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Academic Entrepreneurship

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This paper proposes a model of the choice to commercialize research, of the amount and type of pre-commercial research to perform, and of the timing of commercialization by an academic scientist, and analyzes the returns and costs of these choices. The behavior and performance of the academic scientist is compared with that of an industrial researcher. Unlike the industrial researcher, the academic scientist receives direct benefit from performing research, e.g. in the form of publication and peer recognition. However, the type of research that is more effective in reducing commercialization costs may not be the one generating the highest scientific benefit. It is shown that, while in some cases the academic scientist is more reluctant to commercialize research, in other cases she may commercialize faster than a solely profit-seeking agent would—and perform less research. Academic and non-academic scientists also select different projects, and this may explain the good performance of academic entrepreneurs found in several empirical studies. The model offers a unified framework to interpret the mixed evidence on the success of, and the arguments in favor and against, the involvement of universities into commercial activities. Managerial and public policy implications are also examined. Copyright © 2009 John Wiley & Sons, Ltd.

INTRODUCTION

Over the past 30 years, there has been an increasing interest toward academic entrepreneurship, i.e. the direct involvement of academic scientists into the development and commercialization of their research.[1] Some scholars argue that the involvement of academic scientists in commercial activities solves some imperfections in the transmission of knowledge, and motivates researchers to undertake projects with greater economic and social relevance (Gibbons *et al.*, 1994; Zucker and Darby, 1995; Etzkowitz, 2004). In the US, policymakers have enacted legislation aimed at stimulating universities to undertake more industrially relevant research.[2] Other scholars, by contrast, are skeptical about the ability of academics to manage commercial activities, while at the same time abiding by the rules and missions of academia, such as the production and timely diffusion of scientifically relevant knowledge, subjected to peer evaluation (Dasgupta and David, 1994; Stern, 1995; Heller and Eisenberg, 1998; Nelson, 2004).

Despite the attention toward these issues in the scholarly and policy debate, little is known about whether academic entrepreneurship is *different* from private-firm entrepreneurship. In order to evaluate the role of universities for the successful commercialization of research, and for striking an 'appropriate' balance between research and commercial activities, we need to understand to what extent universities and academic scientists offer something that other actors, e.g. 'pure' firms, cannot replicate.

This paper analyzes the behavior of academic entrepreneurs through a study of two key decisions: whether to undertake a commercial

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opportunity and the timing of commercialization. In order to identify the peculiarities of academic entrepreneurship, the outcomes obtained by an academic entrepreneur are compared with those of a non-academic (or industrial) entrepreneur facing the same choices. Before moving to commercialization, a scientist (academic or industrial) may choose to perform additional research activities. These activities delay commercialization but reduce commercialization costs—they have an investment value. The scientist can choose among different types of research that are more or less effective in reducing commercialization costs. Finally, academic scientists, unlike industrial researchers, derive direct benefit from the performance of research with no direct economic value, for example, in the form of publications and peer recognition.[3] The benefit, in turn, may depend upon the type of research that is performed, if some types of research are more consistent with the way the reward and recognition system works in the scientific community. Academic entrepreneurs are therefore characterized as having multiple missions: they derive direct utility from the completion of a project and the monetary returns from its commercialization (just like industrial actors), as well as from the research activities that precede commercialization. Research activities have for academics, therefore, both an investment value and an immediate consumption value. This dual value of research, the presence of different types of pre-commercial research, and the differences in objectives and incentives in different institutional environments (universities and firms) are the key features of the model.[4]

The following results are obtained. While in some cases the academic scientist is more reluctant to move to commercially relevant activities, in other cases she moves even faster than a profit-seeking company inventor would. On the one hand, the direct benefit that academic scientists derive from the performance of pre-commercial research reduces the likelihood that they will engage in commercialization. On the other hand, if the kind of research that scientists are more motivated to perform in academia is not easily applicable to commercially oriented activities, then academic scientists, despite the consumption value they derive from performing research, may find its investment value too low, and may soon prefer to move to commercial activities. Industrial researchers have incentives to perform research more easily applicable to commercial problems (for example, research that is multidisciplinary), as this makes the cost-reducing investment in research more profitable. The timing of commercialization, moreover, determines also the costs and, therefore, the commercial profitability of the project: the later the commercialization, the lower the costs. Two implications derive from these findings. First, a trade-off between the timing of commercialization and cost-effectiveness exists, and different organizations solve it differently. Second, academic scientists tend to commercialize projects with higher expected revenues than do industrial actors: the opportunity cost of commercialization for academics is higher because of the additional consumption benefit from pre-commercial research. Thus, a selection process is at work: academic and non-academic inventors move different types of projects from the lab to the market. In addition, when the same type of projects is undertaken, there are different incentives to invest in a given type of research, and this will also impact the expected commercial profitability of the project.

