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Abstract

Literature highlights the importance of university spin-offs and their assistance mechanisms. However, there is little evidence on how to select and operationalize the appropriate variables for assessing this type of firms. This paper provides tools to estimate and interpret the efficiency of spin-offs embedded in university-based support mechanisms. We thus contribute to the literature in at least two ways. First, we identify the specific inputs and outputs that are required by both the organisational and regional development perspectives. Second, an application considers a unique sample of spin-offs created at Catalan universities within a regional support programme. Main descriptive results indicate that many efficient spin-offs have formal technology transfer agreements and emerge from universities with more technological background. Second stage analyses show that higher levels of innovation and specific academic knowledge or experience related with the university of origin are associated with higher efficiency.

Keywords: university spin-off, regional development, efficiency, entrepreneurship, technology transfer, innovation

JEL codes: M1, R1

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1. Introduction

This paper devises and applies a multidimensional approach for assessing the efficiency of technology-based spin-offs that benefited from both financial and infrastructure support. It does so in a regional development scenario by providing evidence on spin-offs created within a special case of technology transfer network placed at Catalan universities (an autonomous community in the northeast of Spain). This research is thus embedded in the literature on generating innovation technology for regional development and, more generally, on the importance of SMEs for economic growth. Over the past decades, the potentially positive influence that SMEs have on economic development has convinced various public administrations to establish support systems linked to these types of firms (RUPRI 2006). Early studies scrutinised the increasing number and many times improved survival rate of SMEs (*e.g.* Cromie 1991; Hawkins 1993; White and Reynolds 1996). Also, seminal research from the 1980s and 1990s investigated more systematically how assistance policies to business creation impact positively on job creation (Birley 1987; Kirchhoff and Phillips 1988; Storey 1994), economic growth (Sexton 1986; Dubini 1989; Wennekers and Thurik 1999), or innovation (Drucker 1985; Pavitt *et al*. 1987; Acs and Audretsch 1988).

Linked to this stream of literature, more recent studies indicated that SME creation increasingly originates from commercialised research that is attained via university-based innovations (Carayannis 1998; Siegel *et al*. 2003; Vohora *et al*. 2004; Clarysse *et al*. 2005; Lockett *et al*. 2005). Accordingly, and considering that the correct incentives are in place, universities and governments moved to institute support systems in a variety of countries. The implied underlying efforts of public research institutions and the business sector to collaborate towards firm creation have been understood, following the influential contribution of Etzkowitz (1998, 2003 and 2004), as the university's "third mission". This mission is nowadays predominantly present in European universities, which traditionally focused on teaching and academic research, while technology or knowledge transfer remained somewhat neglected. To further link theory to practice, Etzkowitz designed the Triple Helix model to highlight that university, industry and government must coordinate and cooperate towards achieving the common goal of knowledge-based economic development. On most occasions, this objective is pursued through spin-off firms that employ university knowledge.

Given the now obvious importance of academic spin-offs, a newer array of research examined their impact on wealth creation and regional development (Harmon *et al*. 1997; Hindle and Yencken 2004; Ma and Tan 2006). To name just a few specific findings, university spin-offs are identified as sources of job creation, as intermediaries between basic and applied research, or even as drivers of economic change towards a knowledge-based economy (Wright *et al*. 2004). Still, there is scarce evidence from quantitative analyses of spin-offs' performance and its associated factors, both seen through firm or regional development lenses. Even if there are quite a few single case papers describing the spin-off phenomenon promoted at universities (*e.g.* Jacob *et al*. 2003; Carayol and Matt

2004; Debackere and Veugelers 2005; Acworth 2008), this line of research did not measure the efficiency of such companies or their corresponding support mechanisms. However, organisation studies usually assume that assessing efficiency represents a crucial aspect as it is closely linked to meeting financial targets and achieving sustainability and competitiveness.

Using this organisational performance justification, a growing literature links efficiency with technology transfer. Most existing efforts turn to frontier efficiency methods. For instance, Chapple *et al*. (2005) used non-parametric Data Envelopment Analysis ((DEA), see, *e.g.*, Ray (2004) for details on this technique) to study the efficiency of UK university technology transfer offices (TTOs). They concluded that managers' business skills should be upgraded and found decreasing returns to scale indicating that TTOs should be smaller. Contrasting results are reported by Siegel el al. (2003), who employed parametric frontier methods and revealed that TTOs experienced constant returns to scale. A more comprehensive study of the efficiency of university technology transfer is included in Anderson *et al*. (2007). These authors employed DEA and found significantly higher technology transfer efficiency in leading universities and scrutinised differences between public versus private universities. On a related note, and by means of example, DEA was also used to estimate the efficiency of small manufacturing firms (Alvarez and Crespi 2003) or of science parks (Thursby and Kemp 2002), and more recently was indicated as an appropriate way to operationalize innovative entrepreneurial opportunities (Anokhin *et al*. 2011).

We build on this latter research current and tackle various challenges that emerge from existing studies. A first task at hand is to properly identify which resources (inputs) are used to produce value (outputs). It is many times conjectured that superior performance and competitive advantages emerge from resource configurations and firm practices. These perspectives are better known under the label of the resource-based view of the firm (Penrose 1959; Wernerfeldt 1984; Barney 1991; Peteraf 1993) or the more recent resources and capabilities approach (Teece *et al*. 1997; Teece 2007; Grant 2008). Both these theories start from identifying the available resources, which in our case is crucial since the analysed sample comes from a specific context in terms of both geographical location and infrastructure characteristics. Also, under these frameworks the outputs and the underlying input-output relation are strictly linked to the firm objectives. For instance, the outputs that are important from a regional viewpoint need to be measured according to technology transfer objectives. Failure to do so could lead to inconclusive results, as in the absence of support or correct incentives for technology transfer universities may simply pursue other goals.

On this note, a second challenge is to jointly assess the multiple spin-offs' objectives shaped by the distinctive perspectives of the player (*i.e.* the *technological entrepreneur*) or the policy making authority. In the short term, firm targets may simply be to maximise revenues, or to increase the probability to survive, whereas regional support institutions may desire to create patents –that are usually believed to positively impact on performance– and jobs with as low budgets as possible. The latter policy dimension is of current interest, as the financial crisis required many local

administrations to cut budget spending. Indeed, Spanish press consistently indicated during 2010-2012 that cutting R&D funds was a priority within the deficit control measures. Given this multidimensionality, the usual methods (*i.e.* profitability, partial indicators or even traditional DEA measures) are not applicable. To account for both firms' and supporting institutions' perspectives in a regional development context, this paper uses a particular case of DEA-based distance functions. These simultaneously expand multiple outputs and contract multiple inputs, and thus can unite the occasionally divergent firm and regional institutions objectives (*e.g.* revenue maximisation *versus* cost minimisation). Moreover, DEA scores provide benchmarking information through efficiency scores computed with respect to best practice frontiers. Having benchmarking-type feedback is appealing to policy makers, who can observe which types of spin-offs are more efficient jointly with their origin and characteristics. A second stage analyses enhances the interpretations that emerge from the efficiency measure. Specifically, regressions are estimated to reveal the impact of key variables such as generated patents or different types of employed personnel on efficiency.

