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Quality comes first: university-industry collaboration as a source of academic entrepreneurship in a developing country

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Abstract Much in line with what has been happening in developed economies for the past few decades, policy decision makers and industry strategists in developing countries have dedicated increased attention to initiatives that foster University-Industry Collaboration (UIC). The overarching goal is to enhance the capabilities/efficiencies of innovation systems, leveraging the role of universities as generators and disseminators of valuable knowledge, highly concentrated in academia in these laggard nations. In this article we empirically assess the extent to which institutional openness in universities towards UIC linkages affect the generation of knowledge-intensive spin-offs and academic patenting activity in the context of the State of São Paulo, Brazil. We use data for 462 knowledge-intensive entrepreneurial projects related to academics receiving grants from the PIPE Program of the State of São Paulo, Brazil, as well as international patenting behavior for 126 universities and research institutes. Additionally, we have gathered data for UIC activity (2002–2010) in the affected region. The main novelty of our approach is to qualify UIC according to three different dimensions of openness, focusing on UIC levels and objects of collaboration. Results suggest that the quality of linkages (collaboration content) is a stronger predictor of both types of university entrepreneurship than the extent to which universities are connected to firms.

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1 Introduction

It is widely accepted that universities can be influential agents in the context of the knowledge-intensive economy (Czarnitzki et al. 2016; Etzkowitz and Leydesdorff 2000). The impact of their engagement with innovation systems is likely to be felt at regional and national levels (Brown 2016; Cowan and Zinovyeva 2013; Padilla-Meléndez and Garrido-Moreno 2012). This perception has received substantial attention from decision makers in the public and private sectors trying to foster closer connections between academic institutions and businesses in an environment increasingly defined by open innovation (Boh et al. 2016; Lee et al. 1999; Looy et al. 2011; Pfirrmann 1998). For instance, the weight of industrial funding of academic research has grown in the last decades, pinpointing the rising relevance of university-industry collaboration (UIC) for innovation (Gulbrandsen and Smeby 2005).

The overarching goal is to strengthen the capabilities/efficiencies of innovation systems, leveraging the role of universities as generators and disseminators of valuable knowledge. Some of the main conduits for these linkages are related to knowledge transfer activities, such as training, consultancy, R&D and academic spin-offs (Brown 2016). The focus of this article is on the latter, i.e., the generation of new knowledge-intensive ventures as a byproduct of the increased proximity between firms and academia. Literature regards this particular mode of technology transfer as a key transaction mechanism for universities to reach out to markets (Bercovitz and Feldman 2006; Karnani 2012).

An open question is whether such interactions generate substantial learning effects to transform academic institutions into more active generators of knowledge-intensive entrepreneurship (KIE).[1] This subject is not new: the generation of academic spin-offs has served as a performance indicator in many institutions since the 1990′s (Bonaccorsi and Piccaluga 1994), also standing for universities' research prestige (Gras et al. 2008). Notwithstanding these aspects, and the trend of universities becoming increasingly entrepreneurial (Etzkowitz 2004; Pascoe and Vonortas 2015), there is a large variability among universities in terms of start-up generation (Di Gregorio and Shane 2003). In addition, the relationship between research collaboration and spinoffs has not been adequately addressed in the literature and results are inconclusive.

Even lesser attention has been paid to the case of developing countries, which face several constraints in terms of innovation-oriented entrepreneurship (Lederman et al. 2014). These countries not only have limited levels of human capital, they often find it concentrated in universities (Abereijo 2015). Moreover, innovation systems in such countries are characterized by weak, inefficient ties between agents giving additional importance to UIC externalities that might translate into further academic entrepreneurial capabilities. We ask *to what extent does institutional openness in universities towards UIC*

[1] Hirsch-Kreinsen and Schwinge (2014) define KIE as an entrepreneurial activity involving the market exploitation of new opportunities, which can be carried out by individuals or established organizations. These ventures are likely to have significant impacts upon economic growth, social welfare and wealth creation (Beckman et al. 2012).

linkages affect the generation of knowledge-intensive spin-offs in the context of laggard innovation systems?

Originally the target of negative prejudice by the research community, academic entrepreneurship became a legitimate activity (Stuart and Ding 2006), extending the reach of university contributions from traditional forms of technology transfer to a direct vector of economic development (Di Gregorio and Shane 2003). Universities are increasingly perceived as sources of innovation-driven entrepreneurship (Krabel and Mueller 2009; Landry et al. 2006), even though this does not translate into a substantial body of work in terms of investigations concerning research-driven academic entrepreneurship (Goel and Grimpe 2012).

We appraise academic KIE in the State of São Paulo, Brazil, assessing data for 462 KIE projects related to academic personnel (professors, lecturers, researchers, and students) that received grants from the PIPE Program from the São Paulo Research Foundation. This program supports innovative initiatives in small enterprises and it resembles in structure and objectives the Small Business Innovation Research (SBIR) program in the United States (Salles-Filho et al. 2011).

Additionally, we have gathered data from the Brazilian National Council for Scientific and Technological Development (CNPq) Research Group Directory Census, with biennial information available from 2002 to 2010, covering 126 universities and research institutes within the area of investigation. This allowed us to check for three differential aspects of UIC: "Density" (share of cooperating research groups within a university), "Width" (average number of cooperating firms per research group), and "Depth" (object of collaboration). This represents a new and extended way of assessing the issue of UIC from a diversified point of view, offering more detailed results on the topic. Negative binomial models for count data were applied to direct and indirect (via patenting activity) effects of UIC upon academic KIE.

