University Spin-offs vs. Other NTBFs:

Total Factor Productivity Differences at Outset and Evolution

Abstract. Previous empirical research suggests that university spin-offs under-perform in economic terms compared to other new technology-based firms (NTBFs) in their early years. The usual explanations suggest a lower capabilities endowment of university spin-offs compared to other NTBFs. Using a longitudinal Spanish dataset we compare the evolution of firms' total factor productivity (capabilities endowment) in both kinds of firm. Productivity grew faster in university spin-offs and their initial underperformance disappeared after two or three years of operation. The evidence therefore suggests that university spin-offs have lower initial substantive capabilities but greater dynamic capabilities than independent NTBFs. Possible explanations are discussed.

Key words: *university spin-offs, productivity, substantive capabilities, dynamic capabilities.*

JEL CODES: L20, O32, M13

1. Introduction

University spin-off companies, those new technology-based firms created with the support of a university by some of its members, have received increasing attention in the last two decades by policy makers and managers of higher education institutions, particularly in US and Europe. These initiatives directly implied the commitment of public resources to stimulate the development of university spin-offs (Geuna et al., 2003; Lockett et al., 2005; Mustar and Wright, 2010), and opened a research stream aimed at identifying and evaluating the specific factors that facilitate the success and development of university spin-offs. Djokovic and Souitaris (2008) or Mustar et al. (2006) provide excellent summaries of this literature. Underlying this growing interest is the idea that higher education institutions have entrepreneurial capabilities that are underused and which can increase the wealth creation and competitiveness of the economy.

This idea is disputed by Harrison and Leitch (2010), who question the economic relevance of university spin-offs. Furthermore, the evidence comparing the economic performance of university spin-offs with other NTBFs reports that university spin-offs have lower growth rates in terms of sales, net cash-flows, employees, and a lower likelihood of obtaining profits than independent start-ups (Chrisman et al., 1995; Ensley and Hmieleski, 2005; Zhang, 2009). The results are the opposite when the performance of firms is measured in terms of patents (quality or quantity) or product innovation (Cockburn and Henderson, 1998; Gittelman and Kogut, 2003; Toole and Czarnitzki 2007, 2009; Zucker et al., 1998a; Zucker et al., 2002a). In particular, this paper contributes to this literature in two main aspects: it applies a different performance measure (TFP), and a longitudinal approach.

From a managerial perspective, the resource-based view (RBV) literature (Barney, 1991; Peteraf, 1993; Teece, 1980; Wernerfelt, 1984) attributes firms' differences in performance to two sources: the firms' resources (assets that can be acquired and transferred) and the firms' capabilities (how such resources are combined and transformed). On the other hand, Solow (1950) shows that empirical economists usually divide a firm's sales growth into two components, variations in the firm's total factor productivity (TFP) and variations in the firm's resources. Combining both perspectives, the TFP has been proposed in the management (Dutta et al. 2005) and entrepreneurship (González-Pernía et al., 2012; Croce et al., 2012) literatures as an operative measure of the economic importance of differences in the aggregate capabilities of firms or groups of firms. Furthermore, using the terminology of Zahra et al. (2006), the longitudinal analysis adopted in this work allowed us to compare the economic effects of firms' (current) substantive capabilities and also their dynamic (capacity to improve) capabilities.

In empirical terms, this paper compares the evolution of the total factor productivity (TFP) of university spin-offs with that of other technology-based firms (NTBFs) on an unbalanced (since company information is not available for all years) data panel, which covers financial information on 177 Spanish high-technology firms over a twelve-year period (1994 to 2005). According to our estimations, university spin-offs begin to have greater TFP after two or three years of operation. The capabilities used by university spin-offs to develop and exploit new businesses, in the long term, are of higher economic value than those used by other NTBFs. The evolution of estimated TFP indicates that university spin-offs initially possess lower substantive capabilities but show higher dynamic capabilities than other NTBFs. Those dynamic capabilities are economically relevant. This is a basic assumption behind the demands for specific public support for university spin-offs. The evidence is relevant both for policy makers in terms of the distribution of public resources and for university managers in claiming for said resources.

Differences in substantive capabilities have mainly been justified in the literature by two arguments, lack of managerial capabilities and differences in the technical development of projects. We discuss the relationship between those arguments and the differences in dynamic capabilities detected in the paper and we evaluate the consistency of those explanations with the evidence generated.

The paper is organized as follows. The following section engages with three theoretical questions. First, it summarizes previous literature on differences in managerial capabilities between university spin-offs and other NTBFs in order to develop hypotheses on initial differences in their substantive and dynamic capabilities. Second, it discusses alternative explanations to these hypotheses, particularly concentrating on the literature that emphasizes technological differences. Third, it discusses TFP as a measurement of firms' capabilities. Section 3 describes the data used and the empirical tests are presented in Section 4. Section 5 summarizes and discusses the main findings and limitations of the paper. Section 6 presents the conclusions.

2. Theory and hypotheses

2.1. General conceptual framework and main hypotheses

From an empirical perspective, there is some evidence of the economic under-performance of university spin-offs in comparison with other NTBFs. Ensley and Hmieleski (2005) compared two samples of 102 university spin-offs and 154 independent NTBFs in the southeast of the United States. Based on survey data, they report lower net cash-flows and a lower rate of sales growth during the previous five years for university spin-offs. From a cross section database of US firms backed up by venture capitalists, Zhang (2009) compares the performance of 483 university spin-offs versus 3,150 independent start-ups and found a lower probability of making profits and a lower level of employment, although the significance of those parameters depends on the controls used.

From a theoretical perspective, the RBV is a common framework for explaining differences between firms' performance and has guided most empirical work related with research-based spin-offs (Mustar et al., 2006). Those differences are attributed to two sources: the firms' resources and the firms' capabilities. The RBV literature also distinguishes between substantive and dynamic capabilities. Substantive capabilities are the firm's current ones, while dynamic capabilities are those that increase substantive capabilities, reconfiguring internal and external competences (Teece et al., 1997) over time [see Zahra et al., (2006), for further discussion of this distinction].

Notice that while the empirical literature points out differences in performance, it remains silent on the contribution of capabilities to such differences. The firm has contractual rights to its resources but not to its capabilities. Thus, it is difficult to distinguish which capabilities belong to the firm and which to the people who combine and transform the resources, mainly the entrepreneurs and/or managers. Although both kinds of capabilities could be economically relevant, most of the theoretical arguments used to explain the underperformance of the university spin-offs are based on differences in the entrepreneur or founder capabilities.

This is due to the fact that the available evidence on university spin-offs (Darby and Zucker, 2003; Ensley and Hmieleski, 2005) showed that, in most cases, the academic entrepreneur was also the owner and manager of the firm for the initial years of operation. For example, from a questionnaire sent to a sample of Spanish university spin-offs that had been in operation for an average of 3.8 years, Ortín et al. (2007) show that the original founders retained, on average, 90% of the firm's ownership and in 86% of cases were still the senior managers of the firm. Those figures were similar for a comparative sample of high-tech firms. Additionally, certain authors (Heirman and Clarysse, 2004) argue that—in new firms—the founders' managerial capabilities seem to be the most relevant factor because the firm's capabilities (for example, organizational systems, routines or relationships between the firm's members) are probably far less developed.

