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Abstract

We provide a theoretical model for designing academic spin-off contracts between the university Technology Transfer Office (TTO), the researcher and the venture capitalist. The optimal contract entails the allocation of founder shares to the researcher to secure her participation in the venture, and it may also require the researcher to be financially involved in the project to give her incentives to provide effort. We prove that, when this happens, there may be overinvestment in the spin-off. Finally, we show that when the TTO has more accurate information than the other two participants concerning the likelihood of success of the spin-off, the TTO will *signal* profitable projects by taking financial stakes. Hence, the TTO will end up owning both founder and financial shares in the venture.

Key words

Spin-offs, design of contracts, innovation, universities.

Resumen

Proporcionamos un modelo teórico para el diseño de contratos referidos a *spin-offs* universitarios entre las Oficinas de Transferencia de Tecnología (OTT), investigadores y entidades de capital de riesgo. El contrato óptimo asignará al investigador acciones fundacionales para asegurar su participación en la empresa, con la opción de exigirle a la vez una aportación económica para así incentivar su esfuerzo. Se demuestra que esta situación puede generar un exceso de inversión en el *spin-off.* Finalmente, demostramos que cuando la OTT dispone de información más fiable que los otros dos socios respecto a las probabilidades de éxito del *spin-off,* tenderá a *señalar* los proyectos más rentables por medio de una inversión económica. De esta manera, la OTT acabará siendo accionista de la empresa tanto por vía fundacional como financiera.

Palabras clave

Spin-offs, diseño de contratos, innovación, universidades.

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C O N T E N T S

1. Introduction

NEW technology ventures originating from basic research have the potential to introduce technological disequilibria that shake existing industries and form the gene pool from which new industries may emerge in the long run. Academic entrepreneurship in biotechnology is probably the most striking example of these phenomena (Zucker, Darby and Brewer, 1998). Universities and public research institutes play an important role in this process, as they can be a breeding ground for this new venture creation.

While basic research results can either be channeled to industry via collaborative research schemes or licensing arrangements of patented university inventions, *spinning off* is the entrepreneurial route to commercializing public research. The latter attracts a great deal of policy attention in the current wave of start-ups and new venture creation in many countries. The spin-off formation rate is often seen as a key indicator of the quality of industry-science links. The overall policy perspective is that there is insufficient academic entrepreneurship through own commercialization. Policies are currently being designed to stimulate universities to be more effective in generating spin-offs. In the US, commercial activities by academic institutes were stimulated by the Bayh-Dole act of 1980 and the 1986 Federal Technology Transfer Act (Nelson, 2001 and Mowery et al. 2001). But also in Europe, the role of universities and academic spin-offs for innovation and growth has received increasing policy attention (Geuna, Salter and Steinmueller, 2003). In most countries, ownership of inventions from publicly funded research has been attributed to universities, giving them more leeway for commercialization.

Despite the vast policy attention directed towards the issue, the state of the scholarly debate is still incomplete. The motives for creating spin-offs in innovative high-tech industries and the process governing their formation and success are still not well-understood (Klepper, 2001). While empirical studies in the economics and the management literature have attempted to quantify knowledge transfers from academic research in general through various proxies [1], several empirical papers have examined the emergence of

1. Shane (2002) investigated the licensing of university-generated innovations. Henderson, Jaffe and Trajtenberg (1998) and Mowery (1998) looked at citations to academic patents. Siegel, Westhead and Wright (2003) studied university science parks.

academic spin-off activities in particular. Most of this empirical literature is developing around the factors explaining the emergence of academic spin-offs, such as the quality and nature of the research performed at the university as well as the entrepreneurial orientation and commitment of the university to industry-science links (ISL), particularly through a professional technology transfer office and a proper incentive system for researchers (e.g., Lockett and Wright, 2005; Chukumba and Jensen, 2005; Nerkar and Shane, 2003; Zucker, Darby and Brewer, 1998 and Audretsch and Stephan, 1996). Few empirical studies focus on the success of academic entrepreneurship showing mixed results (Lerner, 2004; Lowe and Ziedonis, 2006). While the direct involvement of academic scientists in industrial activities solves some imperfections in the transmission of knowledge (Zucker, Darby and Brewer, 1998; Etzkowitz 2002), because researchers are driven by academic missions and rules, they are not necessarily the most apt and keen managers of commercial activities.

In the literature on start-ups and spin-offs, careful attempts at matching empirical results and economic theories are still at a pioneering stage [2]. The theoretical literature on spin-offs is especially underdeveloped.

In this paper, we provide a theoretical model for designing academic spin-off contracts between the university *technology transfer offices* (TTOs), the researcher, and the venture capitalist. More particularly, we study how the TTO should allocate financial and founder (intellectual) shares in the venture, taking into account the participation constraint of both the star *researcher* and the *venture capitalists*, the moral hazard problem of researcher involvement in the spin-off, and the asymmetric information problem on likelihood of success. Our main results are the following. The optimal contract entails the allocation of founder shares to the researcher to secure her participation in the venture. However, it may also require her to be financially involved in the project. Even if the unit cost of the capital provided by the venture capitalist is lower than the unit cost of the capital owned by the researcher, the allocation of financial shares to the latter may be the only way to make sure that she really has an incentive to provide effort into the venture. When the moral hazard problem is acute, the need to financially involve the researcher leads to an additional inefficiency, as the optimal contract requires overinvestment in the spin-off.

2. Chukumba and Jensen (2005) present a model explaining when a university invention is commercialized through a spin-off rather than through licensing, considering a spin-off as an option only in case of failure to find a licensor. They also provide empirical analysis comparing the university characteristics explaining licensing versus spin-offs (cf. infra).

Given that it is inefficient for the TTO to finance part of the venture (as the cost of the capital is lower for the venture capitalist), the TTO takes no financial shares. It is the residual claimant of the relationship, hence it gets the founder shares that are left after having compensated the researcher for her participation and both the venture capitalist and the researcher for their financing.

The situation is different if, as we argue in the paper, the TTO has more accurate information than the other two participants concerning the likelihood of success for the spin-off. In this case, the TTO is forced to *signal* profitable projects by taking financial stakes in them. Hence, it ends up owning both founder and financial shares of the ventures.

Since our model builds strongly on empirical evidence, particularly from the KULeuven experience, section 2 summarizes the existing, mostly empirical, literature on academic spin-offs. We discuss the model structure in section 3 and present the results in sections 4 and 5 for the case where all the agents involved have symmetric information concerning the value of the project. Section 6 analyzes the situation where the University TTO possesses more accurate information than the researcher and the venture capitalist about the expected value of the spin-off. All the proofs are included in an appendix.

2. Academic Spin-offs: Determinants and Effects

SIGNIFICANT research has recently been devoted to measuring academic entrepreneurship (e.g., Shane, 2002; Zucker , Darby and Brewer, 1998; Bartelsman, Scarpetta and Schivardi, 2003). A number of empirical studies have investigated why certain universities are more successful in generating academic spin-offs. A decentralized model of technology transfer, through a dedicated and specialized TTO, characterizes most of the universities with a high record of ISLs (see Bercovitz et al., 2001, for the U.S.). Di Gregorio and Shane (2003) found the availability of venture capital funds, the commercial orientation of the university research, the intellectual eminence of the university, and its ISL policy to increase new firm formation significantly. With respect to ISL policy, equity investments by the university TTO in start-ups and low inventor's share of royalties are important catalysts. Also Lockett and Wright (2005) find empirical support for the importance of TTOs for spin-off formation, more particularly their personnel and spending on intellectual property rights, business development expertise and attention to royalty regimes. O'Shea et al. (2005) find strong path dependence in predicting technology transfer activities by universities, although size, faculty quality, and orientation of science and engineering funding and commercial capabilities also predict university spin-offs.

Less examined are the success and growth of academic spin-offs. With respect to spin-off performance, the evidence is mixed. Lowe and Ziedonis (2006) compare the outcomes of academic licenses to start-ups versus those to established firms. They find that royalty income from start-ups for universities is higher on average, but successful commercialization only occurs after acquisition by an established firm. Also, for a sample of MIT inventions, Shane (2002) finds that licenses to start-ups perform poorly compared to licenses to established firms. A number of recent papers have approached the analysis of spin-offs as compared to other start-ups and, within spin-offs, compared university-based to others (e.g., Franco and Filson, 2000; Klepper and Sleeper, 2005; Nerkar and Shane, 2003). This literature has provided different predictions about their post-entry performance and the nature of innovations and new products introduced by spin-offs (imitation, innovation, differentiation from the parent organizations, etc.), and the linkages with their parent organizations (competition versus cooperation). For instance, Klepper and Sleeper (2005) show that in the U.S. laser industry, spin-offs have outperformed other start-ups. Link and Scott (2005) discuss spin-offs at university science parks, and Rothermael and Thursby (2005) discuss those developed at university incubators.

