting mechanisms for collaboration (though living labs or other structures), in order for these organizations to be able to unveil the whole spectrum of their capabilities. In a more ideal situation this would even be not nationally bounded but in a European or even globalized perspective. Especially, in times were social challenges are abundant, the contribution of RTOs to open innovation initiatives that could solve societal problems through co-creation is promising.

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