Ample evidence shows that the level of previous managerial experience is an indicator of the current entrepreneur's managerial capabilities (Agarwal et al., 2004; Boeker, 1989; Kimberley, 1979; Klepper, 2001; Schein, 1984). Moreover, with regard to university spin-offs and other NTBFs, extensive evidence suggests that there are significant differences in managerial and industrial experience between founders of university spin-offs and other NTBFs (Chrisman et al., 1995; Colombo and Delmastro, 2002; Ensley and Hmieleski, 2005; Ndonzuau et al., 2002; Siegel et al., 2003). For example, Shane and Khurana (2003) show that in 1,397 MIT-assigned inventions between 1980 and 1996, only 21% of the research teams had at least one founder with previous industry experience. Consequently, some authors argue that a lack of managerial skills may directly influence the behaviour of academic entrepreneurs (D'Este et al., 2012; Landry et al., 2006) and thus the performance of university spin-offs (Roberts, 1991; Shane, 2004; Vohora et al., 2004). We therefore formulate the following hypothesis:

Hypothesis 1: University spin-offs have lower endowment of initial *substantive* capabilities than other NTBFs.

In comparative terms, it could be argued that academic entrepreneurs on average have little managerial experience because they have devoted more time to applied research and knowledge-generation than is the case for other entrepreneurs. This fact could affect their dynamic capabilities.

Clarysse and Moray (2004) describe the learning process for the founding members of a university spin-off from different critical situations and how this process affects the reorientation of the firm's activities in adapting to a competitive environment. They illustrate the difficulties of acquiring such knowledge from external sources, such as for example venture capitalists (Ortín-Angel and Vendrell-Herrero, 2010).

In fact, in the literature on organizational learning (Huber, 1991; Yeo, 2005 or Thomas and Allen, 2006), it is usually assumed that people and organizations have different modes of learning of differing efficiency. Existing research (see Zahra et al., 2006 p. 933-936 for a summary) has identified four learning modes: (i) *Improvisation*, (ii) *Trial-and-error* learning, (iii) *Experimentation* and finally (iv) *Imitation*. More or less explicitly, the knowledge acquisition literature seems to postulate that, although *Experimentation* might be the most expensive mode, it is also the one that provides higher-quality knowledge: "knowledge or behaviours gained are more likely to be generalizable, systematic, and contain information about main and interaction effects" (Table 2 in Miner et al., 2001, p. 319). For example Argyris, one of the most representative authors in this field, observed the following in 1991:

"Once companies embark on this learning process, they will discover that the kind of reasoning necessary to reduce and overcome organizational defenses is the same kind of `tough reasoning' that underlies the effective use of ideas in strategy, finance, marketing, manufacturing and other management disciplines. Any sophisticated strategic analysis, for example, depends on collecting valid data, analyzing it carefully, and constantly testing the inferences drawn from the data. The toughest tests are reserved for the conclusions. Good strategies make sure that their conclusions can withstand all kinds of critical questioning." (p.11)

Even Nevis et al. (1995) suggest that "managers need to learn to act as applied research scientists at the same time as they deliver products and services" (p. 80). Universities are perhaps the oldest institutions specializing in generating knowledge. If their members, most particularly applied research scientists, have more expertise in the experimentation-learning process, we would on average expect academic entrepreneurs to be more efficient, or to have an advantage in the learning process or in organizing such processes inside firms, especially when this process takes time to be assumed and implemented. We therefore formulate the following hypothesis:

Hypothesis 2: University spin-offs have higher endowment of *dynamic* capabilities than other NTBFs.

There is evidence that seems to be consistent with this hypothesis. In contrast to other NTBFs, over time, university spin-offs reduce the level of relationship with their parent institutions, focussing instead on new commercial connections (Pérez-Pérez and Martínez-Sánchez, 2003).

The above arguments understand university spin-offs as a homogenous category. However, certain authors (see for example Druhile and Garnsey, 2004 or Van

Geenhuizen and Soetanto, 2009) criticize this perspective and provide evidence on behavioral differences among categories of academic spin-offs. Such categories are usually based on a firm's economic activities or degree of innovativeness. It is difficult to argue that other NTBFs cannot also be classified in these same categories. For our research purposes, the point is not whether firms' behavior differs among categories, but rather whether differences among university spin-offs and other NTBF capabilities are maintained across categories. We leave this as an open theoretical question to be responded by empirical evidence. Nevertheless, for the convenience of argumentation, we formulate the following hypothesis:

Hypothesis 3: Differences in the substantive and dynamic capabilities of university spin-offs are independent of their economic activities.

2.2. Evaluating alternative explanations

Hypotheses 1 and 2 can also be explained by any capability that meets the following two conditions: 1) university spin-offs are less endowed of such capability at the outset and 2) this capability is developed over time at decreasing rates. If these conditions do not change among economic sectors, Hypothesis 3 also will be predicted (for a formal discussion see Appendix 1).

Current evidence appears to suggest that technical capabilities accomplish both conditions. Jensen and Thursby (2001) indicate that 71% of university inventions are at such an embryonic stage that commercial success requires further product development. Löfsten and Lindelöf (2005) corroborate this finding, claiming that average product-development time required by university spin-offs is over 30 months compared to 17 months for corporate spin-offs. On the other hand, there is also evidence to show decreasing rates of technology development over time. In this regard, technology development shares similar patterns to product development, which has been broadly analyzed empirically under the concept of product life cycle –see Klepper (1996) for further discussion.

However, the presence of decreasing rates of capability development also has other implications: the dynamic-capabilities advantage of university spin-offs will be reduced over time (formally discussed in Appendix 1). To test this, we formulate the following hypothesis:

Hypothesis 4: The higher endowment of *dynamic* capabilities in university spin-offs with respect other NTBFs is reduced over time.

Furthermore, another technical characteristic highlighted in the literature of the university spin-offs projects is that they are also more *cutting-edge* than those developed by other NTBFs. Zucker et al. (1998b; 2002a; 2002b), for example, show how new technological sectors were developed from academics who were directly involved in scientific breakthroughs related to the US biotechnology and Japanese semiconductor industries. They argue that those firms in direct contact with such academics obtained better performance, as measured by patent quality, quantity or product development (Cockburn and Henderson, 1998; Gittelman and Kogut, 2003; Zucker et al., 1998a; Zucker et al., 2002a). Toole and Czarnitzki (2007; 2009) show that, in the case of the biomedical industry, similar success was achieved even in the case of scientists not directly involved in scientific breakthroughs.

The combination of more embryonic and cutting-edge technologies can explain hypotheses 1 and 2 (see appendix 1 for a formal discussion). For this to occur, other NTBFs must also have dynamic capabilities.

Hypothesis 5: Other NTBFs have positive *dynamic* capabilities.

Furthermore, we would expect that more cutting-edge technologies, as with different technologies, will also be reflected in the higher productivity (or elasticities of production) of particular inputs and not only in an increase of capabilities. To test this, we formulate the following hypothesis:

Hypothesis 6: The inputs productivities of university spin-offs are higher than in other NTBFs.