Compared to the recently growing empirical analysis of academic spin-offs, the theoretical analysis remains underdeveloped. Major issues facing universities in technology transfer are first whether researchers have sufficient *incentives* to disclose their inventions and second how to induce researchers cooperation in further development. Although the Bayh-Dole act stipulates that scientists must file an invention disclosure, this rule is rarely enforced. Instead, the university needs to have proper incentive schemes in place, specifying an adequate share for the inventors in royalties or equity. This is studied for researchers' cooperation in commercializing through licensing in Macho-Stadler, Martínez-Giralt and Pérez-Castrillo (1996); Jensen and Thursby (2001); Dechenaux et al. (2003), and with respect to inventor disclosure, in Jensen, Thursby and Thursby (2003). The importance of proper inventor royalty sharing rules for university performance in terms of inventions disclosed and license income is confirmed by Lach and Schankerman (2003). Analyzing panel data on U.S. universities they find that private universities with higher inventor shares have higher license incomes. All of these models focus on licensing rather than on commercialization through start-ups. Nevertheless, the empirical analysis of start-up creation by universities has shown that establishing royalty regimes is also important for improving the creation rate of academic spin-off (e.g., Lockett and Wrigh, 2005).

Even when disclosure is remedied through appropriate incentive schemes, not all inventions will be patented and licensed by the university, which may have to, or prefer to, *shelve* inventions. This relates to another problem in the market for technology transfer, namely the asymmetric information between buyer and seller on the value of the innovations. Buyers typically cannot assess the quality of the invention ex ante, while researchers may find it difficult to assess the potential commercial profitability of their inventions. This problem is studied in Macho-Stadler, Pérez-Castrillo and Veugelers (2005), who use a reputation argument for a TTO to alleviate the asymmetric information problem. Again this model studies licenses rather than development through spin-offs.

Very few theoretical models on technology transfer focus on academic spin-offs. Chukumba and Jensen (2005) develop a model of university licensing, considering the spin-off option in case the TTO is unable to find an established firm willing to purchase the license for the technology. The TTO may assist the inventor in searching for a venture capitalist to fund the start-up but typically will focus its efforts on licensing to established firms. The Chukumba and Jensen (2005) model predicts that start-ups only occur when they earn greater expected profits as compared to an established firm, i.e., when the start-up firm has in advantage in development or commercialization. Their model focuses on the choice between licensing and spin-offs, abstracting from moral hazard problems.

A final issue of relevance for understanding technology transfer activities of universities is the trade-off between applied and basic research and the quality of education when the faculty are engaged in technology transfer (Jensen and Thursby, 2001). In accordance with an institutional approach to the analysis of science (e.g., Dasgupta and David, 1994), academics have specific objectives they pursue, and incentive systems they respond to. More particularly, academics derive direct benefit from fundamental research in the form of publications and peer recognition. Just like industrial actors, academics involved in technology transfer, will respond to economic incentives but also value the peer recognition from applied research and own commercial activities, which may be positive or negative. Lacetera (2005) discusses the decision by academic research teams if and when to undertake commercially oriented activities and their performance, as compared to industrial teams, taking into account the differences in objectives and organizational structures. Also Aghion, Dewatripont and Stein (2005) model the specific characteristics of agents belonging to the scientific community as compared to industrial teams when discussing the decision whether to commercialize. These models are helpful in explaining the differential performance of academic versus non-academic spin-offs and the decision when to license versus spinning off.

In this paper, we provide a theoretical model for how a university technology transfer office should design its spin-off contracts, taking into account the moral hazard problem of star researcher involvement, the participation constraints of the researcher and the venture capitalist, and the asymmetric information problem on success of the venture. Our model builds strongly on empirical evidence from the KULeuven experience. The following box details the organizational features of the KULeuven technology transfer and spin-off process that motivates our model set-up.

Managing spin-off activities within universities: the case of KULeuven LRD [3]

KULeuven Research & Development (LRD) was founded in 1972 to manage the industry component of the R&D portfolio of the Catholic University of Leuven, Belgium. It currently represents about one-quarter of the total university research budget and employs 24 support staff professionals, giving it the critical size, expertise, and experience required for success in technology transfer, as evidenced in most empirical studies, cf. supra.

From its start, LRD has received a large amount of budgetary and human resource management *autonomy* within the university. LRD, although being fully integrated within the university, manages its own budgets as well as the research personnel employed on those budgets. Researchers belonging to different departments and faculties, can decide to integrate the commercial-industrial component of their knowledge portfolio in a *research division* at LRD. A group of innovation coordinators acts as permanent liaison officers between LRD and its divisions, helping to spot and develop ideas fit for commercialization.

The creation of *spin-off* companies constitutes a third activity pole, next to contract research and patenting/licensing. In 2004, the university had generated 60 spin-off companies. These spin-offs generated a turnover of 350 million Euros and employed over 2,000 people. Two spin-offs have realized a successful IPO on NASDAQ and EASDAQ. There have been eight failures. However, the highest failure rate occurs during the phase of spin-off creation. About two-thirds of the projects never make it to the actual stage of spin-off incorporation.

LRD's venture unit has developed the necessary mechanisms and processes that assist in business development. A major focus of LRD is first to assist the academic entrepreneurs in developing their business plans. Finding a proper funding structure, as well as the right management team, figures high on the agenda of the LRD venture unit. The university, in partnership with two major Belgian banks, created two seed capital funds to fund start-up companies that exploit university-based know-how. LRD together with two investment managers from both banking partners constitute the investment committee. Accommodation and managerial support for its spin-offs is provided through an *Innovation & Incubation Center.* In addition three science parks are available in the close vicinity of the KULeuven.

3. See Debackere and Veugelers (2005) for a more in-depth analysis of LRD.

But perhaps the most significant factor explaining LRD's success is its *incentive system*. Whereas the incentive system within the departments and faculties of the university uses promotion along the academic ladder, LRD has developed an incentive system that is based on budgetary flexibility and financial autonomy. LRD research divisions enjoy complete autonomy to balance revenue and expenses from their ISL activities. LRD divisions are further entitled to participate both intellectually and financially in the spin-off companies that they have grown and developed. Finally, incentives are given to individual researchers as well. In the case of spin-off creation, individual researchers can receive up to 40 percent of the intellectual property shares (i.e., the intellectual property stock or founder shares) in exchange for the input of their know-how and goodwill. They can also invest financially in the spin-off and hence obtain a pro rata share in the common stock (capital shares) of the company. In the case of lump sum and royalty payments proceeding from license agreements, individual researchers are entitled to receive up to 30 percent of the income generated (after expenses have been recouped).

Top generators of new technology ventures and industrial contract volumes also tend to be among the top performers in terms of academic research, further supporting the importance of a broad scope of complementary activities in the activity profile of a technology transfer unit.

3. The Model

THE empirical literature has indicated that universities that are successful in spin-off creation pay due attention to a careful allocation of shares in spin-off contracts. Our model studies the optimal allocation of these shares. Three agents are involved in the spin-off: the university TTO which owns the innovation and sets the contracts; the researcher, whose effort is needed for the development of the innovation; and the venture capitalist (the VC hereafter) who provides financial capital. The university TTO and the researcher can also provide financial capital to the project, but they have a higher opportunity cost for the capital than the VC [4]. The spin-off success and its value depend on the involvement of the researcher (or team of researchers) who has developed the initial innovation and on the financial capital invested in it.

More precisely, the expected value of the spin-off is $p\,B(e, F)$, where p denotes the probability of success, F the financial capital invested, and e the researcher's effort. The function $B(e, F)$ represents the profits of the venture in the case of success. For the sake of simplicity, we assume that there are only two possible efforts: $e \in \{e^L, e^H\}$, with $e^L < e^H$. We also assume $B(e^H, F) > B(e^L, F)$ for all $F > 0$ and that $B(e, F)$ is strictly increasing and strictly concave in F.