By offering a wide range of results for different environmental conditions (as expressed by the parameter values), this study makes sense of the contrasting empirical evidence on the role and performance of academic entrepreneurs. It also helps to spot some limits in the existing empirical studies, such as the endogeneity problems deriving from not accounting for project selection. The analysis also points to the institutional and policy challenges of having academic organizations undertake commercial activities while not renouncing to the original mission of producing knowledge for its own sake. This paper, finally, sheds light on the tensions a firm would have to deal with, when providing academic incentives to its scientists, or collaborating with individuals and organizations belonging to different institutional environments.

This paper is part of a recent stream of theoretical works that analyze the performance of commercial activities by universities. Some papers study licensing activities, and focus on such issues as the agency relationships between scientists, the university and the Technology Transfer Office, and the relation between appropriability of research and the different types of licenses arranged by universities (Jensen and Thursby, 2001; Jensen *et al*., 2003; Dechenaux *et al*., 2003; Mazzoleni, 2005). Macho-Stadler *et al*. (2006) model the design of optimal contracts for spin-offs from universities. Banal-Estañol and Macho-Stadler (2007), finally, propose an analysis closest to the one in this paper. They study the choice of an academic scientist between undertaking a new project and bringing the current one to commercialization, and how financial incentives affect this decision. This paper instead focusses on the progress of a given project, and on the comparison between academics and non-academics.

The model is set up in the first section. The results of the model, the intuitions behind them, and their relations to the empirical evidence are reported and discussed in the second section. The third section discusses further insights of the model, including proposals for empirical tests, managerial implications and policy relevance. The last section offers concluding remarks.

THE MODEL

A theory of academic entrepreneurship is presented here, through a two-period model. Appendix A summarizes the notation used in the model. The proofs to the propositions derived below are all gathered in Appendix B. The model can be nested within a more elaborate framework in an infinite-time setting. The main results and intuitions, however, are obtained also from a two-period version. Since the main interest of this paper is on the insights and implications of the model rather than its mechanics, the simpler version is presented in the main body of the paper, and the complete, infinite-time model is reported in Appendix C.

The Academic Scientist

Environment and timing. An academic scientist[5] has the opportunity to complete an economically valuable research project, given the amount of knowledge available and the amount of research performed up to that moment. There are two periods, $t=0$ and $t=1$. In period 0 the scientist faces the following choice set: she can perform some additional research (with no direct economic applications, but with novel scientific content), and possibly move to commercialization in the following period, or she can engage in commercial activities right away in period 0.[6] The scientist can also stay idle. Define a_0^u the choice made in period 0 with $a_0^u \in \{s, c, \emptyset\}$. The superscript u stands for 'university'; s stands for 'pre-commercial research' (or 'science') and c for 'commercial activities'. The symbol $\emptyset$ stands for 'idle'.

If the scientist chooses to perform additional research, she also chooses how 'applicable' to the commercial project the research will be. For example, and according to a number of studies, pre-commercial research is more applicable if it is multidisciplinary.[7] Consider, for example, a case where the current state of knowledge can lead to the development and commercialization of a particular device, say a new microchip. Developing the device is plausibly more effective if knowledge from several disciplines is brought together in order to complete the project. However, scientists can also opt for proceeding along well-defined disciplinary paths, for example, with a focus on the properties of a given material. Or, consider research in biology and the possibility to bring some findings to pharmacological applications. Again, this is typically going to be easier if a researcher has accumulated knowledge from other disciplines, such as chemistry and physiology. Alternatively, scientists may just explore biological properties through their single-disciplinary lenses.