Controlling for the Knowledge Transfer Infrastructure, Intellectual Environment, and Entrepreneurial Traits of projects, results indicate that the "density" of interactions has a detrimental effect on academic KIE, while "width" has minor effects. On the other hand, the quality of collaboration ("depth") seems to be a key ingredient for the generation of desirable externalities. The low propensity of the analyzed innovation system to establish high-quality, R&D-oriented interactions between academia and firms may then negatively influence the emergence of academic KIE from this perspective.

The remaining of the article is structured as follows: Sect. 2 reviews previous research on UIC and academic entrepreneurship, as well as it sets our research hypotheses. Section 3 makes a description of the sample. Section 4 states the analytical rationale. Results can be found in Sects. 5 and 6 concludes with final remarks and implications of our research.

2 University-industry collaboration as a conduit for academic knowledge-intensive entrepreneurship: hypotheses

From universities' perspective, academic spin-offs are an important vehicle for university research commercialization (Landry et al. 2006; Zucker et al. 2002), allowing basic research to reach out to industry (Perkmann and Walsh 2007). The notion of the university as a support entity for evolutionary processes of entrepreneurial ecosystems is not new (Dorfman 1983). This perception rests on the institutional role of universities as sources of ideas, manpower, and entrepreneurs themselves. In the same vein, Etzkowitz (1998) puts the university and academic researchers as fundamental agents of innovation systems through knowledge transfer and entrepreneurial activities.

But the entrepreneurial university does not only generate academic spin-offs. Such institution is also prone to cooperate closely with industrial partners (Etzkowitz 2004). Even though UIC-related impacts are not always straightforward (Bercovitz and Feldman 2006), expected benefits are clear: firms can enhance their innovative potential and reduce R&D costs, while accessing new knowledge in scientific and technological fields (Agrawal 2001). This is basically what makes academic institutions important partners for firms' open innovation strategies (Tether 2002). On the other hand, universities can have access to external funding and boost research productivity (Arza 2010).

As it turns out, universities have increasingly participated in open innovation activities, playing a central role in these interactions (Striukova and Rayna 2015). This can be largely attributed to a decline in innovation self-sufficiency as a function of agents' needs for external sources of knowledge, and cost and risk sharing (Chesbrough 2003). Consequently, within the dynamics of open innovation, U-I links play a central role in innovation processes (Perkmann and Walsh 2007; Roshani et al. 2015).

But this tells only part of the story. It is well established that, at least for developed economies, UIC serves its purpose and it widens the reach of academic knowledge towards innovation systems. However, we propose that these activities generate learning and networking externalities within the academic context, planting the seed for increased entrepreneurial capabilities. This could help explaining why UIC is closely related to the emergence of academic entrepreneurs (Abreu and Grinevich 2013). Such argument is in line with the Triple Helix approach, which states that a closer connection between universities, industry and government improves overall conditions for innovation (Etzkowitz 2004). Hence, outcomes of UIC may be felt not only by incumbents' evolving innovative capabilities, but also by the emergence of new players.

The mechanisms through which these learning effects take place are somewhat simple. First, the historical cognitive distance between university and industrial worlds may hamper academic entrepreneurship from getting into practice (Colyvas et al. 2002). This is not only a condition related to technical aspects of academic research, but it is also associated to the relational character of entrepreneurship. Starting a new venture (particularly an innovation-driven firm) involves the formation of networks by the nascent entrepreneur and depends on existing levels of trust among agents (Stam 2009). For this reason, some authors have put strong emphasis on "entrepreneurial support networks", i.e., business agents that offer complementary resources, relevant information on business dynamics and external sources of support and services to the activity of entrepreneurial ventures (Birley 1985; Kenney and Patton 2005; Neves and Franco 2016).

In line with these propositions, the literature on academic spin-offs provides strong support for the assumption that business networks matter for the emergence of successful academic entrepreneurship (e.g. Hayter 2016; Lockett et al. 2003; Moutinho et al. 2014; Nicolaou and Birley 2003; Shane and Stuart 2002; Walter et al. 2006). Additionally, U-I linkages facilitate the generation of academic spin-offs through the provision of a better understanding of market potential and development of adequate business models (Looy et al. 2011). In its turn, UIC has the potential of bringing beneficial impacts upon academic researchers' social networks, providing a bridge from academia to market (Landry et al. 2006, 2007; Padilla-Meléndez and Garrido-Moreno 2012).

Some authors find close ties to industry to have positive influences on levels of academic entrepreneurship (Krabel and Mueller 2009). Perkmann et al. (2013) identify that academic engagement with business firms is often associated with research commercialization via academic spin-offs or licensing agreements. Results from Arvanitis et al. (2008) suggest the access to industrial knowledge and funding functions as a driver of entrepreneurial propensity in universities. Other authors have achieved similar outcomes, where the level of R&D funding from industry in a university leverages potential for spin-off generation (Gulbrandsen and Smeby 2005; Landry et al. 2006; O'Shea et al. 2005; Powers and McDougall 2005; Rasmussen et al. 2014). Most of these analyses are focused on cases taking place within the United States and other developed economies, but Abereijo (2015) has found analogous evidence for developing countries.

Based on this conceptual and empirical body of work, our expectation is that more "open" academic environments for UIC will lead to an institutional context that offers higher levels of relational capital, market awareness and business orientation for academic entrepreneurs. Our first research hypothesis, thus, takes the following structure:

H1 Universities that establish higher aggregate levels of University-Industry Collaboration will be endowed with stronger capabilities in terms of generating knowledge-intensive academic spin-offs.

Nonetheless, it must be recognized that results leading to this hypothesis do not go unchallenged. For example, by investigating the proportion of universities' research that was sponsored by industry, Di Gregorio and Shane (2003) do not find significant effects of increased UIC in the entrepreneurial propensity of academics. Lee (2000) finds that only a minority of academics perceive UIC as a source of business opportunities. Landry et al. (2006) suggest that UIC may bind academic researchers to directly transfer research outputs to firms, negatively influencing their entrepreneurial propensity.