We consider an initial innovation for which the decision to develop this further through a spin-off rather than through licensing has already been made (cf. Chukumba and Jensen, 2005). The licensing alternative only shows up in the reservation utilities of the players. The timing of the game is the following. First, the university TTO designs and offers the contracts to the researcher and the VC. Second, these two agents accept or reject their contracts [5]. If both the researcher and the VC accept the contracts then the capital is invested and the researcher provides the effort. Finally, nature decides the result, which is assumed to be observable.

4. The financial capital provided by the researcher is not necessarily her own personal wealth, but also includes funding provided through her research unit (cf. LRD case).

5. The acceptance decision is sequential in order to avoid equilibria where (even when the contracts are acceptable for the researcher and the VC) each agent rejects the contract because the other also does.

The contract specifies the financial contributions and the (contingent) payments. We assume that the researcher's effort is not verifiable; hence it cannot be part of the contract. Concerning the financial contribution, the contract states the total capital invested, F, and the contribution of each participant: F^U, F^R and F^V, with $F^U + F^R + F^V = F$. As to the payments, we assume that payoffs can only be based on the final outcome so the contract sets the shares that each agent gets of this outcome. Following the contracts that the KUL uses, we will distinguish two types of shares: financial shares and founder (intellectual property) shares. The first type of shares is directly related to the capital invested. Founder shares reflect the compensation for the intellectual property brought in by the researcher and her team and owned by the university TTO. The following table summarizes the terms of the contract shares:

TABLE 3.1: Contract shares

Agent	Total shares		Financial shares		Founder shares
University TTO	s^U	=	f^U	+	i^U
Researcher	s^R	=	f^R	+	i^R
Venture Capitalist	s^V	=	f^V	+	i^V

Obviously, $s^U + s^R + s^V = 1$, and all shares take values in the interval $[0, 1]$. Financial shares must be proportional to the capital invested, that is:

$$\frac{F^i}{F^j} = \frac{f^i}{f^j}, \text{ for all } i, j = U, R, V$$

We typically have $i^V = 0$, since the VC does not contribute intellectual property.

We now define the objective function of the three agents. The venture capitalist incurs a cost from investing capital that reflects his outside market opportunity. We denote by r^V the unit cost of capital of the VC. Hence, his expected profits when he invests the amount F^V and receives the shares s^V are equal to:

$$\pi^V = s^V p\, B(F, e) - r^V F^V$$

We assume, without loss of generality, that the VC's reservation utility is equal to zero.

The researcher's utility function is:

$$U^R = s^R\, p\, B(F, e) - c(e) - r^R F^R$$

where $c(e)$ is the cost of making the effort e. In this type of project, this cost may have two different components: $c(e) = C(e) - \lambda(e)$, where $C(e)$ represents the usual cost associated with devoting time and effort to the spin-off. Researchers are driven by monetary rewards, like any other non-academic entrepreneur, but also by peer recognition and the *puzzle* joy (cf. Stephan and Levin, 1992). The term $\lambda(e)$ represents the nonmonetary utility that the researcher obtains by being involved in the spin-off. It can be positive if involvement in spin-off activities gives positive spillovers to basic research in terms of increased research experience, increased funding for basic research, or peer recognition. Alternatively, $\lambda(e)$ can be negative if there are negative spillovers to basic research and/or the researcher loses peer recognition from spin-off involvement. We denote r^R the unit cost of capital for the researcher and $\underline{U}^R$ her reservation utility. This reservation utility could reflect the returns that she would get in case the invention were licensed rather than spun off. We assume that the cost of providing financial funds for the researcher is higher than for the VC: $r^R > r^V$.

Finally, the utility function of the university TTO reflects its net revenue from the spin-off. But the TTO not only cares about maximizing returns/profits in the short run. It also (should) take into account its long-run viability. This long-run viability depends on the involvement of star researchers, which implies the TTO should also care about what drives the utility of the researcher, including the importance attached to basic research and the cost of providing effort into commercialization by the researcher:

$$U^U = s^U\, p\, B\,(e, F) - r^U F^U + k\, U^R$$

where r^U is the unit opportunity cost of the capital invested by the university, $r^U > r^V$. Note that when $k = 0$, the university TTO does not care about the researcher. The parameter k allows us to study the importance of the long-term perspective in the TTO objective function. When $k = 1$, the university TTO cares about the researcher as much as it does about itself [6].

We assume that for the project to be profitable it is necessary for the researcher to exert high effort. Since effort is not verifiable, the contract

6. For simplicity, we do not take into account alternative payoffs for the TTO, although the possibility of licensing the invention could be considered as its reservation payoff.

should satisfy the researcher's incentive compatibility constraint (ICC) that can be written as:

$$s^R\, p\, B^H(F) - c^H \geq s^R\, p\, B^L(F) - c^L$$

where we denote $B^H(F) \equiv B(e^H, F)$, $c^H \equiv c(e^H)$, and so on. Denoting $\Delta c \equiv c^H - c^L$ and $\Delta B(F) \equiv B^H(F) - B^L(F)$, we can write the ICC as:

$$s^R \geq s^{R^o} \equiv \frac{\Delta c}{p\, \Delta B(F)}$$

The minimum share that provides incentives to the researcher, s^{R^o}, is lower the higher the probability of success of the venture is, the more profitable the project is in case of high effort, and the less costly exerting high effort is.

4. The Optimal Sharing Contract

THE university TTO, having the property rights over the critical IP, decides on the contract $\{(s^U, F^U), (s^R, F^R), (s^V, F^V)\}$ to maximize its expected utility, taking into account the researcher's ICC and both participation constraints (PCs). That is, the optimal contract is the solution to the following program:

$$\underset{\{(s^U, F^U), (s^R, F^R), (s^V, F^V), F\}}{\text{Max}} \left\{ s^U p\, B^H(F) - r^U F^U + k\left[s^R p\, B^H(F) - c^H - r^R F^R \right] \right\}$$

$$\text{s. t.} \qquad s^R \geq \frac{\Delta c}{p\, \Delta B(F)} \tag{4.1}$$

$$s^R p\, B^H(F) - c^H - r^R F^R \geq \underline{U}^R \tag{4.2}$$

$$s^V p\, B^H(F) - r^V F^V \geq 0 \tag{4.3}$$

$$s^U + s^R + s^V = 1 \tag{4.4}$$

$$F^U + F^R + F^V = F \tag{4.5}$$

$$F^U \geq 0, \quad F^R \geq 0, \quad F^V \geq 0 \qquad (4.6), (4.7), (4.8)$$

where: (4.1) is the researcher's ICC, (4.2) is the researcher's PC, (4.3) is the VC's PC, (4.4) states that the benefits from the spin-off are shared among the three agents, (4.5) states the sharing of the capital, and (4.6), (4.7) and (4.8) are the non-negativity constraints of the financial contributions.

Apart from the constraints that appear in the program, some others have to hold. The constraint $s^R \geq 0$ always holds given (4.1) and $s^V \geq 0$ is satisfied because of (4.3) . The constraint $s^U \geq 0$ holds if the spin-off is profitable. We will write the optimal contract assuming that the spin-off is profitable in the case of high effort (this is always the case if p is high enough). A necessary condition is $p\, B^H(F) \geq c^H + \underline{U}^R + r^V F$ for some F.

To better highlight the characteristics of the optimal contract, we consider spin-offs where the level of total investment F is given, that is, spin-offs whose required level of financial capital is determined exogenously, i.e., where investments are completely driven by technical and market conditions. The TTO only decides about the sharing of F. In section 5, we characterize the optimal level of F when the investment is endogenous.