Thus, this paper contributes to the literature in at least two ways. First, it detects and conceptualises the specific inputs and outputs needed to assess university spin-offs from both the firm and the regional development perspectives. Second, an application provides insights into the general university spin-offs phenomena and the particular case of the analysed firms. To reach these goals, a unique sample of spin-offs from the so-called Catalan Technological Trampolines (TTs) is evaluated.[1] This autonomous Spanish community is well known for its propensity to invest in R&D and therefore offers an ideal setting for our study since the firms in our sample benefit from various types of regional institutional support, both in monetary and infrastructure terms. The Catalan technology transfer context and our distinctive data are described in Section 3. Next, Section 4 presents the efficiency measure and employed variables jointly with the main analysis stages. The discussion of the empirical results and their conclusions and implications are developed in Sections 5 and 6, respectively. To clear the ground for the remainder of the paper, Section 2 briefly reviews the related literature.

2. Related literature

This section briefly reviews the related literature and provides a first step towards operationalizing the variables required for assessing the efficiency of the spin-off firms that originated from the Catalan TTs. We start by assuming that firm performance –efficiency in our case– is a function of, or can be partially explained using, differences in resources (*i.e.* the available inputs). Probably the most extensively used framework that proposes and sustains this assumption is the resource-based view of the firm (Penrose 1959; Wernerfeldt 1984; Barney 1991; Peteraf 1993). Management literature further developed this approach to suit in-depth analyses that integrate not only

[1] TTs are support units integrated –in the Catalan case– in TTOs. Section 3 describes them in more detail.

the concept of unique resource bundles, but also organisational practices used for transforming inputs into outputs. Competitive advantages and differences in efficiency are thus expected to spur from core operational processes under what is best known as the resources and capabilities (or dynamic capabilities) framework (Teece et al. 1997; Teece 2007; Grant 2008).

Note that while this is a rather straightforward view, there are a few considerations necessary. Foremost, we are dealing with a particular sample for which it is difficult to find a match with firms from other regions or even firms from the same region that are not university spin-offs. The analysed spin-offs use region- (or institutional-) and unit-specific resources, directly implying that their inputs define a homogenous technology and must be specified as given by the regional and TTs settings. Using resource-based view conceptual lenses, we identify these inputs in the related literature, and match them with the objectives (*i.e.* the outputs) firms and regional policy makers pursue. Furthermore, once the variables are operationalized, the modelled input-output relationship represents –according to the resources and capabilities framework– the net effect of organisational practices. These resources and routines are determined to a great degree by the regional context, a view that stems from perceiving university spin-offs as a manner to exploit intellectual property emerged from science and are embedded in parent organisations (see Mustar *et al*. (2006) for more details on this approach). In addition, the regional emphasis is even stronger, since the analysed organisations are in their turn rooted in the Catalan environment that is believed to positively influence industrial growth and innovation capabilities (see Ahedo (2006) or Buesa *et al*. (2006)).[2]

For the case of business start-ups in the academic context, literature identifies several factors that condition firm creation (see Di Gregorio and Shane 2003; Nicolaou and Birley 2003; Siegel *et al*. 2003; Clarysse *et al*. 2005; Debackere and Veugelers 2005). Key regional and institutional factors, or simply drivers of spin-offs' promotion, include the availability of venture capital in the university area (Di Gregorio and Shane 2003), the university reward system (Nicolaou and Birley 2003), the bureaucracy and inflexibility of university administrators (Siegel *et al*. 2003) or the resources of the TTOs (Clarysse *et al*. 2005). It is worth stressing that these studies did not specifically attempt to evaluate the performance of spin-offs or support institutions similar to the Catalan TTs and therefore do not offer us a set of operationalized variables. Nevertheless, they do put forth useful regional development inputs provided by the supporting institutions, such as economic aid or infrastructure use.

Note that even in the presence of positive market conditions for firm creation, there have long been various reasons that attempt to justify why universities should invest in generating spin-offs. Matkin (1990) stated three core ones: reasons related to the academic staff, economic reasons and technology transfer. The first type of reasons, many times overlooked in the literature, indicate that creating a new venture could retain a scholar with commercial interests, whom otherwise would

[2] Yet another comprehensive review specifically tailored for the Catalan context –but with a qualitative nature and therefore not aiming at assessing efficiency– can be found in Serarols *et al*. (2009).

probably leave the institution. In line with this assumption, it would be interesting to evaluate the impact of using university personnel on firm performance. Moreover, evidence indicates that creating spin-offs is more profitable for inventors than external licensing to established companies (Wright *et al*. 2004). This integrates well jointly with the economic reasons, as profits obtained by universities through equity ownership are expected to be greater than royalties from sales.

The reasons related to the impact of technology transfer are more straightforward. Spin-offs usually increase the number and amount of contract research with universities, particularly in their initial phases of development, because they often externalise their R&D activities (Pérez and Martínez 2003). As a natural result, technology transfer is expected to also positively influence teaching and research by creating opportunities for doctoral theses or master's degree projects. However, and on the one hand, there is literature that empirically demonstrates a non-significant or even negative relationship between technology transfer and regional contribution. For example, Harmon *et al*. (1997) showed that technology transfer processes were successful, but without any substantial evidence that they significantly contributed to both new business and job creation. Additionally, they warned that "scholars and policy makers should proceed with caution before accepting a notion that new or high technology firms will have any direct economic impact" (Harmon *et al*. 1997: 424).

On the other hand, as aforementioned, entrepreneurship research most often assumes –or does not question– the importance of university spin-offs. Nor does it investigate in detail the potential dissimilarities that may exist between spin-offs from the same or different support institutions. One can find in the academic entrepreneurship literature sentences such as "spin-offs create wealth" (Hindle and Jencken 2004; Wright *et al*. 2004; Mustar *et al*. 2006), "spin-offs create jobs" (Steffensen *et al*. 2000; Clarysse *et al*. 2005) or other similar statements on the general idea that spin-offs provide many benefits to both universities and the region, statements typically complemented with some absolute figures. Consequently, in this array of literature spin-offs are always seen as valuable entities that play a key role in enhancing local economic growth and foster job and wealth creation, all of which are closely related, or emerge from, innovation and management practices (Ireland *et al*. 2001; Shane 2004). Yet again, the role of university personnel seems crucial given its direct relation to innovation and, on most occasions, to the spin-offs' administrative tasks.

The caveat of most reviewed studies is that they fail to give a definitive answer to how to empirically assess spin-offs' efficiency. Problems with evaluating spin-offs from both the firms' and the regional institutions' standpoints may well appear when variables are not defined systematically. According to this brief overview of the literature, one should carefully account not only for the usual firm inputs and outputs but also for regional institutional variables that directly support spin-offs, and for variables that foster (regional) economic growth. For instance, in the absence of institutional support for technology transfer, universities may simply lack the correct incentives for spin-off creation, and hence direct their efforts only towards teaching and research.