2.3. Measuring aggregate capabilities

Following Dutta et al. (2005) the firms' endowment of capabilities can be formalized through standard production functions. Departing from Solow (1958), we assume that the level of output sold by one firm *i* in its year *y* of operation, Q_{iy}, depends on the quantities X_{jiy} of each of the *J* resources (or inputs) used (j=1,…,J), and on the firms' substantive capabilities used, or TFP, at each year of operation, A_{iy}. Dynamic capabilities would imply differences in the substantive capabilities (TFP) of one firm (*i*) over the course of its operations (*y*). From the research question formulated we propose the following production function:

$$Q_{iy} = A_{iy}\, f(X_{1iy},\dots,X_{jiy},\ \dots X_{Jiy}) = e^{a+\lambda_1 USO_i+\lambda_2 y+\lambda_3 USO_i y}\, f(X_{1iy},\dots,X_{jiy},\ \dots X_{Jiy}) \qquad (1)$$

USO_i is a dichotomous variable (1 for university spin-offs and 0 otherwise). The parameter a measures the substantive capabilities (TFP) of the other NTBFs (USO_i=0) at the outset (y= 0). The parameter λ_1 captures the difference in substantive capabilities (differences in TFP) between university spin-offs and other NTBFs at the outset (y= 0). From Hypothesis 1 we expect that $\lambda_1<0$.

The parameter λ_2 is the annual growth of the TFP of other NTBFs (USO_i=0), Ln (A_{iy} / A_{iy-1}) = λ_2. From Hypothesis 5 we expect that $\lambda_2>0$. The parameter λ_3 is the difference in the annual growth of the TFP (difference in dynamic capabilities) between university spin-offs and other NTBFs. From Hypothesis 2 we expect that $\lambda_3>0$.

Under this approach, the TFP reflects the differences in firms' sales that are not explained by differences in exploited resources, or, in accordance with RBV terminology, that are explained by differences in firms' capabilities. For example, firms can rent facilities to their parent institutions or outsource activities. In both cases, they reduce fixed assets by increasing current assets or expenses. The function f captures how different combinations of those resources affect production and this function will be determined by the data. Then, those effects are separated from firms' substantive capabilities (TFP).

Obviously, those capabilities have been used; therefore, latent or ineffective capabilities (Argyris and Schon, 1978 p. 323; Fiol and Lyles, 1985 p.803) are not considered. TFP by itself does not provide indications of exactly what capabilities are behind those differences, of the relative importance of each capability or of how those capabilities are affecting the business model. However, TFP does provide an evaluation of the economic importance of differences in firm's aggregated capabilities.

3. Data

3.1. Data Collection

To test the hypotheses formulated we use an unbalanced data panel which covers financial information on 104 Spanish university spin-offs and 73 other NTBFs for the 1994-2005 period. As in many other countries, in Spain there is no official or unofficial census of university spin-offs or NTBFs, so this subsection describes how we collected this data.

Inspired by the Bayh-Dole Act (1980) and the Federal Technology Transfer Act (1986), and like many other European countries, including France, Italy, and the UK (Geuna et al. 2003), Spain adopted legislation transferring the right to own and license inventions stemming from government-funded research to universities. From the beginning of the 1990s, and based on these legislative changes, many Spanish universities have been developing official programs that devote resources to the support of entrepreneurial activities. Those supported are mainly researchers; however, they can also include undergraduates or other workers.

To identify the firms founded under such programs, we contacted the Technology Transfer Offices (TTOs) in all 58 Spanish universities in March and April 2006. From 30 of these TTOs we obtained 496 names of spin-offs and their activity description. These figures are close to those that the *Red Otri* (the association of Spanish TTOs) provided in its annual reports (Ortín et al., 2008). From the activity description, around 80% of these firms can be classified into the following NACE'2008 codes: 62

Computer science, 72 Research and development, 71 Engineering, 20 Chemicals and 61 Telecommunications. There is a clear group of firms (4%) dedicated to Biotechnology activities (subsector 72.11) with the remaining firms (16%) being a set of heterogeneous technology companies classified in ‘other sector’ categories. Using university of origin information, firms can be classified in five geographical areas (Madrid, Catalonia, the Basque Country, Valencia, and Andalusia).

To identify comparable NTBFs in terms of activity and geographical distribution, we followed Quintana-García and Benavides-Velasco’s (2005) strategy of looking for those firms on the website of the *Centro para el Desarrollo Tecnológico Industrial* (CDTI), an agency of the Spanish Ministry of Industry, Tourism and Commerce, that promotes innovation and technology development among Spanish companies. Those firms have developed innovation projects supported by the CDTI. Those projects are selected mainly on the basis of their entrepreneurial viability. We identified 167 NTBFs and checked that none of these firms were listed among the 496 previously identified university spin-offs.

From this first step, we obtained two lists of firms classified by their activity and geographical distribution. All Spanish corporations must present information about their foundation, their annual financial statements, and their dissolution, among other documentation, to the “Registro Mercantil.” Bureau Van Dijk collects and sells this information under a database called SABI. Therefore we proceeded to look at SABI for the financial information of the firms identified. We finally could download available information on the balance sheets and income statements of 104 university spin-offs and 73 other NTBFs. In terms of the variables available (geographical and sector distribution), there are no significant differences between the initial list of firms and the firms finally found in SABI.

The older firm was founded in 1994, so we analyze a period of 12 consecutive years, until 2005, the last period available when the data was collected. Given firms' discretion in fulfilling legal information requirements and common with other studies using secondary accountancy databases (García-Lara et al., 2006), financial information was missing for several years. The 104 university spin-offs have a total of 347 observations and the 73 other NTBFs have 333 observations. During the period analyzed none of the firms has appeared in SABI as legally dissolved.

Table 1 compares the distribution of the foundation year, the number of observations, and the missing data on university spin-offs and other NTBFs in the sample.

[Insert Table 1 here]

As can be seen in the last row of Table 1, the other NTBFs on average had more observations per firm (4.56 versus 3.33) because they are older. On average, other NTBFs were 2.25 years (2.25= 2002-1999.75) older than university spin-offs but also had 1.02 years (1.02=1.67-0.65) more of missing data (4.56-3.33=2.25-1.02).

Djokovic and Soutaris (2008) report that the annual number of spinouts increased from 202 in 1996 to 424 in 2001 in the US, a sharp rise of spinout creation between 1996 and 2001 has also been reported in the UK from an average of 94.8 per year in the 4 years up to the end of 2000 to the 175 created in 2001. According to information from *Red Otri* a similar process occurred in Spain. The number of university spin-offs created each year in Spain was growing until the opening years of the current century, when it stabilized and the data reflects this process. The first column of Table 1 shows that the year 2000 is the first quartile of the founding-year distribution of university spin-offs, while it is the second quartile in the case of other NTBFs (second column).

Red Otri's annual reports provided yearly information only on the number of firms created after the year 2000 and only on the total number of firms founded previously. From the information provided by these reports it was possible to compute the percentage of university spin-offs created in Spain in each year of our sample. This data is shown in Figure 1. The representativeness of each year was broadly similar, the exception being the firms created in the last two years of the period analyzed, which were under-represented.

[Insert Figure 1 here]

This latter fact can be explained by the delay between the time when firms present their information to the "Registro Mercantil" and when this information finally appears in SABI. To corroborate this explanation, we counted the missing values for university spin-offs and other NTBFs in the last two years of the study. In both cases, the year 2005 concentrated 40% or more of the total missing data while around 65% were concentrated in the years 2004 and 2005.

3.2. Definitions of Variables and Sub Samples

We constructed the variables related to resources and output using the balance sheet and income statement information obtained from the SABI. We used accounting data (monetary values) for economic purposes (physical units) making it necessary to deflate the monetary variables using accurate deflator price indexes. All the monetary variables were deflated to 1994 € equivalents.