The complete choice set in period 0 can be summarized as $\{a_0^u, \gamma_0^u\}$, where $\gamma^u \geqslant 0$ represents the scientist's choice of the level of applicability of research to the commercial activities. The choice set in period 1 is the same as in period 0, unless the scientist has chosen c in period 0 and the project was successfully completed. There is no discounting between the two periods.[8]

Commercial returns. If the scientist moves to commercial activities, there is a probability $p \in (0,1)$ that the project will be completed (economic returns are earned at completion). If the scientist commercializes in period 0 and is successful, she earns a return $R>0$ and there are no more choices to be made. Thus, the expected (gross) return from commercial activities is pR.

Commercialization costs and applicability of research. The cost of commercial activities is

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borne only once, when the scientist undertakes commercialization (i.e. chooses c for the first time). Call this cost C_c^u and define:

$$C_c^u = \begin{cases} K & \text{if } a_0^u = c \text{ or } \emptyset \\ K - \gamma^u & \text{if } a_0^u = s \end{cases} \tag{1}$$

If the scientist commercializes in the second period ($t = 1$) after having performed research in the first period, the cost of commercialization declines with the level of applicability of the research chosen by the researcher. Commercialization costs are highest when the chosen type of pre-commercial research has the lowest applicability level ($\gamma^u = 0$), or when the scientist undertakes commercial activities in period 0, without performing any additional research. By commercializing in the second period after having performed applicable research in the first period, the scientist gives up the option of a second try, but incurs in lower costs.[9]

Costs and benefits from basic research. The academic inventor receives a direct benefit, e.g. peer recognition, each period she performs research. Call the expected (gross) return from research B^u. As for the cost of performing research, let us call it C_s^u and define:

$$C_s^u = \frac{(\gamma^u)^2}{2\alpha} + \lambda^u \gamma^u \tag{2}$$

where $\alpha \in (0,K]$ and $\lambda^u \in (0,1)$. α is a scaling parameter and the parameter λ^u will be discussed below. This form of the cost function captures the difficulties in organizing applicable research. For example, if more applicable research requires an heterogeneous, multidisciplinary group to be formed, or knowledge from different fields to be acquired, there may be additional (and increasing) coordination costs that a more homogeneous, single disciplinary group might not bear (Porac *et al.*, 2004; Pereira, 2006). Figure 1 summarizes the choice sets and payoffs of the academic scientist.

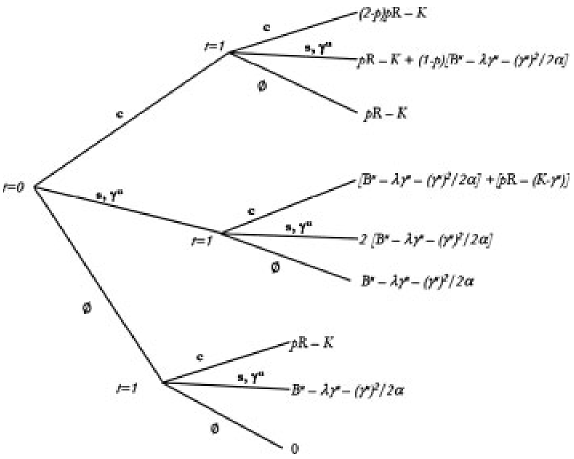

Figure 1. Decision tree for the academic scientist. The actions are reported in bold types. *Ex ante* payoffs are reported at the end of each branch.

The Company Scientist

> Private firms feel no obligation to advance the frontiers of science as such. [...] they are always asking themselves how they can make the most profitable rate of return on their investment (Rosenberg, 1990, p. 169).

> In academia you probably wouldn't go to lunch with someone in a different department—says Maciewicz, a biochemist—but because the company's success depends on a group effort, you get to interact with people who have a really different skill base (Urquhart, 2000).

The decision to commercialize, the timing of commercialization, as well as the returns and the costs for the academic scientist, are compared with a company researcher. The problem and the payoffs for the company scientist are the same as above, except for two modifications (see also Figure 2):

1. The industrial researcher cares only about the completion of the project, which is when potential economic returns occur.
2. The industrial researcher bears a lower cost from increasing the level of applicability of the performed research.