Proposition 1 portrays the optimal sharing contracts when F is fixed and k is not too high, i.e., the TTO does not care too much about the researchers' objectives $(k \leq r^V / r^R)$. Since we are considering a situation where the total capital is fixed, we simplify notation and use B^H and ΔB instead of $B^H(F)$ and $\Delta B(F)$. Also, we differentiate among three regions of parameters:

Region I: $$\frac{\Delta c}{\Delta B} \leq \frac{c^H + \underline{U}^R}{B^H}$$

Region II: $$\frac{\Delta c}{\Delta B} \in \left(\frac{c^H + \underline{U}^R}{B^H}, \frac{c^H + \underline{U}^R + r^R F}{B^H} \right)$$

Region III: $$\frac{\Delta c}{\Delta B} \geq \frac{c^H + \underline{U}^R + r^R F}{B^H}$$

Proposition 1. *For a given $F > 0$, when $k \leq r^V / r^R$, the optimal contract is* $F^U = 0$, $F^V = F - F^R$, $s^U = 1 - s^R - \dfrac{r^V (F - F^R)}{p\, B^H}$, $s^V = \dfrac{r^V (F - F^R)}{p\, B^H}$, and *$(F^R, s^R)$ given by:*

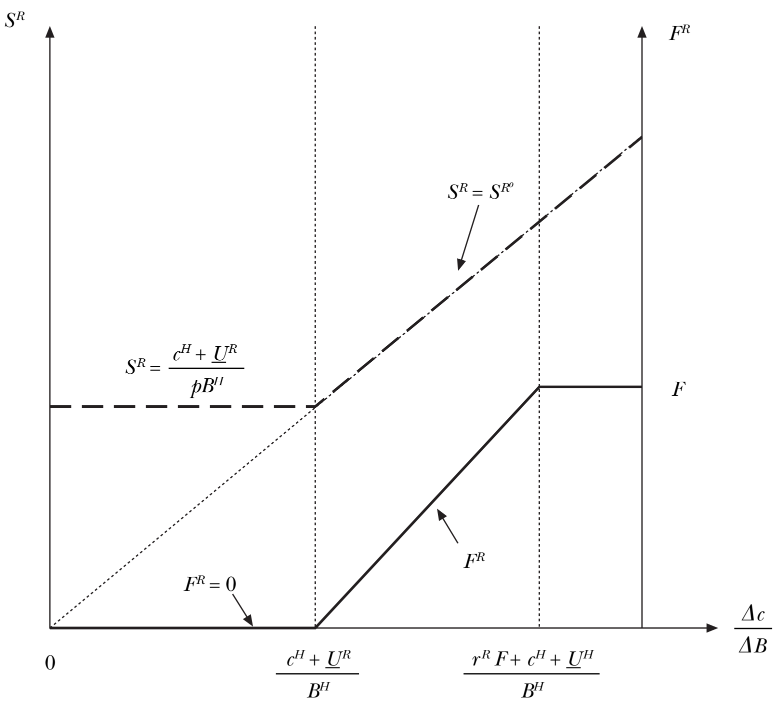
(Region I) $$F^R = 0 \text{ and } s^R = \frac{c^H + \underline{U}^R}{p\, B^H}$$

(Region II) $$F^R = \frac{B^H}{r^R} \left[\frac{\Delta c}{\Delta B} \right] - \frac{c^H + \underline{U}^R}{r^R} \text{ and } s^R = \frac{\Delta c}{p\, \Delta B}$$

(Region III) $$F^R = F \text{ and } s^R = \frac{\Delta c}{p\, \Delta B}$$

Hence, for a given F, and for a k that is not too high, the researcher's contract has the form shown in graphic 4.1.

GRAPHIC 4.1: **Optimal shares for a given $F > 0$, when $k \leq r^V / r^R$**



The left region in graphic 4.1 (Region *I)* depicts the situations where it is easy to provide the researcher incentives to provide effort: the ratio $\Delta c/\Delta B$ is small, so supplying high effort is not very costly and/or it is very profitable. The number of (founding) shares given to the researcher for her to participate in the venture provides more than enough incentives for her to work hard. Hence, in this region, the PC is binding while the ICC is not. Efficiency implies that it is better that the VC provides the financing, given $r^R > r^V$ and $r^U > r^V$, so $F^U = F^R = 0$.

When the moral hazard problem is more severe, which corresponds to Region *II*, the researcher needs more inducement to provide effort, so the contract must give the researcher more shares. Given this situation, the TTO will require the researcher to participate in the financing of the venture up to an amount so that her PC is binding; hence F^R is positive and increasing with $\Delta c/\Delta B$. Even if this financial arrangement is not efficient (in the sense that the opportunity cost of the capital for the researcher is higher than r^V), it allows the TTO to obtain larger profits because it induces higher effort by the researcher. Note that efficiency arguments explain that the university's financial involvement is always zero. In this region, both the PC and the ICC of the researcher are binding.

Finally, it can be the case that the total financing F needed in the project is lower than the amount of money the researcher would be ready to contribute. In this case, which corresponds to *Region III* and is represented in the right side of graphic 4.1, the researcher finances the project completely and her ICC is binding while her PC is not. In this region, there will be no venture capital.

Proposition 2 translates the main characteristics of the optimal contract into the agreement on financial and founding shares (the items in table 1) that will be settled between the TTO, the researcher, and the VC:

Proposition 2. *For a given $F > 0$, when $k \leq r^V / r^R$, the optimal sharing contract is the following:*

(Region I) $$f^U = f^R = 0,\ f^V = \frac{r^V F}{pB^H};\ i^U = 1 - \frac{c^H + \underline{U}^R + r^V F}{pB^H};\ and\ i^R = \frac{c^H + \underline{U}^R}{pB^H}$$

(Region II) $$f^U = 0,\ f^R = \frac{r^V}{r^R}\frac{\left(B^H\left[\dfrac{\Delta c}{\Delta B}\right] - c^H - \underline{U}^R\right)}{pB^H},\ f^V = \frac{r^V F}{pB^H} - f^R$$

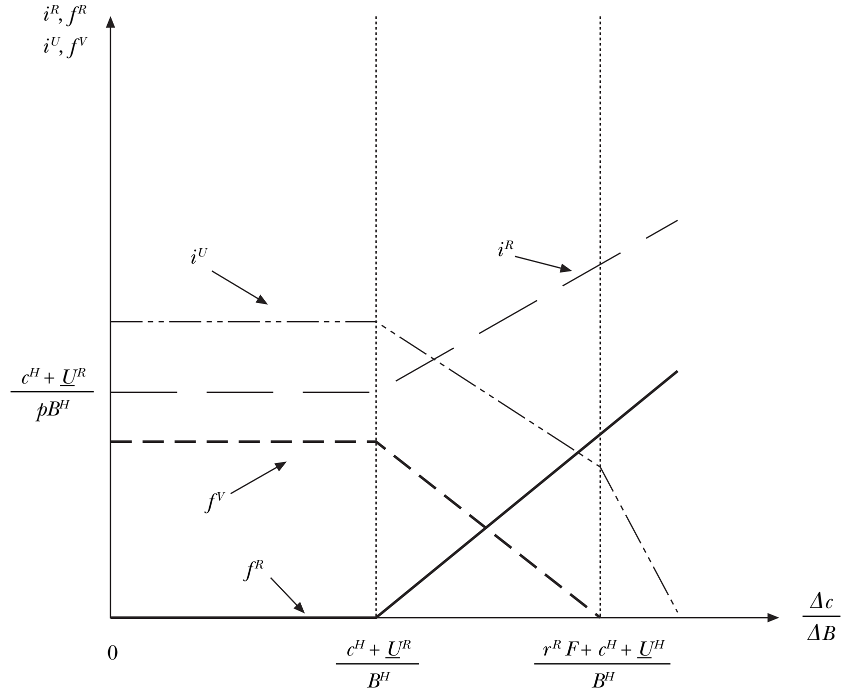
$$i^U = 1 - i^R - \frac{r^V F}{pB^H};\ and\ i^R = \frac{(r^R - r^V)\, B^H\left[\dfrac{\Delta c}{\Delta B}\right] + r^V\,(c^H + \underline{U}^R)}{r^R pB^H}$$

(Region III) $$f^R + i^R = \frac{\Delta c}{p\Delta B},\ f^U = f^V = 0,\ and\ i^U = 1 - \frac{\Delta c}{p\Delta B}$$

The terms of the optimal sharing contract when k is small are depicted in graphic 4.2.

In Region *I*, having not made any financial investment ($F^R = 0$), the researcher receives only founder shares i^R. The VC receives all the financial shares to compensate, at the market value, his contribution $F^V = F$, hence $f^V = r^V F/pB^H$. Once having compensated the researcher and the VC for their participation, the university TTO appropriates its founder shares $i^U = 1 - i^R - f^V$. The VC also receives a *fair (market-valued)* number of shares to compensate his financial involvement when the spin-off is in Region *II.* This value also determines the amount of financial shares that should accrue to the researcher given her financial participation in the project. The rest of her shares are given as intellectual founder shares, to make her PC binding.

GRAPHIC 4.2: **Optimal contract for a given $F > 0$, when $k \leq r^V / r^R$**



The residual founder's shares are kept by the TTO. Finally, no venture capital is involved in the spin-off in *Region III*. The researcher is given all the shares needed to provide incentives for her to work hard (whether the shares are given as financial or founder shares does not matter), and the TTO keeps the rest as founder shares.