Another reasonable explanation for this variability in research findings is that not all collaborations are made alike. Therefore, the mere analysis of amount of UIC as a conduit to academic KIE may be misleading. The key element in these dynamics is the object of interactions,[2] since the knowledge exchange content can be highly representative of the learning curves that are at play. Arza (2010) proposes that proactive, strategic behavior of firms is much more likely to lead to the emergence of academic entrepreneurship. For Thursby and Thursby (2002), high-quality engagement is mainly oriented towards R&D interactions, but not routine training and consulting activities, where only the first functions as a driver of universities' patenting and entrepreneurial trends.

This is probably because University-Industry links with high relational involvement (joint production of knowledge, innovation and research) are the ones that represent a true network-based mode of innovation (Perkmann and Walsh 2007). In this case, the expectation of positive externalities within the academic entrepreneurial environment must take into account how relationships unravel. This poses a difficulty for academic KIE in immature innovation systems, where UIC is fundamentally based on consultancy and training activities (Arocena and Sutz 2001; Fernandes et al. 2010). These linkages are often representative of operational (rather than strategic) collaborations, with core focus on cost savings (Rapini et al. 2009). In developed economies, instead, increase in companies' knowledge base has been reported as the main reason behind U-I partnerships (Caloghirou et al. 2001). As a result, the generation of spin-offs is not a common outcome from UIC in

[2] Illustratively, Schartinger et al. (2002) classify types UIC into four groups: (i) joint research; (ii) contract research; (iii) personnel mobility; and (iv) training activities. In Brazil, UIC can be classified according to fourteen groups, ranging from basic and applied scientific research to material supply and outsourced training activities.

developing economies (Fernandes et al. 2010). These discussions lead us to propose the following research hypothesis:

H2 Universities that establish University-Industry Collaborations of higher quality will be endowed with stronger capabilities in terms of generating knowledge-intensive academic spin-offs.

The next sections are focused on presenting and discussing the empirical approach related to our research hypotheses, as well as discussing additional control variables and specifications of econometric models.

3 Data description

Our data sample comprehends 126 higher education institutions (HEIs) and research institutes in the State of São Paulo, Brazil.[3] These organizations were included in the Brazilian Census from the CNPq Research Group Directory, with biennial data available from 2002 to 2010 (5 periods—more recent versions of the census have not been made public). Institutions did not necessarily participate in every census, thus configuring an unbalanced panel.

For every institution we have information on research groups that have established cooperative projects with industry, with how many companies each institution has interacted with, and the content of the collaboration (see Table 1 for an overview of the UIC context according to our sample). These data allow us to represent the degrees of UIC that constitute our proxy of university openness. While there is no guarantee that the dataset presents a comprehensive picture of the entire population of research groups and their respective collaborations with industry—the census is based on self-reports by research groups' leaders—the fact that updated information on these groups is required for accessing public grants gives us confidence that the data closely resembles the actual situation of UIC in the State of São Paulo.

The other key aspect of this research concerns the emergence of academic knowledge-intensive entrepreneurship. The grants of the PIPE program (Innovative Research in Small Enterprises) are used as a proxy for KIE activity in the State. This initiative is managed by the São Paulo Research Foundation (FAPESP) and it subsidizes entrepreneurial projects with high levels of knowledge intensity and innovative potential. It was created in 1997, inspired by the Small Business Innovation Research (SBIR) program in the United States. After a careful analysis of information from projects and entrepreneurs, 462 PIPE projects could be associated with academic entrepreneurs for the period 2002–2011 (out of a total of 730 projects). Institutional affiliation includes both academic personnel (faculty and researchers) and temporary staff (students and post-docs). This is justified by the perspective that graduate students and post-doctoral researchers are important agents in the context of academic startups (Boh et al. 2016).

We allow for a lag between entrepreneurial activity and its institutional correspondence in terms of UIC. This was done in two steps: first, institutional affiliation was considered valid up to two years before the start of the project. Second, KIE projects were associated

[3] Even though the vast majority of institutions in our sample consist in universities, there are also several research institutes. Following the extant literature on UIC, we adopt a flexible view of the term "university" to also include these additional cases. Hence, whenever we refer to UIC (or universities as a whole), research institutes are part of the discussion (Cohen et al. 2002; Zawislak and Dalmarco 2011)..

Table 1 UIC overview in the State of São Paulo, Brazil

Census	Research Groups	Interacting Research Groups	Cooperating Firms[a]	R&D-oriented Collaborations	Training and Consultancy-oriented Collaborations	Total[b]	% of R&D-oriented Collaborations
2002	4338	253	511	752	359	1111	67.69
2004	5540	464	901	1359	599	1958	69.41
2006	5678	527	985	1413	644	2057	68.69
2008	5908	572	1276	1545	650	2195	70.39
2010	6314	745	1596	1809	977	2786	64.93

[a] Cooperating firms are computed according to each established UIC. Hence, if a company cooperates with several groups it will be counted or each one of these links

[b] The number of collaborations exceeds the number of companies and research groups because each company can establish up to 3 different kinds of UIC agreements with each group

with each wave of the Research Group Census until the next census took place. Since the census took place every two years, we ascribed academic KIE projects to previous UIC data. Hence, the 2002 UIC information is associated with entrepreneurial projects taking place from January, 2002 until December, 2003. This procedure is valid for every period in the sample, explaining why KIE data goes until the end of 2011 while the last UIC census is available for 2010.[4]

We recognize that this dataset represents only a fraction of the academic KIE activity in the State of São Paulo. However, this source provides the opportunity of identifying the year of entrepreneurial projects' start, as well as identification of entrepreneurs. This allows us to gather complementary data on institutional affiliation, field of knowledge, and professional and academic backgrounds of individuals (Curriculum Lattes Database).[5] Furthermore, it offers an interesting source of "certified" knowledge-intensive entrepreneurs selected after careful expert review. We only consider approved PIPE grants in the evaluation in order to filter for business endeavors that can actually be associated with knowledge-intensive entrepreneurship. Unsuccessful projects are highly likely to not fit into this classification, thus not warranting that they are representative of KIE activity.