[Figure 1 about here]

Figure 1 provides a basic design of the types of appropriate variables for assessing the efficiency of academic spin-offs. One first identifies the impacts desired by the promoting institutions. These can be broadly expressed as enhancing regional development, with economic growth as a central factor. In addition, regional policies usually adopt a twofold perspective: wealth and job creation. In the specific case of university spin-offs innovation plays an essential role, and thus institutions will be interested in developing patents. While pursuing these objectives, support institutions offer several types of assistance. These can also be categorised into two blocks. First, the most common resources consumed for incentivising spin-offs' creation are the grants and other financial aids. Second, various services can be offered to spin-off companies (*e.g.* free use of infrastructure or needed technology) to ease the early development processes.

Note that Figure 1 and its interpretation set the ground for the operationalized variables that are defined in detail in Section 4. For the efficiency analysis, the above discussion isolates inputs such as grants or economic aid and external services (from the supporting institutions angle), and funds received from contracts and expenditures (from the traditional economic and accounting sides). As a natural output for firm and economic growth one can consider the total revenues of spin-offs. Additionally, regional and institutional-specific outputs for university spin-offs may well be the number of generated patents and the number of jobs created. A comprehensive efficiency measure should include all these dimensions. Moreover, according to most related literature the level of innovation and the type of employed personnel potentially affect spin-off efficiency and hence this relation should be scrutinised (Ireland *et al*. 2001; Shane 2004).

3. Context and data

3.1. Regional environment

The R&D system of Catalonia is considered a special case within Spain due to its levels of resources that generally are significantly higher than in other regions. Collecting only one sixth of the Spanish population (about seven million inhabitants in an area of 32,000 square kilometres), Catalonia produces 34.6% of its high-technology exports and 22.50% of the R&D expenses, thus accounting for approximately a quarter of the industrial GDP (25.52%). In 2009 Catalonia's R&D spending reached 1.68% of its GDP, and the region employed 46,000 researchers (ACC1Ó 2011). Additionally, its innovation system is mainly sustained through the business sector, which holds 58.40% of the total expenses.[3]

In Catalonia the "third mission" is principally based on commercialising research. Various institutions mediate the academia-business interaction. Among these, three may directly intervene in the process: the Centre for Innovation and Business Development (CIDEM, now named ACC1Ó), the

[3] One can refer to ACC1Ó (2011) or Serarols *et al*. (2009) for more detailed information on these issues.

Ministry of Science and Technology (MCYT), and the Centre for the Development of Industrial Technology (CDTI). While the first one acts at a regional (Catalan) level, the last two are national bodies. Since it was CIDEM that fostered the TT project, this paper focuses on this entity's programmes. It was created in 1985 by the regional government to improve the competitiveness of Catalan industrial firms, which were mainly SMEs, and since its beginning policy efforts have had innovation at their core. Furthermore, the institution's positive results determined the European Commission to indicate that the "Catalonia Innovation Plan" is a role model for businesses (EC 2002). Out of the six programmes in the plan, our interest specifically targets the university-level support mechanisms for venture creation (CIDEM 2006).

Note that although all mentioned institutions form part of the public system, spin-offs sometimes receive support from other actors. These may simply be venture capitalists in search of profitable projects or various foundations that seek to promote entrepreneurship for women, youngsters, unemployed managers or ethnic groups. It is thus important to also account for funding received from sources external to the regional support programmes. Finally, one should bear in mind that jointly with the support of public and private institutions, this process of spin-off creation is deeply embedded within the Catalan culture and attitude towards entrepreneurship. This further backs the intuition that CIDEM is the institution that not only copes better with the context but also is defined via the appropriate regional values.

3.2. Technological Trampolines at Catalan universities

The so-called Technological Trampolines (TTs) were founded by CIDEM to encourage and sustain business creation. They specifically promote technology- and knowledge-based spin-offs from the academia, having as main objectives to detect, select, evaluate and offer advice to new projects. A TT usually provides services as: seminars or workshops to explain entrepreneurial activity, office spaces and related infrastructure (meeting rooms, fax services, etc.), feed-back on business projects, assistance and management of intellectual property rights, and information and support for applying for public funding.

[Figure 2 about here]

TTs were developed during the 2000s and are typically independent entities integrated in TTOs from public universities. While, TTs and TTOs frequently share office spaces and other physical resources, TTs have separate budgets from universities and TTOs. For instance, CIDEM funds all the TTs' activities, apart from the aforementioned physical assets that are provided by universities at no charge. Moreover, TTs have certain technological orientations and must follow the directions given by CIDEM when choosing which spin-offs to support. In general, selected projects should incorporate differentiating or unique technologies and be oriented towards global markets or venture capital.

Figure 2 presents the technology transfer activity at Catalan universities, as previously identified by Serarols *et al*. (2009).

[Table 1 about here]

The TT network has ten units located at different universities, all coordinated through CIDEM. Table 1 shows the universities in this network and their joining year. Between 2001 and 2007 CIDEM spent around 6,656,000 Euros (mostly as personnel expenses) for funding the TT network. Somewhat in parallel, CIDEM granted 10,180,000 Euros of "Concept Capital" and 2,396,000 Euros of "Genesis Capital" to 111 spin-offs.[4] Also, it took part in the venture capital firm Invertec[5] that has invested 2,199,000 Euros in 12 spin-offs.

3.3. Sample

A two-step methodology was used to build our unique sample. First, an exploratory qualitative stage was performed to test the underlying research design and develop the questionnaire for the data gathering. Thus, the questionnaire was subject to a pre-test in order to correct potentially misleading or confusing questions. Second, all spin-offs created within the TT network were considered for interviewing. The total sample consisted of 335 firms, 33 of which had ceased their operations, 32 were not accessible and 8 stated that they had no relationship with the TTs. Consequently, the total registers were 262.

Data were gathered between February 2007 and May 2008 through structured telephone and self-administrated Internet interviews. For the core part of the questionnaire, respondents had to indicate and evaluate the services used from the TTs, jointly with key financial and other kinds of data on founding team, employees and all types of economic aid obtained. This process yielded 94 valid questionnaires (*i.e.* with complete answers to all questions). Furthermore, the sample was checked for selection bias (*e.g.* spin-offs' typology, sector, age, number of employees) and the financial information provided by the participants was validated and complemented using the SABI database.[6]

The oldest firms in the sample were created in 1998, and the youngest in 2007. Nevertheless, more than 86% of these spin-offs were created after 2002. They have on average between 6 and 7 employees (2 to 3 of which represented personnel from the parent university). Therefore, the sample comprises very young and small technology-based spin-off firms. In addition, it includes three activity areas: (a) technological sciences (*i.e.* computer science and engineering, 73 firms), (b) bio-chemical

[4] Concept Capital is a participative loan, up to 100,000 Euros, for new technology-based companies spinning-off from public research institutions with at most 2 years of existence. Genesis Capital is a grant, up to 20,000 Euros, provided to new technology-based entrepreneurs used to evaluate the feasibility of the project within its first year of operation.

[5] Invertec handles over 5.86M Euros, given by CIDEM, Innovation and University Ministry (DIUE), Universitat Autònoma de Barcelona (UAB), Universitat de Barcelona (UB), Universitat de Girona (UdG), Universitat Politècnica de Catalunya (UPC), La Salle, IESE Business School and Universitat Rovira i Virgili (URV).