Graphic 4.2 has shown the variation of the optimal sharing contract as a function of Δc and ΔB. The next corollary presents the comparative static of the shares that the participants receive as a function of the exogenous parameters $\underline{U}^R$, r^V, r^R and p in Regions *I* and *II* (similar effects appear in *Region III,* with any *reasonable* decomposition of s^R in f^R and i^R).

Corollary 1. *For a given $F > 0$, when $k \leq r^V / r^R$, the optimal sharing contract has the following properties:*

— *Shares f^R and i^U are non-increasing while i^R and f^V are non-decreasing with $\underline{U}^R$ and r^R.*

— *Shares i^R and i^U are non-increasing while f^R and f^V are non-decreasing with r^V.*

— *Shares f^R, i^R and f^V are non-increasing while i^U is increasing with p.*

An increase in the researcher's reservation utility (or a decrease in the value of the nonmonetary utility obtained by being involved in the spin-off, $\lambda(e)$), will result in a contract that includes more founder shares and fewer financial shares for the researcher. Hence, we should expect to see a higher rate of founder shares for researchers who are more reluctant to participate in spin-offs, as may be the case for researchers who are more oriented toward basic research or whose inventions would have a higher alternative return through licensing. With respect to the profitability of the venture, as measured by the probability p, more (ex ante) profitable spin-offs lead to fewer shares for the researcher and the VC, which will lead to a larger portion of founder shares accruing to the university TTO. Hence the TTO clearly has an incentive to invest in selecting projects with a high p and/or improving the venture's probability of success, not only because they give higher profits to the TTO directly, but also, indirectly, because the TTO can secure a higher share of the higher profits, needing to leave less on the table to induce participation and provide incentives.

When the university TTO is very concerned about the well-being of its researchers (i.e., when $k > r^V / r^R$), it prefers to increase the researcher's utility rather than introduce an inefficiency in the relationship by forcing her to take a financial stake in the venture. Hence, the optimal sharing contract in the regions where the ICC is binding has some differences with respect to the contract in proposition 1. Proposition 3 states the optimal contract for the researcher when F is fixed and k is high; the shares for the university and the VC satisfy the same relation as in proposition 1.

Proposition 3. *For a given $F > 0$, when $r^V / r^R < k \leq 1$, the optimal contract designed for the researcher is:*

(Region I) $$F^R = 0 \text{ and } s^R = \frac{c^H + \underline{U}^R}{pB^H};$$

(Regions II and III) $$F^R = 0 \text{ and } s^R = \frac{\Delta c}{p\,\Delta B}.$$

The main difference with respect to the previous case is that the researcher's PC is not binding in *Regions II* and *III*. The optimal contract includes $F^R = 0$ and $s^R = \Delta c / p\,\Delta B$, and the researcher receives informational rents. Since the researcher's contract never requires her to participate in the financing of the spin-off, all her shares take the form of intellectual shares: $f^R = 0$ and $i^R = s^R$. In other words, the TTO cares so much about the researcher's utility that to solve the moral hazard problem it allocates shares to the researcher only in the form of founding shares, not financial shares. This requires that the VC supplies all the financing for the venture which in turn implies fewer shares for the TTO.

5. The Optimal Investment

IN this section we analyze the optimal choice of the financial funds F assuming that the TTO chooses it. Part of the task of the TTO's venture unit is indeed to determine the amount of financial investments needed for take-off (cf. LRD case). For the sake of simplicity, we will assume that $B^H(F) = b^H g(F)$ and $B^L(F) = b^L g(F)$.

Proposition 4. *When $k \leq r^V / r^R$, the optimal investment level is:*

(1) $F = F^o$, where F^o is defined by $p\, b^H g'(F^o) = r^V$, if $\dfrac{\Delta c}{\Delta b} \leq \dfrac{c^H + \underline{U}^R + r^R F^o}{b^H}$

(2) $$F = \frac{b^H}{r^R}\left[\frac{\Delta c}{\Delta b}\right] - \frac{c^H + \underline{U}^R}{r^R}, \; \text{if } \frac{\Delta c}{\Delta b} \in \left(\frac{c^H + \underline{U}^R\, r^R F^o}{b^H}, \frac{c^H + \underline{U}^R + r^R F^{oo}}{b^H}\right)$$

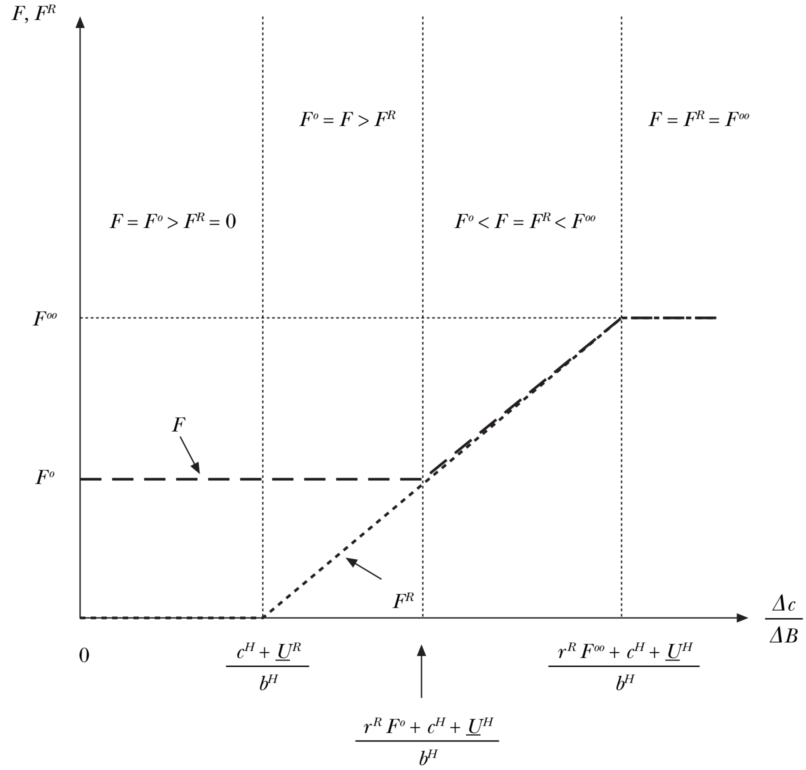
(3) $F = F^{oo}$, where F^{oo} is defined by $p\, b^H g'(F^{oo}) = k\, r^R$, if $\dfrac{\Delta c}{\Delta b} \geq \dfrac{c^H + \underline{U}^R + r^R F^{oo}}{b^H}$

The optimal decision shown in proposition 4 is depicted in graphic 5.1 (where we also plot F^R). The capital invested is increasing in the ratio $\Delta c/\Delta B$, which as before is a measure of the researcher's moral hazard problem.

The main intuition of proposition 4 is the following. When the moral hazard problem is not very important, the founder shares allocated to the researcher for her to participate in the spin-off give her enough incentives to work hard (this corresponds to *Region I* in proposition 1). All the financing is provided by the VC at a unit cost of the capital r^V. The optimal investment level F^o is efficient, reflecting the equality between marginal benefits and marginal cost. The optimal investment is still F^o even if the researcher finances part of the capital, as long as the required involvement to solve the moral hazard problem is lower than this level *(Region II)*. The previous analysis corresponds to part (1) in proposition 4.

When the moral hazard problem is very severe (and/or the researcher's reservation utility is very low), the number of financial shares that

GRAPHIC 5.1: Optimal investment when $k \leq r^V / r^R$



must be allocated to the researcher is very large, eventually corresponding to an investment larger than F^o. Given that, the TTO has incentives to increase total investment accordingly (part [2] in proposition 4). The unit cost of the capital in this case is r^R. However, from the point of view of the TTO, the cost is only $k\, r^R$, since k reflects the TTO's concern for the researcher. Hence, the TTO will only stop requiring further financial involvement by the researcher in the extreme case where the marginal benefit of the capital is lower than $k\, r^R$ (part [3]).

Therefore, the need to provide incentives to the researchers in spin-offs can lead to two separate inefficiency problems. First, an inefficiency is introduced any time the researcher is financially involved in the venture (all the regions in graphic 5.1, except the one on the left) since her cost of capital is larger than that of the VC. Second, in addition to the first problem, over-investment in spin-offs appears in the cases where all the financing is made by the researcher (the two regions on the right in graphic 5.1, corresponding to parts [1] and [2]).

The previous arguments also explain proposition 5, which deals with the case $r^V / r^R < k \leq 1$. The concern of the TTO vis-à-vis the researcher is so large that it always gives her shares through founder shares, with all the capital being provided by the VC. The investment level is, in this case, always efficient.