Further variables of interest are outlined in Table 2. We have assigned each variable to a particular block. Besides the core dependent variable (KIE_Projects), four other blocks are added to the analytical exercise, namely: U-I relationships, Knowledge Transfer Infrastructure, Intellectual Environment, and Entrepreneurial Traits. This particular set of variables follows suggestions and similar approaches undertaken by several authors (e.g. Arvanitis et al. 2008; Audretsch et al. 2016; Di Gregorio and Shane 2003; Dietz and Bozeman 2005; Goel and Grimpe 2012; Landry et al. 2006; Looy et al. 2011). Descriptive statistics of analytical variables are shown in Table 3.

The set of variables in Table 2 is arguably more appropriate for the study of university openness and academic entrepreneurship than what has been used elsewhere (usually share of university research funded by industry). For instance, we are able to identify the object of interaction (variables Depth and Depth_2), an issue that is likely to affect the outcomes of collaboration (Fernandes et al. 2010). Moreover, "Density" and "Width" allow assessing the extent of university association with industry and the different companies that collaborate with research groups. These aspects offer the possibility of understanding different scopes of UIC and the corresponding effects on academic entrepreneurship. However, we must highlight that aggregate data does not necessarily reflect a direct relationship between research groups' openness and KIE activity. The unit of analysis is the university, thus UIC indicators should be understood as representations of an institutional culture (not differently than what has been done in Di Gregorio and Shane, 2003 for university funding).

Another characteristic of our dataset is the significant concentration of KIE projects within some key institutions. 71.6% of the 462 PIPE Projects included in the dataset belong to only four universities: University of São Paulo (USP), University of Campinas (UNICAMP), State University of São Paulo (UNESP), and Federal University of São Carlos (UFSCAR). All of these institutions have multiple campuses, spreading their geographical influence across the State. A further evaluation of the sample also helps shedding light on concentration: Gini coefficients for each university-year observation of KIE projects ranges

[4] Additional possibilities of time lags are taken into account in econometric models, aiming at identifying longer-term connections between university openness and academic entrepreneurship..

[5] This database is maintained by the Brazilian Council for Scientific and Technological Development and registration is required for scholars (professors, researchers and students)..

Table 2 Analytical variables

Code	Block	Description	Source
KIE_Projects	Dependent	Number of PIPE projects granted to a researcher affiliated with a university in the State of São Paulo in a given period. Affiliations were considered for people involved with universities (as students, researchers or faculty) up to 2 years before PIPE grants. Multiple affiliations were assigned according to number of hours worked at each institution	São Paulo Research Foundation
Density	U-I Relationships	Share of research groups that have performed interactions with industry. Only formal groups registered at the National Directory of Research Groups are considered	Brazilian Council for Scientific and Technological Development—Census data available from the Research Group Directory
Width		Average number of cooperating firms per research group that has performed interactions with industry	
Depth		Dummy variable. It takes the value of 1 whenever there is a predominance of UIC based on Research, Development and Engineering (“deep” relationships). It takes the value of 0 otherwise (predominance of training activities, consulting and supply of materials for research activities).	
Depth_2		Dummy variable. It takes the value of 1 whenever there is presence of long term commitment to scientific research between partners (basic and applied science)[a]. It takes the value of 0 otherwise (absence of these activities)	
Entrep_Infra	Knowledge Transfer Infrastructure	Dummy variable. It takes the value of 1 whenever the university-year has (or is formally affiliated with) a business incubator and/or science park; 0 otherwise	Institutional websites
TTO		Dummy variable. It takes the value of 1 whenever the university-year has (or is formally affiliated with) a technology transfer office; 0 otherwise	

Table 2 continued

Code	Block	Description	Source
Res_Eminence	Intellectual Environment	Dummy variable. It takes the value of 1 whenever the university-year is above the 75th percentile of the sample in terms citations (Web of Science) per registered research groups; 0 otherwise	Web of Science
Res_Intensity		Dummy variable. It takes the value of 1 whenever the university-year is above the 75th percentile of the sample in terms of total publications (Web of Science) per registered research groups; 0 otherwise	
Patents		Patent priority deposits associated with each university-year of the sample (worldwide, no duplication)	Orbit Intelligence
PhD %	Entrepreneurial Traits	Share of KIE projects assigned to a university-year that are granted to PhDs.	Lattes Platform (Academic CVs database)
Prof_Exp %		Share of KIE projects assigned to a university-year that are granted to entrepreneurs with previous non-academic professional experience.	
STEM %		Share of KIE projects assigned to a university-year that are belong to STEM field.	

[a] This assessment also allows to look at UIC that is more closely related to bidirectional knowledge flows between firms and academia. Other specifications often refer to unilateral knowledge transfer. As noted by Meyer-Krahmer and Schmoch (1998), bidirectional knowledge flows (knowledge exchange) are likely to provide more positive results for academia and industry

between .92 and .94 in the periods analyzed. This high concentration might be related to localized social influences that academic entrepreneurs exert upon its colleagues, creating an institutional culture that favors entrepreneurial activity.[6] This proposition is in accordance with previous studies in the field of intra-organizational academic culture concerning entrepreneurship (Stuart and Ding 2006).