Output was measured by *Net Sales (Q)*. We calculated the total sales as reported on SABI and deflated them by two-digit industry level deflators (Brynjolfsson and Hitt 2003; Wakelin 2001). The sectors included computer science, R&D, engineering, chemicals, biotechnology, and telecommunications. We constructed the deflator indexes using information obtained from the INE (Spanish Institute of Statistics).

We considered the following resources:

Fixed Assets (*KF*): We computed this variable using the book value of total fixed assets in SABI. Consistent with Wakelin (2001), we deflated it based on the capital investment price index (INE). It should be noted that it was necessary to deflate this figure using the price index for the year of acquisition (Hall, 1990; Hernando and Nuñez, 2004), where the year of acquisition equals the current year (*t*) minus the age of the fixed assets (*Age*). To estimate the age, we divided accumulated amortization by current amortization. Using the method first proposed by Hall (1990), we then divided the book value of the total fixed assets (KF_{BV}) by the price on the date of acquisition ($KF = KF_{BV}/[Price\ index\ (t\text{-}Age)]$).

Current inputs (*KC*): We calculated this variable on the basis of operating expenses net of depreciations, amortizations and labor expenses. The consumption of materials (intermediate goods) is usually its most important item. Following Hernando and Nuñez (2004), we deflated the current inputs using the industrial intermediate goods price index (IPRI from INE).

Labor expenses (*LE*): This variable was obtained directly from SABI and was deflated using the INE's labor cost index (harmonized and corrected).

Since the firms' information is not observed for all years, we created a variable to calculate the operating period of the firm (*y*): the year that refers to the financial information (*t*) minus the founding year according to SABI information.

Throughout the process of data collection, we obtained time invariant information on the firms. Whether the firm was a university spin-off (*USO*), in what geographic region the firm had its legal address (we grouped them into five regions: Madrid, Catalonia, Basque Country, Valencia, and Andalusia), the economic sector in which the firm operated (computer science, R&D, engineering, chemicals, biotechnology, telecommunications, and other sectors), and what its founding year was. Twelve dummy variables for the founding year can cause mulitcolinearity, and so this information was summarized in a dummy variable, *Founded before 2000*, using value 1 if the firm was created in the 90s and 0 otherwise. We recall that the year 2000 is when the annual number of spin-offs created in Spain stabilizes after an initial growing period. *Missing data* has been computed as the difference between the number of observations that in a balanced data panel would refer to a firm (2006- founding year) and the number of observations that really refer to this firm.

Table 2 reports the descriptive statistics of all the variables. Main differences between university spin-offs and other NTBFs appear in their geographical distribution, founding year and missing data. In order to control that our results were not caused by these differences, or by the fact that university spin-offs were overrepresented, we proceeded by constructing a sub-sample of matched firms following propensity score-matching literature. We estimated a probit using university spin-off (*USO*) as the dependent variable, and the independent variables were the others measured at the time of the firms' foundation. The average difference in the matching scores (Leuven and Sianesi 2003) between university spin-offs and other NTBFs were statistically significant at 1%.

[Insert Table 2 here]

We follow the nearest neighbor without replacement methodology (Deheija and Wahba, 2002) and with a caliper (which sets a maximum distance between potential pairs) in order to maintain the largest number of firms with insignificant differences in their matching scores. When the caliper was 0.12, we could not reject the null hypothesis that the average propensity scores for university spin-offs and other NTBFs were equal (p-value = 0.192). This matched sub-sample contained 78 firms (39 university spin-offs and other NTBFs) and 290 observations (128 university spin-offs and 162 other NTBFs). Descriptive statistics of the matched subsample are reported in Table 3.

[Insert Table 3 here]

4. Results

4.1 Econometric Approach

In each period analyzed, information is available on firms with different years of operation. The years of operation of firm *i* at period *t* can be computed as: $y_{i,t} = t$- founding year of firm *i*, and will take different values for different firms observed in the same year *t*. In fact, the dependent variable of the study will be the net sales of firm *i* in year t, $Q_{i,t}$. From Equation (1) and, as is customary in the applied literature (Chambers, 1988), we assume that the production function *f* would conform to a Cobb-Douglas (1928) function and that there are error terms, the logarithm of $Q_{i,t}$ can be expressed as:

$$Ln\,Q_{it} = a + \lambda_1 USO_i + \lambda_2 y_{it} + \lambda_3 USO_i y_{it} + \beta_1 LnKF_{it} + \beta_2 LnKC_{it} + \beta_3 LnLE_{it} + \varepsilon_i + \varepsilon_t + \varepsilon_{it} \quad (2)$$

where β_j is the elasticity of production with respect to the resource j ($KF= X_1$; $KC= X_2$; $LE= X_3$). We have estimated other functional specifications, like Translog functions. The main results are maintained, so for space considerations we do not provide such estimations in the text.

In order to take full advantage of the information content in panel data is recommended to decompose the error term in a firm persistent effect, ε_i , a year effect ε_t and a specific error term for firm i at year t, ε_{it} .This lets control for time trends and firm invariant characteristics. The analyses conducted and previous evidence (Mas-Ivars and Quesada-Ibañez, 2006) do not found significant time trends in the TFP growth at Spanish firms during the period analyzed. Regarding firms invariant characteristics, part of the literature on Stochastic Frontier Models suggests comparing firms on the basis of differences between the firm-fixed effect and the highest estimated firm-fixed effect. This is simply a scale change from our proposal. For further insight, see Greene (2005).

It should be noted that the model's estimated parameters and explanatory capacity will not be modified on the addition into the analysis of any persistent variable (for example, company's founding year, characteristics of the founding team or—in our study—the economic sector) or of any macroeconomic variable having the same value for all the firms in the same year (year effect). Such information is redundant; it only explains the variability in ε_i among firms and ε_t over time, but does not add additional relevant information to that already available in order to explain production differences. This approach therefore allows the comparison of firms observed and founded in different years.

The specification where ε_i are a set of parameters to be estimated (firm fixed-effects) and ε_t are different realizations drawn from a random variable with a normal distribution (time random-effect) is the one used throughout the paper because it outperforms other possible specifications accordingly with the Hausman's test (1978). Consequently, this specification provides an efficient estimation of the parameters ($\lambda_2, \lambda_3, \beta_1, \beta_2, \beta_3$), but does not provide a direct estimation of λ_1, because of the perfect collinearity between firms' dummies and the variable USO. To proceed with λ_1 estimation, and given that USO is the only time-invariant variable considered in the model, we assumed orthogonality upon the variable USO and unobservable components of the firm's fixed effects terms [for further discussion see Hausman and Taylor (1981)]. Then we estimate λ_1 through Equation (2) without including firms' fixed effects (ε_i =0) and restricting the value of the remaining parameters to those efficiently estimated previously.

We provide clustered (by firm) robust (to heteroscedasticity) standard errors for all the parameters estimated. Then, aside from the normal distribution of the error terms ε_{it}, the main assumption is the independence of these error terms between different firms. So, we do not make explicit assumptions on the variance of these error terms, or about the covariance among the error terms ε_{it} within the same firm [see Petersen (2009) for further discussion]. This means that estimations of standard error are robust with respect, for example, to the interplay in the determination of production of the firm's founding year and its age.

4.2. Hypotheses Tests

Table 4 presents the results of estimating Equation (2) with the full sample and the matched subsample.