[6] The SABI (*Sistema de Análisis de Balances Ibéricos*) database includes detailed financial statements, as well as other variables for Spanish enterprises.

industries (*i.e.* pharmaceutical, biological or chemical industries, 16 firms), and (c) firms dedicated to employing technology in the social sciences area (5 firms).

When collecting data, the researchers noticed that many of the spin-offs in the sample did not fulfil Pirnay *et al.*'s (2003: 356) vastly employed definition, according to which university spin-offs are "new firms created to exploit commercially some knowledge, technology or research results developed within a university". That is, various entrepreneurs stated that, even if they had received support from the TTs, they did not have any relationship with the parent university; they just wanted assistance in applying for public funds. Others indicated that they were not exploiting technology developed within the university. Having this in mind, the traditional definition was revised to include three different groups of spin-offs:

- Group 1: Spin-offs with formal technology transfer agreements (STTU).[7] These spin-offs have a formal technology transfer agreement with the parent university (*e.g.* patents, know-how contracts, equity, or contract research). Thus, this group fulfils to a greater degree the definitions that can be found in the literature.
- Group 2: Spin-offs that incorporate personnel from the parent university (SPU).[8] These spin-offs integrate at least one member from the parent university within their current staff or founding team. This group does not include firms that have formal technology transfer agreements with the parent university. Hence, it fulfils to a medium degree the definitions in the literature.
- Group 3: Pseudo spin-offs (PSU). This group does not incorporate members from the parent university, nor does it have any formal agreement with the parent university. Formally, firms in this category cannot be considered spin-offs and therefore we call them pseudo spin-offs since they do appear in the TT network database.

4. Efficiency measure, variables and stages of analysis

4.1. Efficiency measure – The proportional distance function

TT networks represent complex settings that pursue multiple objectives for firm and regional development, but act uncertain environments. On the one hand, this implies that various outputs must be expanded simultaneously, while also controlling for input quantities. On the other hand, efficiency levels should be provided accurately even if the real technology distribution is unknown. In these conditions literature usually employs non-parametric efficiency measures based on DEA (see Ray (2004) for detailed descriptions). These methods approximate true but unknown technology frontiers. Also, since they are non-parametric, no a priori technological restrictions are imposed on the sample

[7] This is equivalent to the typology "Direct research spin-offs (DRSO)" identified by Hindle and Yencken (2004: 798).
[8] This is equivalent to the typology "indirect spin-off" identified by Nicolau and Birley (2003).

distribution and no availability of prices is necessary. DEA computes the degree of inefficiency separating a certain firm from the best practice efficiency frontier. In this sense, frontier analysis is a more complex technique for benchmarking the relative performance of firms. Moreover, as opposed to single ratio methods, these technical efficiency estimations permit either to expand various outputs with no more inputs, or to contract various inputs maintaining the output level constant.

However, this last characteristic of traditional efficiency estimators represents a shortcoming for our analysis. That is, from both the TT network's and the spin-offs' perspectives, output expansion is a desired objective. Nevertheless, for the regional development institutions, simultaneous input contraction is of equal importance. Efficient input use is a crucial aspect for the support programmes that aim to obtain the maximum amount of output with the minimum provided aid. Furthermore, this policy angle is of increased importance on the background of the recent financial crisis, which forced local administrations to cut budget spending in all areas. Actually, many press articles from leading Spanish newspapers indicated during 2010-2012 that cutting R&D spending was a priority for the deficit control measures.

One solution is to utilise the directional distance functions proposed by Chambers *et al*. (1996). The advantage of these DEA-based functions is that, instead of focusing only on input or output orientation (as traditional DEA measures do), they account for output expansions and input contractions simultaneously. Within this family of distance functions a special case is represented by the proportional distance function, defined by Briec (1997). This function is especially useful for analyses that account for firm-specific characteristics, since each unit chooses its specific direction when measuring its performance against the best practice frontier.

Let $\mathbf{x} = (x_1, \ldots, x_N) \in R_+^N$ and $\mathbf{y} = (y_1, \ldots, y_M) \in R_+^M$ be the vectors of inputs and outputs, respectively, which form the technology *T*, representing the set of all output vectors (**y**) that can be produced using the input vector (**x**):

$$T = \{(\mathbf{x}, \mathbf{y}) : \mathbf{x} \text{ can produce } \mathbf{y}\}. \tag{1}$$

Following Briec (1997: 105), the proportional distance function to estimate the efficiency score of firm *k'* is defined as:

$$D(x^{k'}, y^{k'}) = \max_{\delta} \{\delta : ((1-\delta)x^{k'}, (1+\delta)y^{k'}) \in T(\mathbf{x}, \mathbf{y})\} \tag{2}$$

or as the solution to the following linear programming problem:

$$\begin{aligned} & D(x^{k'}, y^{k'}) = \max \delta \\ & \text{s.t. } \sum_{k=1}^{K} \lambda^k y_m^k \geq y_m^{k'} + \delta y_m^{k'}, \ m = 1, 2, \ldots, M; \\ & \quad \sum_{k=1}^{K} \lambda^k x_n^k \leq x_n^{k'} - \delta x_n^{k'}, \ \text{n} = 1, 2, \ldots, N; \\ & \quad \sum_{k=1}^{K} \lambda^k = 1; \\ & \quad \lambda^k \geq 0 \ (k = 1, 2, \ldots, K). \end{aligned} \tag{3}$$

Note that this specification assumes variable returns to scale, an important issue when dealing with firms that develop their activity in dynamic sectors. Efficient firms are indicated by a score of 0 (*i.e.* $D(x^{k'}, y^{k'}) = 0$), while the inefficiency degree of units below the best practice frontier is shown by positive values of $D(x^{k'}, y^{k'})$. Figure 3 illustrates the proportional distance function assuming a simple technology of one input and one output.

[Figure 3 about here]

Observe that points A, B and C form the best practice convex efficiency frontier, whereas the rest of the (inefficient) units are enveloped below this frontier. For instance, to reach the frontier, points D and E must expand outputs and contract inputs as shown by the positive results (*i.e.* the inefficiency degrees) of $D(x^D, y^D)$ and $D(x^E, y^E)$, respectively. The directions of these two functions are given by the proportional expansion (contraction) of the employed outputs (inputs). Moreover, the efficiency scores consider convex combinations on the best practice frontier as benchmark points.

4.2. Inputs, outputs and final sample

Inputs and outputs are specified according to Section 2 and its concluding remarks, and our specific dataset. Since we aim at evaluating performance from both the spin-offs' and the regional supporting institutions' viewpoints, variables are set for scrutinising firms from a twofold perspective: as fund receivers and as traditional players in the market. Figure 4 shows how inputs and outputs can be divided into three categories: (a) inputs from supporting institutions (for regional development) and other production inputs for economic growth, (b) commercial outputs that are main firm-level economic growth objectives but also produce regional development, and (c) desirable outcomes from the public policy perspective (*i.e.* job generation for regional development). Considering the goals at firm and regional/institutional levels altogether, the last two categories are introduced as outputs for the efficiency analysis, while the first category is used as inputs. Descriptive statistics corresponding to inputs and outputs are shown in Table 2.