4 Models and estimations

Estimations of econometric models are developed in a two-stage structure (Fig. 1 illustrates a simplified version of the approach). The first stage aims at checking for direct connections between KIE_Projects and the remaining analytical blocks (U-I Relationships, Knowledge Transfer Infrastructure, Intellectual Environment, and Entrepreneurial Traits). For these estimations, each block is added at a time cumulatively. Because the timeframe

[6] We would like to thank Chris Hayter for pointing this out.

Table 3 Sample description

Variable	Obs.	Mean	S.D.	S.D. within Universities	S.D. between Universities	Min.	Max.
KIE_Projects	630	.73333	3.838	18.581	34.699	0	53
PhD %	630	.12738	.31928	.26266	.2167	0	1
Prof_Exp %	630	.1267	.31974	.27776	.20168	0	1
STEM %	630	.12363	.3146	.2638	.20855	0	1
Density	485	.092218	.1456	.082218	.147	0	1
Width	485	10.122	14.044	.91026	11.207	0	86.667
Patents	630	2.947	16.086	5.377	15.398	0	187

Variable	Observations	Frequency (0)	Frequency (1)
Depth	485	267 (55.1%)	218 (44.9%)
Depth_2	458	231 (50.4%)	227 (49.6%)
TTO	630	543 (86.2%)	87 (13.8%)
Entrep_Infra	630	555 (88.1%)	75 (11.9%)
Res_Eminence	630	505 (80.2%)	125 (19.8%)
Res_Intensity	630	509 (80.8%)	121 (19.2%)

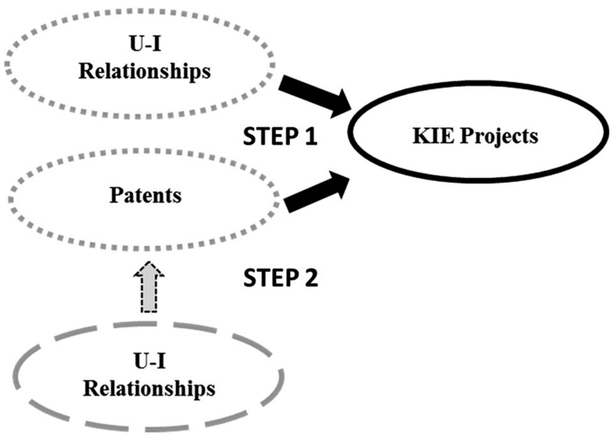

Fig. 1 Analytical rationale of the two-stage approach

may render misleading results due to longer-term relationships between the U-I Relationships block and the dependent variable, an additional set of estimations is provided for lags of these variables in a complete version of the model (t-1). This procedure is consistent with the proposition that university openness might generate internal capabilities that take time to mature and become actual KIE projects able to receive grants from external sources.

The second stage of the approach consists in an indirect form of evaluating predictors of academic KIE through its impacts on universities' patenting behavior (assuming that patents may translate into other forms of technology transfer, such as entrepreneurship). If on the first set of models Patents was inserted within the Intellectual Environment Block, now it assumes the role of dependent vector. We do so based on an expectation that this variable performs a positive and significant role as predictor of KIE_Projects in the first stage, and that U-I collaboration may lead to stronger patenting activity, provided that patents represent a key form of intellectual property management in knowledge transfer activities (Salimi et al. 2015; Zucker and Darby 2001). If this is the case, even the lags introduced previously may fail to capture this indirect channel of impacts arising from stronger and deeper UIC. In this stage, since KIE projects are not part of the analysis, the Entrepreneurial Traits block is dropped from estimations.

Econometric procedures applied to the sample, considering the dependent variable in both steps outlined above, is that of Generalized Estimating Equations (GEE) for count data. This approach is suitable for our analysis due to the structure of the dependent variables, the possibility of autocorrelation in standard errors, the large share of universities with no KIE projects over time, and the unobserved unit-level heterogeneity that can influence the emergence of entrepreneurial activity. Tests for over-dispersion warranted the use of Negative Binomial estimations.

5 Results

Following the structure of econometric estimations, results of step 1 (KIE_Projects as dependent variable) are offered in Table 4 and those of step 2 can be found in Table 5. Initially, eight models are analyzed, adding predictor blocks one by one and using separately the two variables for UIC "depth" (Depth and Depth_2). Firstly, it is fundamental to check the validity of our two-step analytical procedure by turning to the evaluation of the variable Patents. As it can be seen in Table 4, patenting output functions as a solid, significant predictor for entrepreneurial activity, even though its impact is not very large.[7] It is thus reasonable to accept that our analytical rationale is valid for this particular sample.

The overall impression of the results regarding the effects of university openness on university entrepreneurship are mixed. Contrary to expectations, the density of relationships, i.e., the share of research groups that are involved in UIC in a given university-year is significant in most estimations, but with a negative sign. This also holds for the interpretation of the lagged (t-1) variable (models 4 and 8). The large coefficients of Density can be partially explained by the structure of this variable (a ratio). On the other hand, in step 2 (where university patenting activity is the dependent variable), Density does not enter any specification (Models 9–14) as a significant predictor.

As a first diagnostic we find no evidence that the extent of industry collaboration of university research groups has positive effects on academic entrepreneurial activity. In some cases it seems to be related to decreasing levels of KIE. One can think of this as introductory evidence into the importance of the qualitative aspects present in UIC: more does not necessarily translate into better (in terms of KIE activity and patenting behavior). Although contrary to our expectations, this result is not entirely surprising. Using just the level of university research funding by industry to proxy UIC, Di Gregorio and Shane

[7] Some caution must be taken for the appropriation of estimations in Models 9–14. Patents might also be somewhat associated with institutional size, and in the absence of a proper size control it is difficult to disentangle these effects. Nonetheless, other variables also help to control for size effects (Res_Intensity and Entrep_Infra), thus helping to control for potential instabilities in the model.