Proposition 5. *When* $r^V / r^R < k \leq 1$ *, the optimal investment level is* $F = F^o$.

6. The Informational Advantage of the TTO

IN the previous sections, we have analyzed the optimal sharing contracts among the TTO, the researcher, and the VC assuming that the only major informational problem in the venture is that the researcher needs incentives to provide effort. In this section, we address the design of the spin-off contracts when information about the profitability of the project is not symmetric.

Out of the three participants in the project, the one with information about both the scientific and the financial side of the venture is the TTO. A good technology transfer office has boundary-spanning personnel, who are in permanent contact with the researchers, which help in assessing and even improving the potential commercial value of the invention. Hence, the TTO knows about the scientific content of the innovation. Also, by experience, it has better knowledge than the other two participants (especially the researcher) about the commercialization of inventions and the steps and difficulties that the spin-off will encounter on its path to profits. Therefore, a good TTO has better information than the researcher and the VC concerning the potential value of the spin-off.

To model this asymmetric information situation in a simple way, we assume that the probability of success of the venture can be either p_1 or p_2, with $p_1 > p_2$. The TTO knows the true value of the probability of success, but the researcher and the VC do not. Also for simplicity, we consider a situation where the TTO only cares about its profits (i.e., $k = 0$), and where the moral hazard problem is not very acute (i.e., the parameters lie in Region I in proposition 1) [7]. Finally, we suppose that the spin-off is only profitable when the probability of success is high, that is, $p_1 B^H > \underline{U}^R + c^H + r^V F$ and $p_2 B^H < \underline{U}^R + c^H + r^V F$ [8].

7. We present this case for the sake of simplicity of exposition, to avoid the exhaustive presentation of the results for many parameter combinations when all of them lead to similar results.

8. Generalizations of the proposed model will not alter the qualitative results. In particular, the analysis and the results are similar if the environment is such that both projects are profitable under symmetric information, that is, if $p_2 B^H > \underline{U}^R + c^H + r^V F$.

Under symmetric information, when the TTO faces a good project, it offers a contract involving $s_1^{U*} = i_1^U = 1 - \frac{c^H + \underline{U}^R + r^V F}{p_1 B^H} > 0$ and $F_1^{U*} = 0$. But, when the TTO has private information concerning the quality of the project, the previous contract is even more profitable for the TTO if the chances of success are small. Therefore, if the probability of success is unknown o them, the researcher and the VC will never accept such a proposal by the TTO. To be acceptable, the contract must be a clear *signal* that the project is indeed a good one.

For a contract to signal that the project of the TTO is good it has to be the case that it would never be offered when the project is a bad one. That is, the contract must satisfy the following ICC for the TTO:

$$s^U p_2 B^H - r^U F^U \leq 0$$

There are many contracts that satisfy the previous condition. Several criteria have been proposed in the literature to refine the set of equilibria. The most widely used criterion to eliminate some *unreasonable* Bayesian equilibria is called the *intuitive criterion,* and was proposed by Cho and Kreps (1987). The next proposition characterizes the unique contract that satisfies this criterion.

Proposition 6. *For a given $F > 0$, if the parameters lie in Region I, when the TTO has private information concerning the probability of success, the unique contract designed for good projects that satisfies the intuitive criterion is: $F^R = 0$, $F^V = F - F^U$,*

$$s^U = 1 - s^R - \frac{r^V (F - F^U)}{p_1 B^H}, \; s^V = \frac{r^V (F - F^U)}{p_1 B^H}, \text{ and } (F^U, s^R) \textit{ given by:}$$

(i)
$$F^U = \frac{p_2 (p_1 B^H - \underline{U}^R - c^H - r^V F)}{p_1 r^U - p_2 r^V} \textit{ and } s^R = \frac{c^H + \underline{U}^R}{p_1 B^H}$$

$$\textit{if } p_1 B^H \left[1 - \frac{r^U F}{p_2 B^H} \right] - c^H \leq \underline{U}^R$$

(ii)
$$F^U = F \textit{ and } s^R = 1 - \frac{r^U F}{p_2 B^H}, \textit{ if } \left[1 - \frac{r^U F}{p_2 B^H} \right] p_1 B^H - c^H \geq \underline{U}^R$$

The most important characteristic of the contract highlighted in proposition 6 is that $F^U > 0$. In fact, it is easy to check that this is a characteristic shared by all the contracts designed to signal good projects (not only those contracts satisfying the intuitive criterion). That is, the financial involvement of the TTO in spin-offs (e.g., through a joint VC fund) is a way to signal to both the researcher and the VC that the chances of success are good. It is only by getting financially involved in the project that the TTO clearly shows to its partners that it is worthwhile to provide effort (the researcher) and invest (the VC). This may explain the participation of universities in the financing of spin-offs. For example, KULeuven LRD has a 20 percent share in the seed capital funds that finance the spin-off companies that exploit KULeuven know-how (the rest is financed by two major Belgian banks). In some cases, the LRD participation is even larger.

7. Conclusions

DESPITE the policy attention devoted to academic spin-offs, the processes governing their formation and success are not yet well-understood. This paper provides a theoretical analysis of how to design academic spin-off contracts. It focuses on how to allocate financial and founder (intellectual) shares in the venture to the university technology transfer office, the star esearcher, and the venture capitalist. The design of the contract takes into account the moral hazard problem of the researcher's involvement in the spin-off, the participation constraints of the star researcher and the venture capitalist, and the asymmetric information problem on likelihood of success.

Our main results are the following. The optimal contract entails the allocation to the researcher of founder shares to secure her involvement in the venture. But it may also require her to be financially involved in the project. Even if the unit cost of the capital provided by the venture capitalist is lower than the unit cost of the capital owned by the researcher, the allocation of financial shares to the latter may be the only way to make sure that she really has incentives to provide effort into the venture. When the moral hazard problem is acute, the need to financially involve the researcher leads to an additional inefficiency, as the optimal contract requires overinvestment in the spin-off. Finally, we show that when the TTO has more accurate information than the other two participants concerning the likelihood of success of the spin-off, the TTO will *signal* profitable projects by taking financial stakes.

Although at this stage of the research, it is too early to draw firm policy conclusions, a number of interesting insights can be drawn from our analysis. First, if policy makers want more spin-offs to form with a positive expected payoff, it is important to tackle the various problems involved with spin-off formation. Our model shows that both financial and intellectual shares are important instruments to tackle moral hazard, participation constraints, and asymmetric information problems. Policy makers should avoid putting in place restrictions that would jeopardize the effective use of these instruments, such as restrictions on whether universities and researchers can take (financial) shares in spin-offs. Although the model clearly indicates the inefficiency of using financial shares from the researcher and the TTO rather than the venture capitalist, they are powerful instruments to solve some of the problems involved in spin-off formation. Our model results allow highlighting the trade-off between costs and benefits of using shares as contract terms.

Secondly, the model indicates several rationales for having a TTO. In our base model, the TTO takes no financial shares. It is the residual claimant of the relationship, simply by being the owner of the invention, hence it gets the founder shares that are left after having compensated the researcher for her participation and both the venture capitalist and the researcher for their financing. In this benchmark version, the main contribution of the TTO is related to its expertise in designing profitable spin-off contracts. Nevertheless, this base version also indicates that TTOs have an incentive to play a more active role by selecting or improving the profitability of the venture. Furthermore, if the TTO has more accurate information concerning the likelihood of the spin-off's success, TTO will *signal* profitable projects by taking financial stakes in them. All this however, requires a TTO sufficiently endowed with financial and managerial capital.