[Figure 4 and Table 2 about here]

Regional support institutions provide the first two inputs, grants (or similar economic aid) (x_1) and external services (x_2), both defined in monetary terms. Data were precise and well structured for the grants (or similar economic aid). However, for the external services a proxy variable had to be computed using the number of TT services used by each firm and the total amount of funds dedicated to these. The next two inputs, that are external to support institutions and are related to the economic growth literature, are the monetary values of R&D contracts (x_3) and firm expenditures (x_4) (excluding wages, a component of the job creation variable). On the outputs side, the traditional dimensions of firm growth are represented through sales or innovation. These are expressed as generated revenues (y_1) and the absolute number of created patents (y_2). The third output is exclusive to the regional

development perspective and captures the absolute number of jobs created (y_3). It is defined as the sum of full time employees and half of the part time ones, the result of which is read as total full time employees. All variables are at their 2007 levels. Provided the sample comprises young firms with significant activity fluctuations during their initial market phases, it is assumed that growth levels may be approximated by the 2007 absolute value. This decision is also recommended by the high amount of zero values encountered for the first years of activity.

Finally, as indicated by previous literature, tests were run for identifying potential outliers. It is well established that extreme points may influence the shape of the estimated efficiency frontier and produce bias in the obtained scores. The seminal contributions of Andersen and Petersen (1993) and Wilson (1993) are generally employed for outlier detection. Potential outliers are identified through super-efficiency coefficients, and are sequentially removed from the sample and each time the efficiency scores are re-estimated. Additionally, as proposed by Prior and Surroca (2010), this process is repeated until the null hypotheses of equality between successive efficiency scores cannot be rejected. After eliminating outliers the final sample is composed of 81 spin-offs.

4.3. Stages of analysis

The remainder of this paper presents the empirical results and their subsequent discussion and implications. This is done according to the following stages of analysis. First, the efficiency results as defined by expressions (1) to (3) are presented. Second, the descriptive efficiency interpretations are further complemented with a second stage regression analysis to study the relationship between efficiency scores and key explanatory factors that capture the level of innovation and the different types of employed personnel, while controlling for types of spin-offs and universities of origin. One can assume the following specification:

$$D(x^k, y^k) = \alpha + \boldsymbol{\beta}\mathbf{Z}^{\mathbf{k}} + \varepsilon^k, \quad k = 1, 2, \ldots, K, \tag{4}$$

which is the approximation of a true but unknown relationship. In (4) α is the constant term, ε^k a random error term (*i.e.* statistical noise), and $\mathbf{Z}^{\mathbf{k}}$ is a vector of variables thought to explain efficiency scores ($D(x^{k'}, y^{k'})$) through the parameters $\boldsymbol{\beta}$ (common for all k) that are estimated.

Literature indicates that the appropriate estimation model is a truncated regression, since estimated efficiency scores are constrained by definition to be equal to or greater than 0 (*i.e.* $\delta^k \in [0, \infty)$).[9] This can also be expressed as $\varepsilon^k \geq 0 - \alpha - \boldsymbol{\beta}\mathbf{Z}^{\mathbf{k}}$. For our model we substitute the true but observed regressand in equation (4), $D(x^k, y^k)$, by the estimate of the linear programming problem in (3), δ^k. Thus, the model is now:

$$\delta^k \approx \alpha + \boldsymbol{\beta}\mathbf{Z}^{\mathbf{k}} + \varepsilon^k, \quad k = 1, 2, \ldots, K, \tag{5}$$

[9] If applied under these conditions, standard linear techniques would be conceptually wrong and parameter estimates would be inconsistent (Greene 2003).

where

$$\varepsilon^k \sim N[0,\sigma_\varepsilon^2], \text{ such that } \varepsilon^k \geq 0 - \alpha - \boldsymbol{\beta}\mathbf{Z}^{\mathbf{k}}, \quad k = 1,2,\ldots,K, \tag{6}$$

which is estimated by maximizing its corresponding likelihood function with respect to $(\beta,\sigma_\varepsilon^2)$ and given the data.

For the firm-specific variables and controls, the following variables are used: number of employees from the university of origin, number of employees holding a PhD, number of employees holding an engineering degree, number of patents divided by number of total employees, firm age and dummy variables for the university of origin and for the type of spin-off (*i.e.* STTU, SPU or PSU).

5. Empirical results

Efficiency results indicate that 15 of the analysed spin-offs (approximately 18.5% of the sample) form the best practice frontier. These have a score of 0, while higher values indicate the degree of inefficiency. Table 3 reports the efficiency scores for the total sample as well as by spin-off type. Their associated distributions can be observed in the different panels of Figure 5, for the total sample (Panel A) and for each of the three spin-off types (Panels B to D). One can notice that mean sample inefficiency is of 0.37, a value consistent with the 0.35 median inefficiency level. Furthermore, percentiles illustrate the distribution of these total sample scores, with units below or at p25 experiencing rather low inefficiencies (less or equal to 0.08), and units at p75 or above showing high inefficiencies (greater than 0.59). In Panel A of Figure 5 the scores' distribution for the total sample becomes more obvious as, for instance, one can note that many of the analysed units fall below the 0.2 inefficiency level.

[Figure 5 and Table 3 about here]

More insights into the scores' distribution are attained at spin-off type level. Intuition suggests that the first group (*i.e.* STTU – spin-offs with formal technology transfer agreements) are the most efficient ones. This is partly true. Although at mean level the inefficiency of this group is slightly higher than for the other two groups (*i.e.* 0.38 as compared to 0.37 and 0.35 for SPU –spin-offs that incorporate personnel from the parent university– and PSU –pseudo spin-offs–, respectively), this is the group with the highest percentage and absolute number of efficient firms. This can be easily observed in Table 3 through the 0 value (which designates fully efficient units) reported at p25. Also, the same conclusion can be drawn by scrutinising Panel B of Figure 5, which shows that many of the efficient spin-offs from the sample are found in this group. However, the lower median and p75 levels of the STTUs reveal that this group also comprises many spin-offs with quite high inefficiency scores. Since this group of spin-offs is embedded to a higher degree in the university, one speculation could be that more monitoring systems from the support institutions may be needed to check for extreme cases *ex ante* and *ex post* transfer agreements. In contrast, the other two groups have similar mean inefficiencies and, even if at p25 the PSUs are more efficient, at p75 inefficiency is roughly the same.

Moreover, Panels C and D of Figure 5 illustrate that, while the PSUs have a higher relative number of efficient firms, in absolute terms the SPUs include more efficient firms (as well as more firms with higher inefficiency).

[Table 4 about here]

Results by university of origin are presented in Table 4. Rankings can be devised to include all universities, however, considering that many of these comprise very low numbers of observations one should focus on the first four institutions. Scores at all levels indicate that most of the efficient spin-offs or spin-offs showing lower inefficiencies originated from UPC and La Salle. Both include firms with the lowest mean, median, and p75 inefficiency levels, and furthermore put forth fully efficient spin-offs at their associated p25 levels. These results are in line with the intuition, as UPC and La Salle are universities with more technological background than their counterparts and are thus expected to be better at selecting and supporting successful projects. At the opposite extreme, spin-offs from UAB show the highest inefficiencies both at mean and at percentile levels, and are followed by firms from UB that have slightly (but not significantly) higher efficiency levels. Among the rest of the analysed universities, URV and IESE have the best results. Nevertheless, a maximum of two spin-offs originated from these last five universities, and thus it is rather difficult to interpret their efficiency scores.