Table 4 Negative binomial models 1–8 (step 1—KIE_Projects dependent)

Block		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
U-I Relationships	Density	−2.409** [1.169]	−.210 [.882]	−3.381*** [1.145]	–	−2.611** [1.235]	−.235 [.930]	–3.414*** [1.132]	–
	Width	.063 [.108]	.134* [.077]	.167* [.086]	–	.046 [.115]	.154* [.081]	.128 [.085]	–
	Depth	1.443*** [.323]	.667** [.289]	.293 [.318]	–	–	–	–	–
	Depth_2	–	–	–	–	1.906*** [.391]	1.008*** [.352]	.678* [.366]	–
Knowledge Transfer Infrastructure	Entrep_Infra	2.233*** [.270]	1.370*** [.229]	1.430*** [.240]	1.174*** [.245]	2.251*** [.284]	1.310*** [.236]	1.522*** [.237]	1.396*** [.245]
	TTO	1.317*** [.285]	.540** [.237]	.081 [.231]	.270 [.248]	1.346*** [.300]	.547** [.244]	.147 [.228]	.363 [.239]
Intellectual Environment	Res_Eminence	–	.521* [.284]	.707** [.295]	1.049*** [.330]	–	.645** [.307]	.675** [.321]	1.040*** [.352]
	Res_Intensity	–	.784*** [.287]	.095 [.317]	-.066 [.342]	–	.677** [.303]	.146 [.327]	−.110 [.351]
	Patents	–	.015*** [.002]	.011*** [.002]	.012*** [.002]	–	.016** [.003]	.010*** [.002]	.011*** [.002]
Entrepreneurial Traits	PhD %	–	–	1.102*** [.326]	.904*** [.335]	–	–	.971*** [.330]	.876** [.344]
	Prof_Exp %	–	–	1.515*** [.309]	1.452*** [.336]	–	–	1.584*** [.321]	1.650*** [.373]
	STEM %	–	–	1.413*** [.295]	1.512*** [.316]	–	–	1.389*** [.303]	1.309*** [.316]

Table 4 continued

Block		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
U-I Relationships (with lags)	Density t-1	–	–	–	−3.574*** [1.380]	–	–	–	−3.208** [1.388]
	Width t-1	–	–	–	.092 [.099]	–	–	–	.004 [.095]
	Depth t-1	–	–	–	.598* [.335]	–	–	–	–
	Depth_2 t-1	–	–	–	–	–	–	–	.955** [.453]
Time dummies	Dummy 2002–2003	1.403*** [.455]	.840** [.404]	.847* [.440]	–	1.267*** [.482]	.545 [.432]	.675 [.455]	–
	Dummy 2004–2005	1.961*** [.417]	1.842*** [.329]	1.413*** [.324]	1.482*** [.331]	2.014*** [.437]	1.851*** [.339]	1.381*** [.328]	1.482*** [.325]
	Dummy 2006–2007	2.182*** [.394]	1.987*** [.319]	1.554*** [.312]	1.749*** [.315]	2.199*** [.412]	2.049*** [.327]	1.510*** [.317]	1.710*** [.311]
	Dummy 2008–2009	1.455*** [.408]	1.141*** [.327]	.740** [.318]	.920*** [.318]	1.358*** [.424]	1.033*** [.337]	.614* [.320]	.806*** [.311]
	Valid N	485	485	485	374	458	458	458	351
	alpha	1.822*** [.387]	.593*** [.220]	.269*** [.091]	.259*** [.092]	1.883*** [.418]	.563** [.223]	.216** [.090]	.186** [.090]

Std. Errors in brackets

* sig. at 10%; ** sig. at 5%; *** sig. at 1%

Table 5 Negative Binomial Models 9–14 (Step 2—Patents dependent)

Block		Model 9	Model 10	Model 11	Model 12	Model 13	Model 14
U-I Relationships	Density	−.859 [1.413]	.012 [1.344]	–	−1.838 [1.523]	−.845 [1.438]	–
	Width	.038 [.164]	.063 [.142]	–	.212 [.182]	.226 [.158]	–
	Depth	2.013*** [.429]	1.720*** [.430]	–	–	–	–
	Depth_2	–	–	–	1.856*** [.469]	1.392*** [.477]	–
Knowledge Transfer Infrastructure	Entrep_Infra	2.647*** [.377]	2.222*** [.383]	2.154*** [.401]	2.721*** [.372]	2.280*** [.388]	2.215*** [.411]
	TTO	2.929*** [.360]	2.621*** [.371]	2.893*** [.415]	2.746*** [.370]	2.606*** [.370]	2.987*** [.422]
Intellectual Environment	Res_Eminence	–	−.217 [.543]	−.521 [.589]	–	−.198 [.531]	-.551 [.593]
	Res_Intensity	–	1.327** [.528]	1.252** [.574]	–	1.287** [.516]	1.234** [.588]
U-I Relationships (with lags)	Density t-1	–	–	-.343 [1.665]	–	–	−.699 [1.896]
	Width t-1	–	–	.342** [.165]	–	–	.287* [.171]
	Depth t-1	–	–	.875* [.496]	–	–	–
	Depth_2 t-1	–	–	–	–	–	.810 [.594]
Time dummies	Dummy 2002–2003	1.949*** [.557]	1.862*** [.533]	–	1.861*** [.562]	1.876*** [.539]	–
	Dummy 2004–2005	1.161** [.549]	.943* [.534]	1.400*** [.535]	1.100** [.545]	.968* [.534]	1.410** [.549]
	Dummy 2006–2007	.731 [.534]	.734 [.511]	1.419*** [.507]	.763 [.524]	.806 [.507]	1.403*** [.514]
	Dummy 2008–2009	1.402*** [.539]	1.285** [.512]	1.649*** [.510]	.954* [.533]	.860* [.512]	1.492*** [.519]
	Valid N	485	485	374	458	458	351
	alpha	5.449*** [.949]	4.967*** [.886]	4.054*** [.862]	5.126*** [.960]	4.648*** [.896]	4.012*** [.903]

Std. Errors in brackets

* sig. at 10%; ** sig. at 5%; *** sig. at 1%

(2003) also reached similar conclusions. Nonetheless, the presence of significant and negative signs in some coefficients for this variable point towards the possibility of decreasing returns to collaboration, where extensive interactions with industry may have detrimental effects on researcher activities related to scientific knowledge production (in favor of applied technological problems), possibly hampering science-based, knowledge-intensive academic entrepreneurial endeavors (Arza 2010).