[Insert Table 4 here]

In both cases university spin-offs had statistically significant lower TFP than other NTBFs at the outset (λ_1<0, so Hypothesis 1 is supported), but their TFP, on average, grew statistically significantly faster (λ_3>0, so Hypothesis 2 is supported) than did the TFP of the other NTBFs, whose productivity decreased slightly throughout the period analyzed, although we could not reject the null hypothesis that other NTBFs do not have dynamic capabilities during the said period (λ_2=0, so Hypothesis 5 is rejected).

During the second and third year of operation ($-\lambda_1/\lambda_3$) the university spin-offs reached the same total factor productivity as other NTBFs. As early as the fifth year of operation, university spin-offs advantage in productivity is statistically significant at the 5% level.

Model 1 in Table 5 provides the test of Hypothesis 3. By some difference, computer science is the sector that accumulates the largest number of firms (40.7%) while the remaining sectors are highly dispersed. In order to keep the model manageable, computer science (*CS*) is the only economic sector considered. We therefore introduce this variable and its interaction terms with the determinants of TFP into Equation 2. None of the coefficients estimated for the computer science sector or their interactive terms are statistically significant. Other specifications not shown in the text have been tested. For example, comparison of more *consultancy-oriented* sectors (computer science, R&D and telecommunications) with those that are more focused on *technology development* firms (the rest). Conclusions are similar. Consequently, we find no evidence that the economic sector specifically affects the TFP pattern of university spin-offs (Hypothesis 3 is supported).

Model 2 in Table 5 presents the estimation for the full sample including quadratic terms of the years of operation in Equation (2). The increase in the explanatory power (R^2) of the model with respect the baseline model (Table 4, full sample estimation) is nearly zero and therefore not statistically significant; so, we found no evidence that TFP decreased over time or that the TFP annual growth advantage of university spin-offs began to decline at any point. Consequently, we find no support for Hypothesis 4.

We now focus on the elasticities of production estimated in Table 4. In the case of the full sample, the estimated elasticity of production with respect to fixed assets (β_1) was 0.0679, which was not statistically significant. The elasticity with respect to current inputs (β_2) was 0.238 and with respect to labor expenses (β_3) was 0.679, which were statistically significant at 1%. Similar results were obtained for the matched subsample . In fact, we could not reject the null hypothesis that $\beta_1 + \beta_2 + \beta_3 = 1$ so these technologies present constant returns to scale. In accordance with Model 3 of Table 5, these elasticities are fairly stable over time and among university spin-offs and other NTBFs, so there is no support for differences in production elasticities, Hypothesis 6.

[Insert Table 5 here]

4.3. Further considerations

Following Mahadevan (2002) we broke down the firms' annual sales growth into growth caused by increases in TFP and growth caused by increases in resources (see Appendix 2). The annual sales growth rate for university spin-offs and other NTBFs is practically the same, around 27.5%. But the other NTBFs' annual sales growth is entirely attributable to increases in resources. While in the case of university spin-offs the increase in resources accounted for only 75% of the total sales growth of university spin-offs, the remaining 25% stemmed from improvements in TFP.

The estimations presented yield results comparable to those obtained in other studies using general samples of Spanish firms. For the 1990–1999 period, Fariñas and Martín-Marcos (2007) estimated elasticities of production for fixed assets, current inputs, and labor of approximately 0.036, 0.58 and 0.23, respectively. Therefore, in our sample of hi-tech firms, production was more sensitive to the labor factor than it was in more traditional firms. While Fariñas and Martín-Marcos (2007) did not find constant returns, Sanchez-Mangas (2007) found constant returns for a representative set of Spanish manufacturing firms for the 1990–2002 period. Unfortunately, Sanchez-Mangas did not specify the estimated production elasticity values.

Using a similar methodology, Mas-Ivars and Quesada-Ibañez (2006) estimated that TFP growth (elasticities were not reported) was -0.0141 for the 1995–2004 period. In addition, Fariñas and Martín-Marcos (2007) estimated a slightly higher TFP growth (ranging from -0.01 to 0.02) for the 1990–1999 period. Therefore, the TFP growth rate estimated in a general sample of firms was close to that estimated for other NTBFs, fairly close to zero, and lower than those estimated for university spin-offs.

5. Discussion and limitations

The evidence provided shows that the substantive capabilities, or TFP, of university spin-offs in the first year of operation are significantly lower than those of other NTBFs (Hypothesis 1 supported). On the other hand, when introducing a dynamic perspective the TFP growth of university spin-offs, or their aggregated dynamic capabilities, is economically and statistically greater than those of other NTBFs (Hypothesis 2 supported). These results are similar in the different sectors analyzed (Hypothesis 3 supported). Over time, the TFP of university spin-offs increased, while in other firms it remained virtually constant (Hypotheses 4 and 5 not supported). University spin-offs needed approximately two or three years to achieve the same productivity as their non-academic counterparts. In the fifth year of life, the university spin-offs' TFP was greater than the TFP of other NTBFs at statistically significant levels. Furthermore, there is no evidence that the particular productivity of any of the resources analyzed is higher in university spin-offs than in other NTBFs (Hypothesis 6 not supported). In summary, the results suggest that, in the long-term, university spin-offs have greater capabilities for developing wealth-creating business models than is the case for other NTBFs; nevertheless, as detected by previous literature (Ensley and Hmieleski, 2005; Zhang, 2009) this is not the case during their first two or three years from inception.

We can not interpret our evidence against the view of Harrison and Leitch (2010) that previous literature may have exaggerated the role of university spin-offs as a development engine in western economies. However, the results presented here justify in economic terms that authorities and policy makers give more attention to university spin-off development than to other entrepreneurial ventures. It should be noted that, as this paper does not evaluate current public programs supporting university spin-offs, we cannot evaluate the state of such support.

As with all empirical research, our evidence could be subject to possible sample biases, and limited by the methodological approach followed and the variables available.

We conducted several tests and construct a matching subsample to ensure that sample biases are not driving our results. We believe that our results could be extrapolated to the Spanish population of university spin-offs and other NTBFS, and to European countries with a similar institutional system over the period analyzed. Obviously, future research is needed to reinforce the validity and consistency of the results presented here for other times and institutional contexts.

We deem the methodological approach followed to be conservative in that it neglects the externalities that the creation and development of a firm can generate in the economy. Zucker et al. (1998b; 2002a; 2002b) or Toole and Czarnitzki (2007; 2009) provide examples of such externalities in the biotechnology, semiconductor or biomedical industry. Previous evidence (Pérez-Pérez and Martínez-Sánchez, 2003) seems to suggest that we might even be underestimating the relative economic importance of university spin-offs. Future research should explore differences between the economic externalities of university spin-offs and other NTBFs, such as spillovers (Bathelt et al., 2010, Ponds et al., 2010) at regional level.

The empirical research presented is based on financial information. Among other limitations, this does not allow exploration of the differences in particular capabilities, such as the development of innovative products, nor in the businesses models driving our results. Derived from previous literature, we postulate three theoretical explanations of Hypotheses 1 and 2 that do not make distinctions among firms' economic activities; they are therefore also consistent with Hypothesis 3. The first explanation is related to the managerial and learning capabilities developed by the founders of university spin-offs and other NTBFs previous to their foundation. University spin-off founders have fewer managerial skills but greater experience in knowledge generation. The remaining two explanations are related to the usual development stages of technologies. Both explanations build on the fact that university spin-offs have more embryonic technologies (Jensen and Thrusby, 2001; Löfsten and Lindelöf, 2005). Hypotheses 1 and 2 could be explained by decreasing rates of technological development (Klepper, 1996) or also because university spin-offs use more cutting-edge technologies (Toole and Czarnitzki, 2007). These explanations based on technological aspects imply other relationships (Hypotheses 4 to 6) not supported by the data.