[Table 5 about here]

The second stage of the analysis consists of truncated regressions that are defined according to equations (4) to (6) and use efficiency scores as dependent variables. The explanatory variables and controls are introduced as illustrated in the last paragraph of Section 4.3. Our key independent variables are employees from the university of origin, the different types of employees and patents divided by total number of employees.[10]

Main findings from Table 5 indicate that having more employees from the university of origin is related with less inefficiency (see the negative sign in the parameter estimate). This appears consistently so in models 1 and 2, which also reveal that the % of PhDs or engineers has no effect on efficiency. However, in model 3 one observes that what actually matters is having PhDs from the university of origin (see the significant and negative coefficient of the interaction term "workers from university × % of PhDs").[11] These findings initially suggested that academic knowledge is not necessarily useful in the market (PhD and engineer degrees not significant), which is consistent with previous literature that indicated a need of upgrading management skills (see, *e.g.*, Chapple *et al.* (2005)). However, specific academic knowledge or experience related with the university of origin seems to make a difference when employees hold PhD degrees and also are from the university of

[10] Note that patents/employees is a variable that is not present in the efficiency analysis. Both patents and number of employees appear as outputs in equations (1) to (3) and therefore their ratio is not computed. Furthermore, keep in mind that for the model in equation (3) more output (*e.g.* more patents or a higher number of employees) does not imply higher efficiency.

[11] The correlation between these two variables is 0.054 and it is not statistically significant.

origin. This type of employees could have a competitive edge when gaining market experience, which is known to positively affect efficiency (see, *e.g.*, Alvarez and Crespi (2003)).

Another consistent result is the negative relationship between patents/employees and inefficiency. That is, a higher ratio of number of patents per employees leads to lower inefficiency. Moreover, the parameter estimate of this variable is rather high in all three models. To corroborate these results, observe in Figure 6 how higher efficiency scores are associated with higher number of patents. Also, extreme results such as very high inefficiency levels are related with very low number of patents. All these outcomes involving the role of innovation are in line with the descriptive literature reviewed in Section 2 (to name just a two of the many studies, see Ireland *et al*. (2001) or Shane (2004)).

[Figure 6 about here]

Next, dummy variables for the university of origin show that spin-offs for UPC and La Salle have lower inefficiencies. This confirms the descriptive statistics of the efficiency scores and upholds the conjecture that universities with more technological background produce more efficient spin-offs. An interesting result is that spin-offs with formal technology transfer agreements (STTU) are associated with a positive and significant coefficient, meaning that less efficient firms belong to this group. This is in accordance with the mean or median results in the descriptive statistics in Table 3. Nevertheless, keep in mind that the STTU group also contains most fully efficient units, which now appear as truncated from the distribution. Therefore, this is a clear illustration of how the two stages of the analysis complement each other. Controls for firm age and activity area are not significant.[12] Failing to find significant parameter estimates linked to the controls for activity area supports the assumption of a homogenous technology defined through the specific variables for this particular sample of spin-offs.

6. Concluding remarks

Recent literature highlights the importance of academic entrepreneurship and its assistance mechanisms. However, there is still little evidence on how to select and operationalize the appropriate variables for assessing spin-offs' efficiency or how to define an efficiency measure that is in line with both the firms' and the regional institutions' objectives. To fill this gap, this paper follows an existing stream of literature that attempts to measure spin-offs performance and provides tools to estimate and interpret the efficiency of spin-offs embedded in university-based support mechanisms. We contribute to the literature in at least two ways. First, we detect and conceptualise the specific inputs and outputs that are needed to assess university spin-offs from both the firm and the regional development perspectives. Second, we define an application that provides insights into the general university spin-offs phenomena and the case of our unique sample.

[12] Models including controls for activity area are not presented in Table 5 for the sake of brevity.

The appropriate variables are identified to simultaneously match firm targets (*e.g.* maximise revenues) and regional goals (*e.g.* generate patents and jobs, use less resources). Naturally, this represents a multiple outputs and inputs analysis, which in this paper is tackled via a special case of distance functions that can simultaneously expand outputs and contract inputs. This feature is crucial for policy makers that on the background of the financial crisis are required to introduce budget cuts. For instance, the Spanish deficit control measures instituted during the economic downturn specifically aimed at minimising R&D spending. Furthermore, the devised efficiency assessment provides appealing feedback in terms of characteristics and origin of spin-off firms.

The empirical application considers a particular sample of spin-offs created at Catalan universities within a specific regional support programme. Note that in these cases variable definition is increasingly important as failure to detect the fitting inputs and outputs may lead to defining a technology that does not correspond with the production possibilities or the entrepreneurs' or policy makers' incentives. One last methodological aspect is that the technology should be less restrictive and assume variable returns to scale, given that previous literature found or directly assumed either decreasing returns to scale (Chapple *et al*. 2005) or constant returns to scale (Siegel *et al*. 2003)

Main descriptive results show that the best practice frontier is mostly shaped by spin-offs with formal technology transfer agreements, an encouraging result for the supporting institutions. Additionally, many of the efficient spin-offs originated from universities with more technological background, thus suggesting that institutional experience in academic innovation may play a role in the open market. These results are corroborated by the second stage analysis. From the regression results we highlight that employing workers from the university is associated with higher efficiency. Furthermore, while employing PhDs does not seem to make a difference, when these are workers from the university of origin the parameter estimate becomes significant and related with higher efficiency.

These findings may indicate that academic knowledge is not always useful in the market (a result consistent with previous literature, see *e.g.*, Chapple *et al*. (2005)), however academic knowledge jointly with experience related with the university of origin seems to make a difference. Consequently, on a general note, management skills may need upgrading (Chapple *et al*. 2005) but PhDs employed locally could have a competitive edge when gaining market experience, which is known to positively affect efficiency (see, *e.g.*, Alvarez and Crespi (2003)). Yet another policy implication is that more patents (both in absolute and relative –size controlled– terms) indeed have a positive effect on efficiency. It could therefore be useful for local administrations to provide incentives for patent development when aiming at efficiency or productivity growth. Moreover, patents could be used as a difficult to imitate signalling technique for efficient firms.

Future research could consider regional and institutional variables for cross-country or cross-region comparisons. Our comprehensive description of the unique university spin-off phenomena in Catalonia could serve as a starting point for defining such studies. On most occasions it is correctly

assumed that a supportive regional environment can act as a catalyser, impacting positively on the efficiency of the development programmes. Indeed, proper resource allocation (*e.g.* devote more resources to protecting intellectual property –patents– in comparison to assistance in writing the business plan) and selection criteria (*e.g.* focussing more on supporting only spin-offs with formal transfer agreements) could lead to regional development projects with positive effects on long-run performance. In this line, a last policy implication for regional institutions could be to invest in creating databases that would provide more detailed longitudinal data for scrutinising economic growth.