"Width", which represents the average number of firms involved in UIC projects, is slightly significant in Models 2, 3 and 6. This variable is also found to be a positive and significant predictor of patenting activity in its lagged version in models 11 and 14. This might indicate some sort of structural, long-term impacts of UIC upon academic KIE activity, leading to non-immediate learning effects of universities' association with industry. Nonetheless, there is a lack of robustness in the results for Width, allowing these discussions to be merely speculative. Consequently, considering the combined effects of "Density" and "Width", our empirical results point towards the rejection of the first research hypothesis. Hence, in the context of the State of São Paulo, Brazil, the extent to which universities are involved in UIC does not seem to exert positive impacts on academic entrepreneurship or patenting behavior (indirect effects).

The following variables of interest (Depth and Depth_2) address a further qualification of UIC processes, since they stand for the content (or object) of interactions (what we define as "relational quality"). Both of these variables perform significant and positive roles in most estimations, although with decreasing reliability once complete models are assessed. Interestingly, "Depth_2″ has higher coefficients than "Depth" when we take entrepreneurial activity as the dependent vector—the opposite situation happens when patenting activity is addressed. An overall evaluation of these outcomes suggests the acceptance of our second research hypothesis, i.e., the quality (or content) of UIC appears to be related to stronger academic entrepreneurial activity (from the spin-off and patent perspectives). This outcome is interesting as it complements the perception of openness level with an idea of openness quality, an issue that has been poorly tackled by the extant literature in the field.

The remaining variables (controls) included in the models offer interesting insights. The Knowledge Transfer Infrastructure block plays an important role in shaping the environment for academic KIE in this sample. This is particularly true for the case of university science parks and business incubators (Entrep_Infra), which is strongly and robustly related to the dependent variables in both steps 1 and 2.[8] Technology Transfer Offices (TTO) are not very good at predicting KIE activity directly, but the effect on patenting behavior is noticeable (and even larger than those found for physical infrastructure). Results for TTOs are partly in line with previous findings that do not find strong support for these offices in terms of technology transfer (Czarnitzki et al. 2016). As it is known, experienced and market-oriented staff are critical assets for TTOs to realize their full potential (Siegel et al. 2003). However, public institutions in Brazil (those concentrating most KIE activity in our sample) do not have flexibility in terms of hiring and managing human resources. This includes the impossibility of commissioning staff according to technology transfer results. In its turn, private universities, with some few exceptions, do not even have TTOs. These institutional features of the São Paulo entrepreneurial system may signal a substantial lack of maturity in designing avenues and incentives for UIC. In contrast, our analysis identifies that TTOs are positively related to patenting activity, an area that requires more bureaucratic action than market knowledge.[9]

Variables included in the Intellectual Environment block provide unstable results. Patents is included as a predictor only in step 1, and, as already pointed out, it is robustly positive and significant. On the other hand, Res_Eminence (as a proxy for institutional

[8] This variable also functions as a proxy for institutional size, as most science parks and incubators are associated with large universities.

[9] As per the roles of TTOs in Brazil, providing support for patent registration is more in line with these offices' remit than developing external business opportunities for academic entrepreneurs.

impact) is only positive and significant in models 2, 3, 4, 6, 7 and 8 (KIE projects). In step 2 it loses its statistical significance and turns negative. In contrast, Res_Intensity is weakly associated with KIE_Projects but plays a significant and positive role as a predictor for the generation of patents. In other words, university strength in quality publications is positively related to KIE projects whereas strength in terms of overall quantity of publications is positively related to patents.

Lastly, project-specific variables (Entrepreneurial Traits block) are only included in the first step of estimations. In all cases, as expected, the share of PhDs, STEM projects and academic with previous non-academic professional experience are positively and significantly related to KIE activity. While the share of PhDs and STEM projects might have their significance affected by the selection characteristics of the PIPE projects, it is noteworthy that the importance of earlier business-oriented activity by scholars might pose some implications for entrepreneurial policy in Brazil. Under current regulations, professors and graduate students at public universities (those with the highest concentration of the most academic KIE projects in our sample) can find it very hard to coordinate academic and non-academic positions within legal limits.

6 Concluding remarks

This article has dealt with the dynamics of academic KIE emergence in a laggard innovation system as a function of institutional engagement in University-Industry Collaboration. We departed from two hypotheses related to the idea of learning effects (externalities) arising from UIC within academic environments, dealing with both direct effects on knowledge-intensive entrepreneurial (KIE) projects and indirect effects through patenting behavior. Results strongly suggest that the quality of linkages (hypothesis 2) is a stronger predictor of entrepreneurship than the level (or quantity) of connections (hypothesis 1).