The differences in managerial capabilities is an explanation fully compatible with the evidence presented in this paper, nevertheless the evidence provided is far to be conclusive. This encourages further research to present evidence on the concrete managerial capabilities that are behind the differences in TFP detected in this paper and provide further evidence that such differences are present along different firm features than those analyzed here. This research stream should also determine whether an entrepreneur’s academic capabilities are learnt, as we previously suggested, or are innate. If they were innate, an alternative explanation could follow the self-selection argument (Jovanovic, 1982). Graduates working at universities (i.e. academics) have a greater innate ability to learn than those who work in the private sector. The fact that during the period analyzed the Spanish labor market accentuated wage differences between the private sector and public universities would argue against this explanation.

In fact, the results provided could also be explained by a combination of the different explanations cited throughout the paper or even by other unexplored capabilities of firms. Future research combining accountancy and survey databases can seek and test for the specific capabilities behind the differences in TFP detected in this paper and their implications on businesses models.

6. Conclusion

This paper presents evidence to suggest that university spin-offs have less aggregate substantive capabilities at the outset but more aggregate dynamic capabilities than other NTBFs. Evidence for other contexts is needed to reinforce our results. A higher learning capability of academic entrepreneurs seems to be the theoretical explanation that is the most consistent with the evidence available, but the results are far from conclusive. Further research is needed to provide better tests of the explanations set out here and to develop new theoretical explanations.

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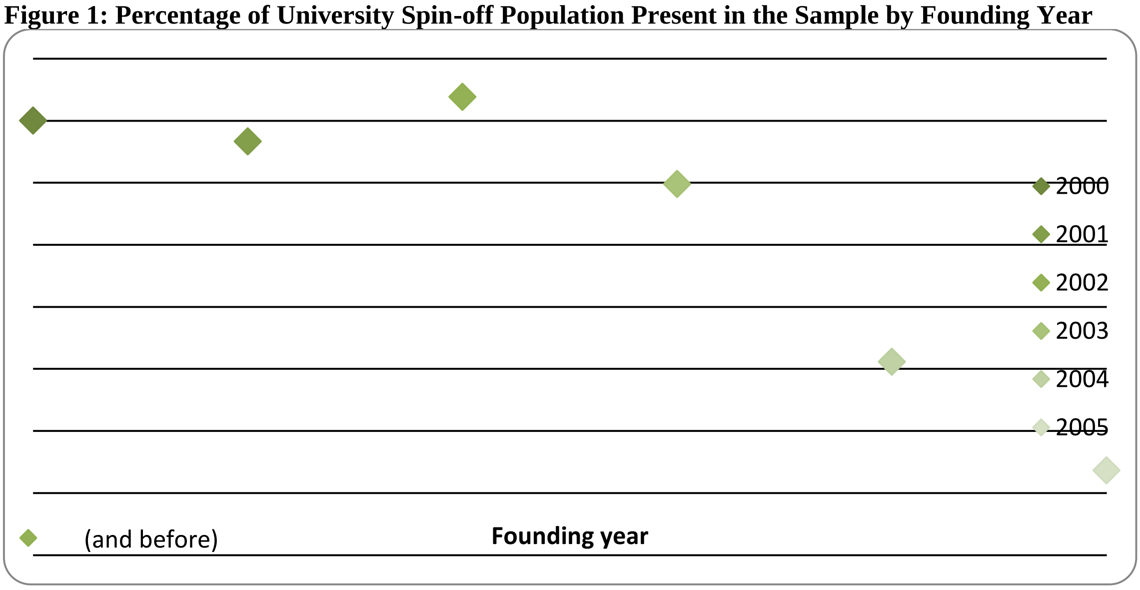
Table 1: Foundation Years, Number of Observations and Missing Data for Firms in the Sample

	FOUNDATION YEAR			#OF EACH FIRM OBSERVATIONS			# OF EACH FIRM MISSING DATA		
	USO	Other NTBFs	ALL	USO	Other NTBFs	ALL	USO	Other NTBFs	ALL
Min.	1996	1994	1994	1	1	1	0	0	0
1 Quartile	2000	1997	2000	2	3	2	0	0	0
2 Quartile	2002	2000	2002	3	4	3	0	1	1
3 Quartile	2003	2002	2003	4	6	5	1	2	1
Max.	2005	2005	2005	7	11	11	5	10	10
Mean	2002	1999.75	2001.07	3.33	4.56	3.84	0.65	1.67	1.07
Firms #	104	73	177	104	73	177	104	73	177

The oldest university spin-off (USO) was founded in 1996 and at least 25% of USOs are from before or in 2000. The oldest other NTBFs was founded in 1994 and at least 50% of other NTBFs are from before or in 2000. There are firms with only one observation, but these represent less than 25% of the sample. More than 50% of the firms in the sample have at least one year with missing data.

Figure 1: Percentage of University Spin-off Population Present in the Sample by Founding Year



Source: *RedOtri* (2006) www.redotriuniversidades.net
RedOtri offers only aggregated information for 2000 and preceding years.

Table 2: Descriptive Statistics of the Full Sample

CATEGORY		University spin-offs	Other NTBFs	Total
SECTOR	Computer science	44.9%	45.3%	45.1%
		(0.498)	(0.498)	(0.498)
	R&D	12.9%	6.6%	9.8%
		(0.336)	(0.249)	(0.298)
	Engineering	13.0%	13.5%	13.2%
		(0.336)	(0.342)	(0.339)
	Chemicals	6.3%	6.3%	6.3%
		(0.244)	(0.243)	(0.243)
	Biotechnology	4.6%	1.2%	2.9%
		(0.210)	(0.109)	(0.169)
	Telecommunications	4.0%	3.6%	3.8%
		(0.197)	(0.186)	(0.191)
	Other sectors	14.1%	23.4%	18.7%
		(0.348)	(0.424)	(0.390)
REGION	Madrid	8.1%	34.5%	21.0%
		(0.273)	(0.476)	(0.408)
	Catalonia	48.7%	21.0%	35.1%
		(0.500)	(0.408)	(0.478)
	Basque Country	8.6%	15.6%	12.0%
		(0.281)	(0.363)	(0.326)
	Valencia	31.7%	3.3%	17.8%
		(0.466)	(0.179)	(0.383)
	Andalusia	2.9%	25.5%	14.0%
		(0.167)	(0.436)	(0.347)
FOUNDING &	Founded before 2000	9.7%	31.5%	20.4%
		(0.298)	(0.465)	(40.3%)
OPERATION YEAR	Operation year (*y*)	2.71	3.80	3.24
		(1.65)	(2.53)	(2.20)
MISSING DATA	Missing data	0.65	1.67	1.07
		(0.94)	(2.00)	(1.54)
RESOURCES & OUTPUT	KF (thousand €)	188.788	850.289	512.734
		(445.261)	(2 916.282)	(2 090.202)
	KC (thousand €)	97.943	1 417.109	743.947
		(267.697)	(8 529.031)	(6 003.391)
	LE (thousand €)	93.638	429.348	258.037
		(153.936)	(860.392)	(634.224)
	Q (thousand €)	272.425	2 209.310	1 220.929
		(436.424)	(9429.992)	(6 672.036)
	LN(KF)	3.59	4.93	4.25
		(1.889)	(2.020)	(2.065)
	LN(KC)	2.89	3.91	3.39
		(2.034)	(2.355)	(2.254)
	LN(LE)	3.87	4.99	4.42
		(1.172)	(1.424)	(1.416)
	LN(Q)	4.91	5.92	5.41
		(1.258)	(1.667)	(1.556)
SAMPLE SIZE	Observations	347	333	680
	Firms	104	73	177