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Figure 1: A regional development and economic growth perspective for assessing the efficiency of academic spin-offs

Figure 2: Technology transfer activity at Catalan universities (Serarols *et al*. (2009: 364))

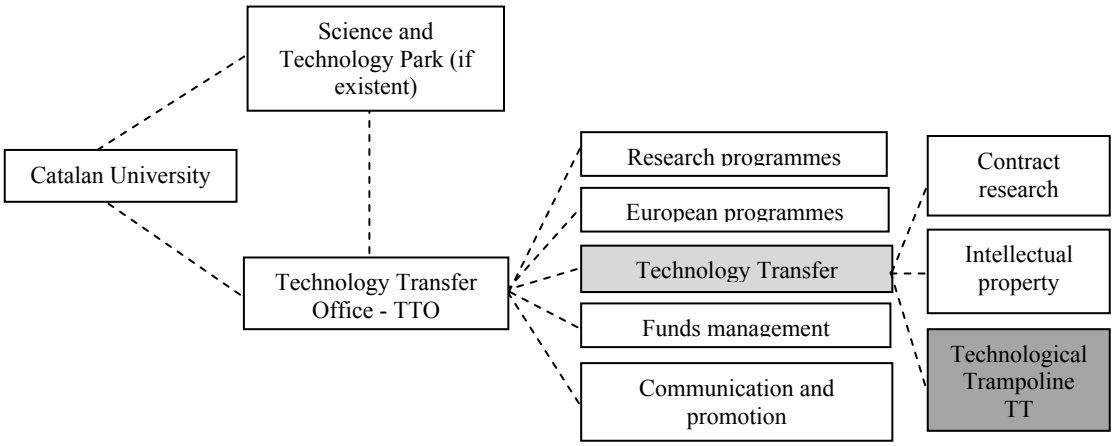

Figure 3: Efficiency measure: The proportional distance function

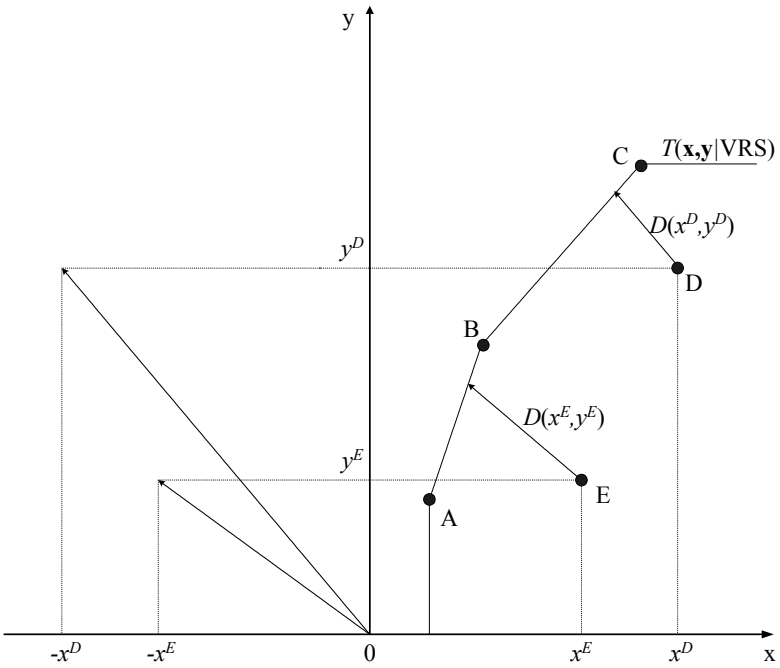

Figure 4: Inputs and outputs from spin-off and public policy viewpoints: A regional development and economic growth perspective

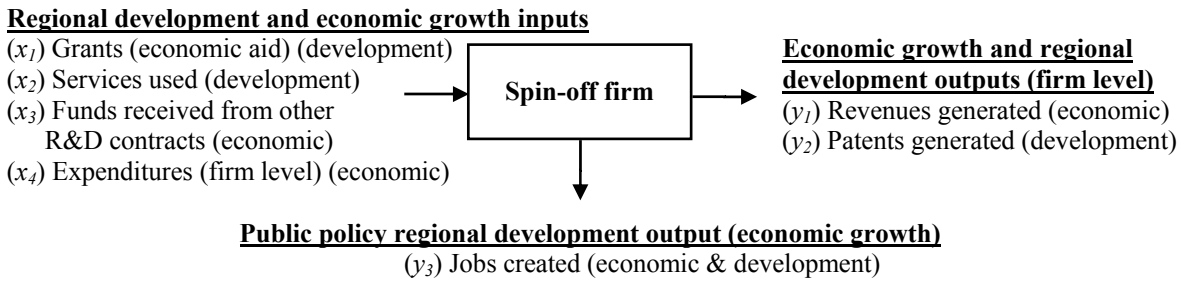

Figure 5: Distribution of efficiency levels, at total sample and by spin-off type