To dig a little deeper into these issues, some contextualization is necessary. Data from the 2011 Brazilian Innovation Survey (PINTEC) show that, in the State of São Paulo, about 2.6% (1119 out of 43,469 responding companies) of the sample develop interactions with universities and research institutes. More importantly, only about half of these firms (52.6% or 589 companies) establish R&D-oriented activities (instead of technical, training and consulting forms of cooperation), what we define as “deeper/higher quality” relationships. Additionally, three quarters of companies with collaborative processes (75.7% of 2749 firms) believe UIC to be of little or no importance for innovative processes. These data, along with recent trends are presented in Appendix 1. Although throughout the 2000′s the numbers of companies establishing UIC has grown, this does not translate into neither a relative evolution of firms involved in higher quality (R&D-oriented) partnerships with universities or research institutes, nor into academia being perceived by corporations as a critical player for open innovation strategies. This descriptive outline of the environment for UIC in the area under study has implications for the evaluation of our econometric results.

First, it helps explaining why the “density” and “width” of relationships have mixed and non-robust outcomes for estimations. UIC does not seem to be a priority for companies embedded in this innovation system. This is likely to affect the objectives of collaboration and, hence, the quality of knowledge exchanges. Second, and complementarily, the “depth” of UIC seems to be behind most of the positive impacts that university openness can offer in terms of academic KIE (directly and via patenting behavior). This may be considered as problematic for the entrepreneurial environment in a developing country context due to the scarcity of R&D intensive U-I interactions that may negatively affect the universities' ability to spawn technology transfer.

In terms of S&T policy implications, a straightforward outcome of these findings would be towards promoting deeper linkages between companies and universities. Nonetheless, this may represent a structural challenge that is more closely related to the lack of R&D orientation in Brazilian firms than a specific problem within the dynamics of UIC. In other words, difficulties to foster higher quality relationships between market and academia in Brazil are likely to be related to more fundamental economic determinants of the innovative activity in this country. Hence, a stronger coordination between industrial policy, regulation of the competitive environment and the institutional framework of UIC is needed in order to build an environment conducive to the deep links we are discussing. Following our findings, the respective entrepreneurial impacts would then be facilitated.[10]

Surprisingly, the density of UIC linkages is negative and significant in several of our models. Although these results are not entirely robust, they ask for some attention. To a limited extent, they suggest that universities that develop larger connections with industry might find themselves in worse positions to launch knowledge-intensive entrepreneurial ventures. Considering the requirements posed by our proxy of entrepreneurship (PIPE Program), it is reasonable to propose that an excessive orientation towards collaborative projects with markets may have detrimental effects on the capacity of generating innovative start-ups. The motives behind this condition are not clear and deserve further attention in upcoming studies. Speculatively we might question if there are constraints for academics to exploit research economically when the institutional is more strongly involved with external partners.

Other findings of interest include the results over the importance of Technology Transfer Offices in patenting but relative unimportance in the entrepreneurial process. It is important to stress that the institutionalization of TTOs is relatively recent in Brazil, since most of these offices have been created as a response to the 2004 Innovation Law, which, among other things, regulates UIC. Thus, it is possible that the examined TTOs had not yet established sufficient levels of business development capabilities necessary to promote higher levels of academic spin-offs (Lockett and Wright 2005).

A careful look at our data and results clearly indicates a bifurcation of the university system in the State of São Paulo. The higher education system in this region is strongly oriented towards training and teaching at undergraduate levels. By and large, universities in this group are not engaged in KIE. On the other hand, those few universities that produce impactful scientific and technological research understand entrepreneurship as part of their mission. They also create/associate with science parks and business incubators, ultimately presenting consistently better results in terms of academic KIE. However, the valid regulatory framework in Brazil during the period of analysis[11] hampers closer approximation between academic staff and industry. More recent developments in Brazilian law try to address this issue by allowing researchers to develop their work in companies, as well as sustaining the academic position while owning their own venture. Unfortunately, it is not

[10] We would like to thank Professor Jeewhan Yoon for highlighting the importance of this discussion.

[11] This institutional background is mandatory only to public universities and research institutes. Nonetheless, in Brazil, these units respond for most of cutting-edge research and represent the main generators of academic spin-offs in our sample.

clear yet when these propositions will be fully effective in the academic context of Brazilian universities and research institutes.

Our research is subject to limitations. The clearest limitation has been the lack of data on various dimensions of interest, particularly on KIE activity. Since we are using data from a specific program, we are not covering the population of academic KIE but a subset of it. To justify our choice, it is important to bear in mind that PIPE grants give us quality information on previously evaluated knowledge-intensive ventures (since projects are assessed and selected according to their innovative content) and also tell us who the responsible entrepreneur is. This is a fundamental link to access their curriculum for institutional affiliations—going back to the time the project was launched—and professional and academic traits, both fundamental for our models.

Several future research avenues arise from the findings reported in this article. First, it would be interesting to get a better perspective on the association between academic patenting and university spin-offs. Second, improved understanding of whether KIE springing directly from university-industry collaboration shows different development cycles and rates of success (following the literature in Sect. 2) would really boost policy arguments in that direction. Lastly, going beyond the State of São Paulo to replicate results in a broader set of developing nations/regions would add validity to the general argument.

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Appendix 1

See Table 6.

Table 6 Brazilian Innovation Survey (PINTEC): UIC trends in the State of São Paulo

PINTEC	Total companies in the survey	Companies with collaborative processes	Companies with UIC	UIC object (only companies with UIC)		UIC importance (companies with collaborative processes)		
				R&D activities	Others	High	Medium	Low/No relevance
2003	29,650	347 (1.17%)	219 (.74%)	151 (69%)	68 (31%)	85 (24%)	54 (16%)	208 (60%)
2005	31,990	933 (2.92%)	330 (1.03%)	159 (48%)	171 (52%)	141 (15%)	93 (10%)	700 (75%)
2008	36,549	1549 (4.24%)	621 (1.70%)	324 (52%)	297 (48%)	288 (19%)	169 (11%)	1092 (70%)
2011	43,469	2749 (6.32%)	1119 (2.57%)	589 (53%)	530 (47%)	410 (15%)	258 (9%)	2080 (76%)

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