Mean and standard deviation (within parenthesis) using all the observations

Table 3: Descriptive Statistics of the Matched Subsample

CATEGORY		University spin-offs	Other NTBFs	Total
SECTOR	Computer science	46.9%	47.5%	47.2%
		(0.501)	(0.501)	(0.500)
	R&D	5.5%	6.2%	5.9%
		(0.228)	(0.241)	(0.235)
	Engineering	18.0%	16.0%	16.9%
		(0.385)	(0.368)	(0.375)
	Chemicals	10.9%	4.3%	7.2%
		(0.313)	(0.204)	(0.260)
	Biotechnology	5.5%	2.5%	3.8%
		(0.228)	(0.155)	(0.191)
	Telecommunications	3.9%	7.4%	5.9%
		(0.194)	(0.263)	(0.235)
	Other sectors	9.4%	16.0%	13.1%
		(0.293)	(0.368)	(0.338)
REGION	Madrid	17.2%	37.6%	28.6%
		(0.378)	(48.6%)	(0.452)
	Catalonia	45.3%	37.6%	41.0%
		(0.499)	(0.486)	(0.493)
	Basque Country	17.2%	14.8%	15.9%
		(0.378)	(0.356)	(0.366)
	Valencia	12.5%	5.5%	8.6%
		(0.332)	(0.229)	(0.281)
	Andalusia	7.8%	4.3%	5.9%
		(0.269)	(0.204)	(0.235)
FOUNDING & OPERATION YEAR	Founded before 2000	12.5%	19.1%	16.2%
		(0.332)	(0.394)	(0.369)
	Operation year (*y*)	2.80	3.39	3.13
		(1.76)	(2.40)	(2.16)
MISSING DATA	Missing data	0.87	0.79	0.83
		(1.10)	(0.92)	(1.01)
RESOURCES & OUTPUT	KF (thousand €)	152.279	172.583	163.591
		(219.004)	(243.549)	(232.858)
	KC (thousand €)	103.806	110.926	107.783
		(262.033)	(162.539)	(211.904)
	LE (thousand €)	94.235	152.203	126.617
		(90.638)	(214.772)	(173.605)
	Q (thousand €)	303.689	439.112	379.339
		(421.235)	(568.114)	(51.168)
	LN(KF)	3.92	4.13	4.04
		(1.750)	(1.749)	(1.750)
	LN(KC)	3.02	3.26	3.15
		(1.978)	(2.078)	(2.035)
	LN(LE)	4.08	4.49	4.31
		(1.106)	(1.027)	(1.080)
	LN(Q)	5.10	5.40	5.27
		(1.185)	(1.301)	(1.258)
SAMPLE SIZE	Observations	128	162	290
	Firms	39	39	78

Mean and standard deviation (within parenthesis) using all the observations

Table 4: Initial TFP Differences and Evolution

CATEGORY	VARIABLES	PARAMETER EQUATION 2	FULL SAMPLE	MATCHED SUB SAMPLE
INITIAL TFP	USO	λ_1	-0.175***	-0.491***
			(0.066)	(0.164)
TFP GROWTH	*y*	λ_2	-0.019	-0.046
			(0.035)	(0.052)
	*y*USO*	λ_3	0.088**	0.173***
			(0.039)	(0.051)
RESOURCES	LNKF	β_1	0.0679	0.046
			(0.052)	(0.034)
	LNKC	β_2	0.238***	0.211***
			(0.035)	(0.063)
	LNLE	β_3	0.679***	0.637***
			(0.091)	(0.092)
GENERAL INFORMATION	R^2		0.887	0.833
	R^2 Within		0.666	0.559
	Observations		680	290
	Firms		177	78

Level of statistical significance: *** 1%, ** 5%, * 10%

OLS regression with firm's fixed effects, time random effects, and clustered-robust standard errors (reported within parentheses).

Table 5: Other production function specifications (full sample)

CATEGORY	VARIABLES	Model 1	Model 2	Model 3
INITIAL TFP	USO	-0.239**	-0.169**	-0.200***
		(0.095)	(0.066)	(0.065)
	Computer Science	0.046		
		(0.098)		
	USO*Computer science	0.127		
		(0.131)		
TFP GROWTH	*y*	-0.015	-0.050	-0.027
		(0.028)	(0.117)	(0.047)
	*y**USO	0.120**	0.081	0.154***
		(0.047)	(0.103)	(0.061)
	*y*Computer Science*	-0.005		
		(0.056)		
	*y*USO*Computer Science*	-0.063		
		(0.084)		
	y^2		0.003	
			(0.009)	
	y^2*USO		0.002	
			(0.013)	
RESOURCES	LNKF	0.070	0.069	0.131*
		(0.058)	(0.055)	(0.073)
	LNKC	0.238***	0.238***	0.192***
		(0.035)	(0.035)	(0.056)
	LNLE	0.671***	0.688***	0.696***
		(0.087)	(0.103)	(0.135)
	LNKF*USO			-0.177**
				(0.082)
	LNKC*USO			0.067
				(0.076)
	LNLE*USO			-0.023
				(0.182)
	LNKF*Five&up+			0.094
				(0.072)
	LNKC*Five&up			0.002
				(0.068)
	LNLE*Five&up			-0.096
				(0.094)
	LNKF*USO*Five&up			-0.248**
				(0.120)
	LNKC*USO*Five&up			0.126
				(0.088)
	LNLE*USO*Five&up			-0.032
				(0.200)
GENERAL INFORMATION	R^2	0.887	0.887	0.891
	R^2 Within	0.667	0.666	0.678
	Observations	680	680	680
	Firms	177	177	177

Level of statistical significance: *** 1%, ** 5%, * 10%

OLS regression with firm's fixed effects, time random effects, and clustered-robust standard errors (reported within parentheses).

+Five&up is a dummy variable with value one when the year of operation is five or more, and zero otherwise. We performed cross-section regressions for each year that the firms were in operation. This analysis enabled us to observe whether the elasticity values of the resources varied over time. We observed clear differences only after the fifth year of operation.

Appendix 1: Formalizing the TFP and Technological Development Relationship.

Let us assume that the substantive capability or TFP (see section 2.3. for details) is determined by the stage of technology development ($l_{i,y}$) of firm *i* at year *y* as follows: $A_{iy} = e^{g(l_{i,y})}$. *Embryonic technologies* imply that on average the technological stage of other NTBFs will be greater than those of university spin-offs with the same years of operation. For simplicity, let us assume that the technological stage of university spin-offs is perfectly correlated with their years of operation, *y*, so in formal terms we express the stage of technology development for firm *i* at year *y* as follows: $l_{i,y}=y + d(1- USO_i)$, where $d>0$ is a parameter measuring the embryonic technological level of university spin-offs. The two theoretical explanations cited in our text (Section 2.2.) imply different functional forms of *g*().