Appendix

PROOF of proposition 1. First, note that constraint holds with equality at the optimum (otherwise, the TTO could decrease s^V and increase s^U). Using also equation we conclude that:

$$s^V = \frac{r^V (F - F^U - F^R)}{pB^H} \tag{A.1}$$

From equation (4.4) and (A.1) we have:

$$s^U = 1 - s^R - \frac{r^V (F - F^U - F^R)}{pB^H} \tag{A.2}$$

Therefore, the TTO's objective function can be written as:

$$\left(1 - s^R - \frac{r^V (F - F^U - F^R)}{pB^H}\right) pB^H - r^U F^U + k \left[s^R pB^H - c^H - r^R F^R\right] =$$

$$= \left(1 - s^R - \frac{r^V (F - F^R)}{pB^H}\right) pB^H - (r^U - r^V) F^U + k \left[s^R pB^H - c^H - r^R F^R\right]$$

It easily follows that, at the optimum, $F^U = 0$. Hence, $F^V = F - F^R$.
Now, we can rewrite the university TTO's problem as:

$$\max_{(F^R, s^R),} \left\{\left(1 - s^R - \frac{r^V (F - F^R)}{pB^H}\right) pB^H + k \left[s^R pB^H - c^H - r^R F^R\right]\right\}$$

s.t. $$s^R \geq \frac{\Delta c}{p\, \Delta B} \tag{A.3}$$

$$s^R pB^H - c^H - r^R F^R \geq \underline{U}^R \tag{4.2}$$

$$F^R \geq 0, \; F - F^R \geq 0 \qquad (4.7), (4.8)$$

Note that, at the solution, it is necessarily the case that the Lagrange multipliers associated to the previous equations are nonnegative, i.e., respectively, $\alpha \geq 0$, $\rho \geq 0$, $\mu \geq 0$, and $\theta \geq 0$. From the first-order condition with respect to s^R and F^R we obtain:

$$\frac{\partial L}{\partial s^R} = -(1-k-\rho)\, pB^H + \alpha = 0 \tag{A.4}$$

$$\frac{\partial L}{\partial F^R} = r^V - k\, r^R - \rho\, r^R + \mu - \theta = 0 \tag{A.5}$$

From (A.4) and (A.5) we have that: $\alpha = (1-k-\rho)\, p\, B^H$ and $\rho = (r^V - k\, r^R + \mu - \theta)/\, r^R$.

We now distinguish three cases: $\alpha = 0$; $\alpha > 0$ and $\theta = 0$; and $\alpha > 0$ and $\theta > 0$.

Region I: If $\alpha = 0$, then $\rho = 1-k > 0$ and $\mu = k\ r^R - r^V + \theta + \rho\ r^R = r^R - r^V + \theta > 0$. Hence, $F^R = 0$ from equation (4.7), constraint (4.8) holds with strict inequality and $\theta = 0$, and

$$s^R = \frac{c^H + \underline{U}^R}{pB^H} \tag{A.6}$$

from equation (4.2). The proposed contract can only be a candidate solution if equation (A.3) holds, i.e., $\frac{c^H + \underline{U}^R}{B^H} \geq \frac{\Delta c}{\Delta B}$.

Region *II*: If $\alpha > 0$, then $s^R = s^{R^o}$. Also, if $\theta = 0$ then $\rho = (r^V - k\ r^R + \mu)/\, r^R > 0$. Taking $s^R = s^{R^o}$ into account, equation (4.2) implies that:

$$F^R = \frac{B^H}{r^R}\left[\frac{\Delta c}{\Delta B}\right] - \frac{c^H + \underline{U}^R}{r^R} \tag{A.7}$$

The previous contract constitutes a candidate solution only if (4.7) and (4.8) hold, that is, if $F^R \in [0, F]$. This is indeed the case if and only if $\frac{\Delta c}{\Delta B} \geq \frac{c^H + \underline{U}^R}{B^H}$ and $\frac{\Delta c}{\Delta B} \leq \frac{c^H + \underline{U}^R + r^R F}{B^H}$. This candidate involves $\mu = 0$, $\rho = \frac{r^V}{r^R} - k$ and $\alpha = \frac{r^R - r^V}{r^R}\, pB^H$. (If F^R defined in is precisely zero, then several combinations of μ and ρ are compatible with the candidate contract.)

Region III: If $\alpha > 0$ and $\theta > 0$, then $s^R = s^{R^o}$ and $F^R = F$. In this case, $\mu = 0$. A necessary condition for this contract to be a candidate solution is that (4.2) holds for $s^R = s^{R^o}$ and $F^R = F$, that is, $\frac{\Delta c}{\Delta B} \geq \frac{c^H + \underline{U}^R + r^R F}{B^H}$. If this inequality is strict, then the contract is indeed a candidate with associated multipliers $\rho = 0$, $\alpha = (1 - k)\ p\ B^H$ and $\theta = r^V - k\ r^R$. (If the weak inequality is in fact an equality, then several combinations of the multipliers are compatible with the candidate contract.)

Since there is only one candidate for each possible configuration of parameters (except in the frontiers of the cases, where there are two identical candidates), the proposed candidates are indeed the optimal contracts.

Proof of proposition 2. It follows from proposition 1, equations (A.1), (A.2), and

$$\frac{F^i}{F^j} = \frac{f^i}{f^j} \text{ for } i, j = U, R, V$$

Proof of Corollary 1. It follows from Proposition 2.

Proof of proposition 3. The FOCs are the same as in the proof of Proposition 1. Again, (A.4) and (A.5) imply $\alpha = (1 - k - \rho)\ p\ B^H$ and $\rho = (r^V - k\ \ r^R + \mu\text{-}\theta)/\ r^R$. Since $r^V - k\ \ r^R < 0$, it is the case that $\mu\text{-}\theta > 0$. Hence, $\mu\ > 0$ and $F^R = 0$ from equation (4.7), which in turn implies $\theta = 0$.

We now distinguish two possibilities: $\alpha = 0$ and $\alpha > 0$.

Region I: If $\alpha = 0$, then $\rho\ = 1 - k > 0$ and $\mu\ =\ r^R - r^V$. Hence, constraint (4.2) holds with equality:

$$s^R = \frac{c^H + \underline{U}^R}{pB^H}$$

The proposed contract is a candidate solution if holds, i.e.,

$$\frac{c^H + \underline{U}^R}{B^H} \geq \frac{\Delta c}{\Delta B}$$

Regions II and III: If $\alpha > 0$, then $s^R = s^{R^o}$. Also, since $\theta = 0$ then $\rho = (r^V - k\ \ r^R + \mu)/\ r^R$. Therefore, $\mu\ =\ k\ \ r^R - r^V > 0$ and $\rho = 0$. The contract based on $s^R = s^{R^o}$ constitutes a candidate solution only if holds, that is, if

$$\frac{\Delta c}{\Delta B} > \frac{c^H + \underline{U}^R}{B^H}$$

Proof of proposition 4. The program solved is the same as in proposition 1, where we now consider the total financing F as an endogenous variable. Given that, we come back to the notation $B^H(F)$ and $\Delta B(F)$. The first-order condition with respect to F is:

$$\frac{\partial L}{\partial F} = \left[1 - s^R (1 - k - \rho)\right] p \frac{dB^H(F)}{dF} - r^V + \alpha \frac{\Delta c \quad d\Delta B(F)}{p(\Delta B(F))^2 dF} + \theta = 0 \qquad \text{(A.8)}$$

From (A.4) we have that $\alpha = (1 - k - \rho)\; p\, B^H(F)$. Hence, we can write (A.8) as:

$$p \frac{dB^H(F)}{dF} - r^V + \alpha \left[\frac{\Delta c \quad d\Delta B(F)}{p(\Delta B(F))^2 \; dF} - \frac{s^R \; dB^H(F)}{B^H(F) \; dF}\right] + \theta = 0. \qquad \text{(A.9)}$$

We use the simplifying assumption that $B^H(F) = b^H g(F)$ and $B^L(F) = b^L g(F)$, we denote $\Delta b = b^H - b^L$, and we also distinguish the three regions identified in Proposition 1.

Region I: $F^R = 0$, $s^R = \dfrac{c^H + U^R}{pB^H(F)}$, $\alpha = 0$ and $\theta = 0$. Total capital F is equal to F^o, where F^o is characterized by equation (A.9) that, in this case, reduces to $p \dfrac{dB^H(F)}{dF}\Big|_{F=F^o} = r^V$, i.e., $p\, b^H g'(F^o) = r^V$. The proposed contract is a candidate solution if $\dfrac{c^H + U^R}{B^H} \geq \dfrac{\Delta c}{\Delta b}$.

Region 2: $F^R = \dfrac{B^H(F)}{r^R}\left[\dfrac{\Delta c}{\Delta B(F)}\right] - \dfrac{c^H + U^R}{r^R}$, $s^R = s^{R^o}$, $\alpha = \dfrac{r^R - r^V}{r^R}$, and $\theta = 0$

Total investment F is determined by (A.9) equation . For the proposed functional form, the term multiplying α in (A.9) is zero when $s^R = s^{R^o}$. Therefore, the optimal investment is also F^o. The contract is a candidate solution if $\dfrac{\Delta c}{\Delta b} \geq \dfrac{c^H + U^R}{b^H}$ and $\dfrac{\Delta c}{\Delta b} \leq \dfrac{c^H + U^R \; r^R F^o}{b^H}$.