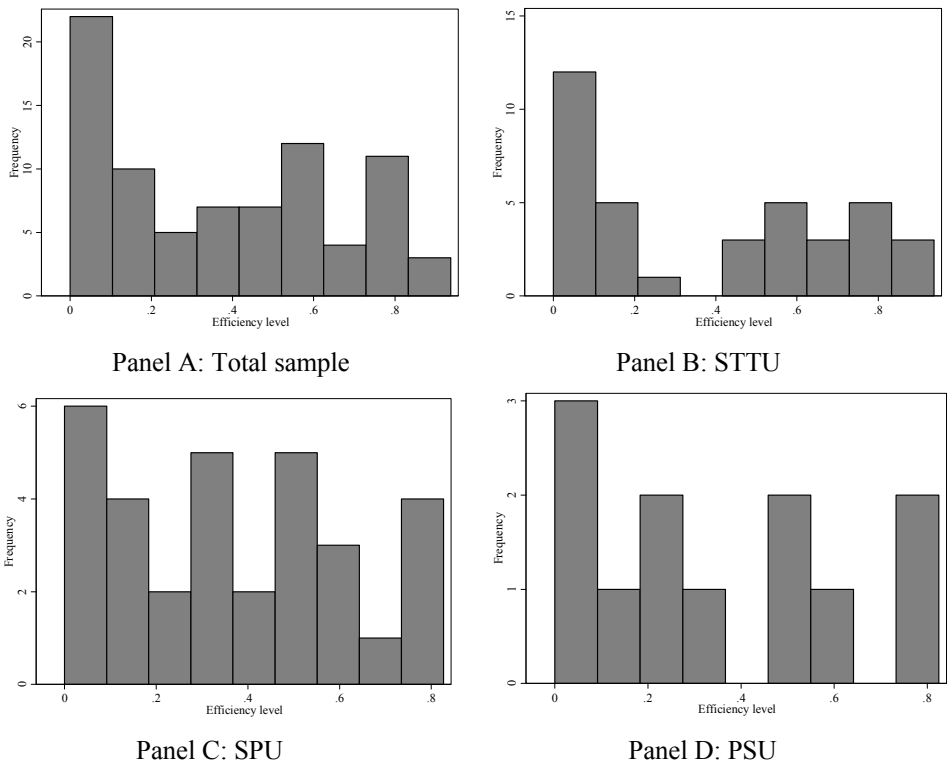

Figure 6: Spin-off types: Efficiency and number of patents

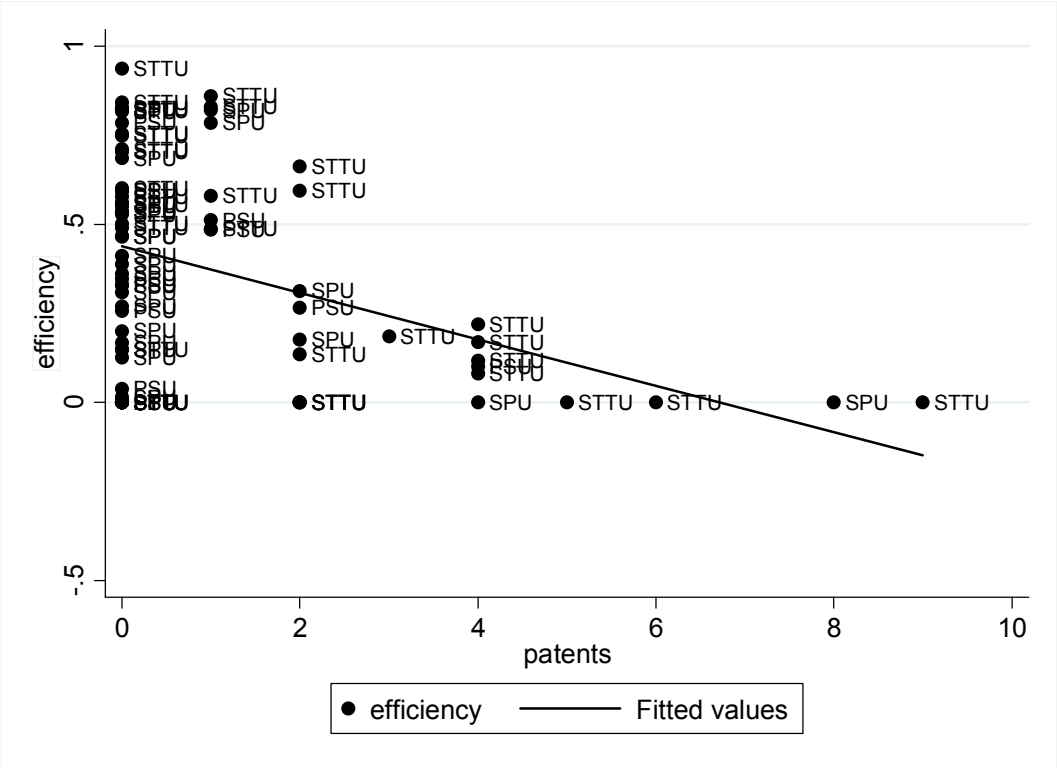

Table 1: Year of joining the TTN (CIDEM (2008))

Year of incorporation	*University*
2001	Universitat Politècnica de Catalunya (UPC) Universitat de Barcelona (UB) Universitat Autònoma de Barcelona (UAB) Universitat Ramon Llull (ESADE and La Salle) IESE
2002	Universitat de Girona (UdG)
2005	Universitat Oberta de Catalunya (UOC) Universitat Rovira i Virgili (URV)
2006	Universitat de Lleida (UdL) Universitat Pompeu Fabra (UPF)

Table 2: Inputs and outputs: descriptive statistics

Inputs and Outputs	*Mean*	*5% Trimmed Mean*	*Std. Dev.*
(x_1) Grants (economic aid) (€)	27321.21	14527.00	76446.08
(x_2) Services used (€)	70625.68	67910.45	53228.31
(x_3) R&D contracts (€)	23862.96	11325.79	64301.90
(x_4) Expenditures (€)	222246.20	143742.19	438045.20
(y_1) Revenues generated (€)	394853.40	270030.96	727482.60
(y_2) Patents generated (no.)	1.02	0.75	1.85
(y_3) Jobs created (no.)	8.23	7.07	8.12

Table 3: Efficiency scores by spin-off type and total sample

Efficiency scores	*Obs.*	*Mean*	*Std. Dev.*	*p25*	*Median*	*p75*
STTU	37	0.3822	0.3389	0.0000	0.4869	0.7048
SPU	32	0.3669	0.2634	0.1582	0.3548	0.5439
PSU	12	0.3495	0.2921	0.0697	0.2982	0.5534
Total	81	0.3713	0.3007	0.0802	0.3475	0.5951

Table 4: Efficiency scores by university of origin and total sample

Efficiency scores	*Obs.*	*Mean*	*Std. Dev.*	*p25*	*Median*	*p75*
Univ. Autònoma Barcelona (UAB)	13	0.5132	0.2704	0.3621	0.5525	0.7048
Univ. Politècnica Catalunya (UPC)	21	0.3058	0.2762	0.0000	0.3099	0.4909
Univ. de Barcelona (UB)	8	0.4623	0.3277	0.1517	0.5566	0.6723
La Salle	31	0.3152	0.2908	0.0000	0.2653	0.5809
Univ. de Girona (UdG)	2	0.5059	0.4539	0.1850	0.5059	0.8269
ESADE	2	0.7352	0.0704	0.6855	0.7352	0.7850
Univ. Pompeu Fabra (UPF)	2	0.5150	0.4448	0.2005	0.5150	0.8295
Univ. Rovira i Virgili (URV)	1	0.0000	.	.	.	.
IESE	1	0.0000	.	.	.	.
Total	81	0.3713	0.3007	0.0802	0.3475	0.5951

Table 5: Second stage truncated regression results[ab]

	Model 1		*Model 2*		*Model 3*	
Variable	*Coef.*	*Std. error*	*Coef.*	*Std. error*	*Coef.*	*Std. error*
employees from university	-0.029*	0.015	-0.026*	0.015	-0.016	0.014
% of phd			-0.002	0.002		
% of bsc in engineering			0.001	0.001		
employees from university × % of phds					-0.001***	0.000
patents / employees	-0.860***	0.210	-0.809***	0.203	-0.777***	0.196
uab			-0.153	0.141	-0.127	0.139
upc			-0.262**	0.133	-0.282**	0.131
la salle			-0.265*	0.137	-0.294**	0.129
ub			-0.180	0.156	-0.206	0.150
firm age	-0.008	0.019	-0.020	0.019	-0.018	0.018
sttu	0.250**	0.121	0.235*	0.130	0.210*	0.124
spu	-0.022	0.116	-0.059	0.118	-0.107	0.114
_cons	0.522***	0.101	0.773***	0.203	0.831***	0.160
obs.	66		66		66	
log likelihood	10.10		13.53		14.13	
Wald chi2	21.08		28.36		30.04	
prob> chi2	0.001		0.003		0.001	

[a] dependent variable: efficiency score; efficient units have scores of 0, values > 0 report the inefficiency degree;
[b] regression truncated at lower limit 0; 15 efficient units truncated;
*, ** and*** stand for significant statistical differences at 90%, 95% and 99% confidence levels, respectively.