1*) Decreasing rates of technological development* are captured by the following function: $g(l_{iy}) = \alpha + bl_{i,y} - \frac{c}{2} l_{i,y}{}^{2}$. The technological development is captured by a positive parameter *b*, while the decreasing rate of technological development is captured by a positive parameter *c*. In order to rule out the possibility of technological recession, or in other words, that TFP decreases at some point in time, we assume that during the period analyzed, twelve years, $l_{i,y} \leq 12+d \leq b/c$.

Combining the *embryonic technologies* and decreasing rates of *technological development* arguments, the differences in the TFP between university spin-offs and other NTBFs, Ln ($A_{i=USO,\,y} / A_{i=NTBF,\,y}$) $=-bd + cd^2/2 + cdy$, will be negative ($\lambda_1 =-bd + cd^2/2 <0$, Hypothesis 1) at the outset ($y=0$) and university spin-offs TFP will grow faster ($\lambda_3=cd>0$, Hypothesis 2).

These arguments have other implications. Let us express the TFP as $A_{iy} = e^{a+\lambda_1 USO_i + \lambda_2 y + \lambda_3 USO_i y + \lambda_4 y^2 + \lambda_5 USO_i y^2}$.

The parameters of this function are related with the technological parameters (α, *b*,*c*,*d*) as follows: $a=\alpha + bd - cd^2/2$, $\lambda_1= -bd + cd^2/2$, $\lambda_2=b-cd$, $\lambda_3= cd$, $\lambda_4= -c/2$, $\lambda_5=0$. So we can explicitly test for the role of the *decreasing rate of technological development* argument ($\lambda_4<0$) and whether the differences in dynamic capabilities are maintained over time or not ($\lambda_5<0$, Hypothesis 4).

2*) Cutting-edge technologies* can be associated with greater annual growth in the productivity of university spin-offs, so we can assume now that $g(l_{i,y}) = \alpha + (\lambda_2 + \lambda_3 USO_i) l_{i,y}$, where $\lambda_2>0$, $\lambda_3>0$ and α measures the TFP at the technological stage $l_{i,y}=0$.

Combining both arguments, embryonic and cutting-edge technologies, the differences in the TFP between university spin-offs and other NTBFs, Ln ($A_{i=USO,\,y} / A_{i=NTBF,\,y}$), will be negative ($\lambda_1=-\lambda_2 d$, Hypothesis 1) at the outset ($y=0$) and the productivity of university spin-offs will grow faster ($\lambda_3>0$, Hypothesis 2).

This argumentation also implies that the TFP of the other NTBFs grows over time ($\lambda_2 > 0$, Hypothesis 5).

Appendix 2: Determinants of Annual Sales Growth

The expected annual sales growth, E ($Ln(Q_{it} / Q_{it-1})$ of university spin-offs ($\mu_1 + \mu_2$) and other NTBFs (μ_1) can be estimated through the equation:

$LnQ_{it} = a + \mu_1 y_{it} + \mu_2 y_{it} * USO_i + \varepsilon_i + \varepsilon_t + \varepsilon_{it}$

where variables and error terms are those described previously in the text. Using a similar procedure, we can estimate the average annual growth of input *j* in the case of university spin-offs (E ($Ln(X_{jit} / X_{jit-1})$= $\psi_{j1} + \psi_{j2}$) and in the case of other NTBFs (ψ_{j1}).

Following Mahadevan (2002), it is also possible to compute the expected annual sales and, consequently, their growth, using the parameters ψ_{j1} and $\lambda_2, \lambda_3, \beta_j$ of Equation 2:

$$E(Ln(Q_{it} / Q_{it-1})) = \lambda_2 + \lambda_3 USO_i + \sum_{j=1}^{J} \beta_j * \psi_{j1} + \sum_{j=1}^{J} \beta_j * \psi_{j2} * USO_i$$

This allows us to break down the expected annual production growth into growth caused by increases in TFP and growth caused by increases in each input:

$$\mu_1 + \mu_2 USO_i = E(Ln(Q_{it} / Q_{it-1})) = \lambda_2 + \lambda_3 USO_i + \sum_{j=1}^{J} \beta_j * \psi_{j1} + \sum_{j=1}^{J} \beta_j * \psi_{j2} * USO_i$$

Estimations of $\lambda_2, \lambda_3, \beta_j$ for the full sample appear in Column 1 of Table 4. The values of the remaining parameters appear in Figure A1, which summarizes the results of this procedure for the full sample.

[Insert Figure A1 here]

In the full sample, the average annual sales growth for other NTBFs (26.7%) and university spin-offs (28.4%) is virtually the same. In fact, the difference (1.7%) is not statistically significant. Annual sales growth of other NTBFs is entirely attributable to increases in inputs. In the case of university spin-offs, increases in inputs accounted for 75% of total growth (≈21.5/28.40), while the remaining 25% (≈6.9/28.4) stemmed from improvements in TFP. In both cases, the inputs that contributed most to total growth were increases in labor expenses, which were five points higher for other NTBFs (18.5%) than for university spin-offs (13.5%). In both types of firm, the contribution of increases in labor expenses was more than twice that of increases in current inputs (5.73% in the case of university spin-offs) while the increase in current inputs represents more than twice that of increases in fixed assets (2.29% in the case of university spin-offs).

We did the same exercise for the matched subsample (results not reported). The main difference is that the university spin-offs' annual sales growth (32.78%) doubles the sales growth rate of other NTBFs (16.15%), a difference that, at 1%, is statistically significant. The remaining results are similar. Annual sales growth of other NTBFs is only explained by growth in inputs. In the case of university spin-offs, increases in inputs accounted for 61% of total growth while the remaining 39% stems from improvements in TFP. The relative contribution of each of the inputs to the growth in sales is similar to that estimated for the full sample.

Figure A1: Determinants of Annual Sales Growth

Sales growth

USO	NTBF
28.4%	26.7%

$\mu_1 = 0.267$*** (0.048) ; $\mu_2 = 0.017$ (0.072)

TFP Growth

USO	NTBF
6.90%	-1.90%

$\lambda_2 = -0.019$ (0.035); $\lambda_3 = 0.088$*** (0.039)

Input growth

Fixed assets growth (KF)		Current inputs growth (KC)		Labor expense growth (LE)	
USO	NTBF	USO	NTBF	USO	NTBF
2.29%	2.35%	5.73%	7.72%	13.43%	18.53%
$0.0229 = \beta_1(\psi_{11}+\psi_{12})$	$0.0235 = \beta_1\psi_{11}$	$0.0573 = \beta_2(\psi_{21}+\psi_{22})$	$0.0772 = \beta_2\psi_{21}$	$0.1343 = \beta_3(\psi_{31}+\psi_{32})$	$0.1853 = \beta_3\psi_{31}$
$\beta_1 = 0.0679$ (0.052); $\psi_{11} = 0.345$*** (0.077); $\psi_{12} = -0.008$ (0.100)		$\beta_2 = 0.238$*** (0.035); $\psi_{21} = 0.324$*** (0.059); $\psi_{22} = -0.084$ (0.086)		$\beta_3 = 0.679$ (0.091); $\psi_{31} = 0.273$*** (0.033) ; $\psi_{32} = -0.076$ (0.052)	

Level of coefficient statistical significance: *** 1%, ** 5%, * 10% estimated by OLS regressions (see further details in the text) with firm's fixed effects, time random effects and clustered-robust standard errors (reported within parenthesis).