Region 3: $F^R = F$, $s^R = s^{R^o}$, $\alpha = (1 - k)\; p\, B^H(F)$, and $\theta = r^V - k\, r^R$. The investment is $F = F^{oo}$, where F^{oo} is characterized by $p \dfrac{dB^H(F)}{dF}\Big|_{F=F^{oo}} = r^V - \theta$, i.e., $p\, b^H g'(F^{oo}) = k\, r^R$. The contract is a candidate solution if $\dfrac{\Delta c}{\Delta b} \geq \dfrac{c^H + U^R + r^R F^{oo}}{b^H}$ (with $\rho = 0$).

In the region where $\alpha > 0$ and $\theta > 0$, we also have to analyze more carefully the region where $\frac{\Delta c}{\Delta B} = \frac{c^H + \underline{U}^R + r^R F}{B^H}$, i.e., $\frac{\Delta c}{\Delta b} = \frac{c^H + \underline{U}^R + r^R F}{b^H}$ since F is now an endogenous variable (hence, this case may not be degenerate). The F defined as previously, together with $F^R = F$ and $s^R = s^{R^o}$, may be a candidate solution for several combinations of the multipliers satisfying $\alpha = (1 - k - \rho)\ p\, b^H\, g(F)$ and $\rho = (r^V - k\ r^R - \theta)/r^R$. $\alpha \geq 0$ if and only if $\rho \leq 1 - k$ while $\rho \geq 0$ if and only if $\theta \leq r^V - kr^R$. The constraints on θ applied to the equation $p\,\frac{dB^H(F)}{dF}\Big|_{F=F^{oo}} = r^V - \theta$ imply that, for the contract to be a candidate, it is necessarily the case that $F \in \left[F^o, F^{oo}\right]$.

The previous analysis leads to the characterization of the candidates in all the regions proposed in proposition 3. The candidate is unique, except in the borders of the regions, where there are two candidates that in fact coincide. Hence, the optimal contract coincides with the unique candidate for all the parameter configurations.

Proof of proposition 5. For $r^V/r^R < k \leq 1$, the program solved is the same as in proposition 3, where we now consider the total financing F as an endogenous variable. Taking (A.9), and given that in this region $\theta = 0$, we have:

$$p\,\frac{dB^H(F)}{dF} - r^V + \alpha\left[\frac{\Delta c}{p(\Delta B(F))^2}\frac{d\,\Delta B(F)}{dF} - \frac{s^R}{B^H}\frac{dB^H(F)}{dF}\right] = 0 \qquad \text{(A.10)}$$

We can also distinguish two regions:

In the first region, $F^R = 0$, $s^R = \frac{c^H + \underline{U}^R}{pB^H(F)}$, and $\alpha = 0$. Total capital F is equal to F^o, where F^o is characterized by $p\,\frac{dB^H(F)}{dF}\Big|_{F=F^o} = r^V$, i.e., $p\, b^H g'(F^o) = r^V$. The proposed contract is a candidate solution if $\frac{c^H + \underline{U}^R}{b^H} \geq \frac{\Delta c}{\Delta b}$.

In the second region, $F^R = 0$, $s^R = s^{R^o}$, and $\alpha = (1 - k)\ pB^H(F)$. Total investment F is determined by the equation . For the proposed functional form, the term multiplying α in (A.10)is zero when $s^R = s^{R^o}$. Therefore, the optimal investment is also F^o. The contract is a candidate solution if $\frac{\Delta c}{\Delta b} \geq \frac{c^H + \underline{U}^R}{b^H}$.

Hence, the optimal contract always proposes F^o when k is high.

Proof of proposition 6. Out of the set of contracts that signal a good-quality project, the one that satisfies the intuitive criterion is the best for the TTO. The reason is the following: denote by C the best contract for the TTO. In order for some other contract. different from C to be an equilibrium, it must be the case that researcher and/or VC have beliefs stating hat the probability that they face a good project when they are offered C, is strictly smaller than 1 (otherwise, the TTO could offer C and the other two participants would accept it). However, these beliefs are not *reasonable* since C is a contract that the TTO would only be interested in offering if it has a good project [9].

Therefore, the contract that the TTO offers in the separating equilibrium that satisfies the intuitive criterion, is the one that solves the following program:

$$\underset{\{(s^U,\, F^U),\, (s^R,\, F^R),\, (s^V,\, F^V)\}}{\text{Max}} \left\{ s^U p_1 B^H - r^U F^U \right\}$$

s.t. (4.2), (4.3), (4.4), (4.5), (4.6), (4.7), (4.8)

$$- s^U p_2 B^H + r^U F^U \leq 0 \tag{A.11}$$

The constraints are the same as in section 3, to which we add the ICC (A.11). We follow the similar steps as in the proof of Proposition 1 to obtain $F^V = F - F^U - F^R$, $s^V = \dfrac{r^V (F - F^U - F^R)}{p_1 B^H}$ and $s^U = 1 - s^R - \dfrac{r^V (F - F^U - F^R)}{p_1 B^H}$.

Also, in Region I, the PC (4.2) implies the ICC (4.1). We then rewrite TTO's problem as:

$$\underset{F^U,\, (F^R,\, s^R)}{\text{Max}} \left\{ \left(1 - s^R - \frac{r^V (F - F^R)}{p_1 B^H} \right) p_1 B^H - (r^U - r^V) F^U \right\}$$

s.t. (4.2), (4.6), (4.7), (4.8)

$$- \left(1 - s^R - \frac{r^V (F - F^U - F^R)}{p_1 B^H} \right) p_2 B^H + r^U F^U \leq 0\,. \tag{A.12}$$

At the optimum (A.12) must be binding (otherwise, the solution would not satisfy the equation). The first-order conditions with respect to s^R, F^R and F^U are:

9. See Macho-Stadler and Pérez-Castrillo (1991) and Macho-Stadler and Pérez Castrillo (2001) for a more extended argument.

$$\frac{\partial L}{\partial s^R} = -(1-\rho)\ p_1\ B^H + \eta p_2\ B^H = 0 \tag{A.13}$$

$$\frac{\partial L}{\partial F^R} = r^V - \rho r^R + \mu - \theta - \eta r^V \frac{p_2}{p_1} = 0 \tag{A.14}$$

$$\frac{\partial L}{\partial F^U} = -(r^U - r^V) + \beta - \theta - \eta r^V \frac{p_2}{p_1} + \eta\ r^U = 0 \tag{A.15}$$

From (A.13), $\eta = (p_1/p_2)\ (1-\rho)$. Then (A.14) can be written as $\mu = p(r^R - r^V) + \theta$. We show that $\mu > 0$. Indeed, if $\rho = 0$ then, $\eta = (p_1/p_2)$ and equation (A.15) becomes:

$$\theta = \beta + \left[\frac{p_1}{p_2} - 1\right] r^U > 0$$

Therefore, equation (4.7) holds with equality and $F^R = 0$.

We distinguish two cases:

For $\rho = 0$. In this case, as we have seen, $\theta > 0$. Therefore, $F^U = F$ (and $\beta = 0$). Also, $\eta = (p_1/p_2)$ and constraint implies $s^R = 1 - \frac{r^V F}{p_2 B^H}$. Finally, the proposed contract (and Lagrange multipliers) constitutes a candidate solution if constraint (4.2) holds, that is, if:

$$\left[1 - \frac{r^U F}{p_2 B^H}\right] p_1\ B^H - c^H \geq \underline{U}^R .$$

For $\rho > 0$. In this case, $s^R = \frac{\underline{U}^R + c^H}{p_1\ B^H}$. Constraint (A.12) can now be written as:

$$-\left(1 - \frac{\underline{U}^R + c^H}{p_1\ B^H} - \frac{r^V (F - F^U - F^R)}{p_1\ B^H}\right) p_2\ B^H + r^U F^U = 0.$$

that, after some calculations, gives:

$$F^U = \frac{p_2}{p_1 r^U - p_2 r^V} \left(p_1 B^H - \underline{U}^R - c^H - r^V F\right)$$

To be a candidate solution, this contract must satisfy $F^U \leq F$, i.e.,

$$p_1 B^H \left[1 - \frac{r^U F}{p_2\ B^H}\right] - c^H \leq \underline{U}^R$$

Given that the two candidates are the unique candidates in their combination of parameters, they constitute the solution to the program.

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