These two assumptions are formalized, as follows (where the superscript f stands for 'firm'):

$$B^u > B^f = 0 \tag{3}$$

$$C_c^f = \begin{cases} K & \text{if } a_0^f = c \text{ or } \emptyset \\ K - \gamma^f & \text{if } a_0^f = s \end{cases} \tag{4}$$

$$C_s^f = \frac{(\gamma^f)^2}{2\alpha} \tag{5}$$

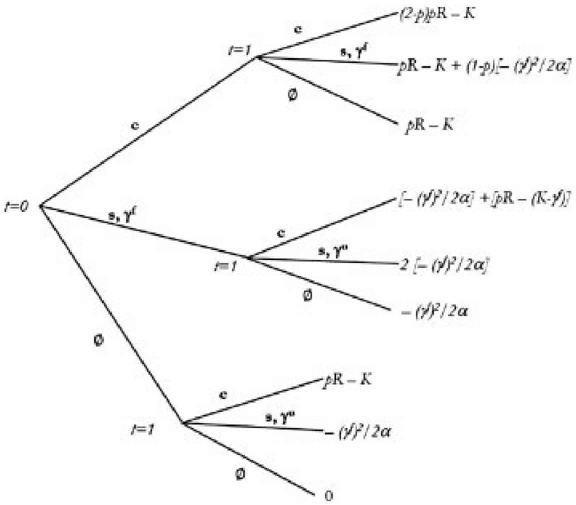

Figure 2. Decision tree for the company scientist. The actions are reported in bold types. *Ex ante* payoffs are reported at the end of each branch.

Inequality (3) captures the fact that there is a more exclusive focus on commercial success in industrial environments than in environment responding to academic rules.[10] Commercialization costs (see (1) and (4)) have the same form for the two inventors. The differences in the level of these costs emerge endogenously from the choices of γ^u and γ^f. Regarding the costs of research ((2) and (5)), the linear term $\lambda^u \gamma^u$ captures the additional loss for academics from performing more applicable research.[11] For example, multidisciplinary research may not be consistent with how the peer review system works, since the academic reward and organizational systems are discipline-based. Multidisciplinarity is also costly to achieve because of the departmentalized structure of universities.[12]

Notice, finally, that the two researchers do not interact, and the behavior of each of them is analyzed in isolation. In the concluding section, some directions for future research that include several forms of interactions are outlined. Since the expressions above are equivalent to setting $\lambda^f = B^f = 0, \lambda^u$ and B^u will be written as λ and B, hereinafter, without loss of clarity.

Expressions (3)–(5) can be therefore seen as capturing either the different preferences of academic and non-academic scientists, or the different incentive systems a given researcher would be subject to, in different institutional environments (Dasgupta and David, 1994). The different incentives operate only at the level of research activities. The academic scientist and the industrial researcher have the same commercial capabilities, given the same amount and type of research performed, and are equally rewarded when they perform commercial activities. All of the sources of heterogeneity reside in the sphere of pre-commercial research. This modeling choice is consistent with a vast literature that focusses on the differences in the performance of *research* in different institutional environments (Merton, 1973; Dasgupta and David, 1994). The extra recognition costs for academics from investing in more applicable research (i.e. from choosing some value of $\gamma > 0$) is not due to the type of activity being more 'commercial', but from the fact that the type of research is not following in full the rules of the scientific community. No stigma or disutility for academics is assumed from *commercialization per se* (except for the foregone private benefit from performing *s* instead). Once commercialization is chosen, the rules of the scientific community do not apply any longer, and the second mission that universities may choose to follow, i.e. commercial success, comes into play. Expressions (3)–(5) can also be applied to the analysis of the internal organization of companies, where the distinction is between companies that provide both academic and commercial incentives, and those providing only commercial incentives to their scientists. Similarly, the model can be applied to different universities or scientific communities that place different emphasis on research and commercialization (Feldman and Desrochers, 2004; Gittelman, 2006).

ANALYSIS

The model generates two sets of results. The first set of results, formalized in Proposition 2.1, concern the decision to commercialize research. The second set of results, expressed in Propositions 2.2 and 2.3, deal with the timing of commercialization. Each set of results is preceded by a short description of the intuitions behind them, and is followed by a discussion of the implications and relations to the existing empirical evidence. Figures 3 and 4 offer graphical representations of the main results.

Academic Reluctance and Project Selection

When deciding whether to move from research to commercialization, industrial and academic inventors have different outside options. As a

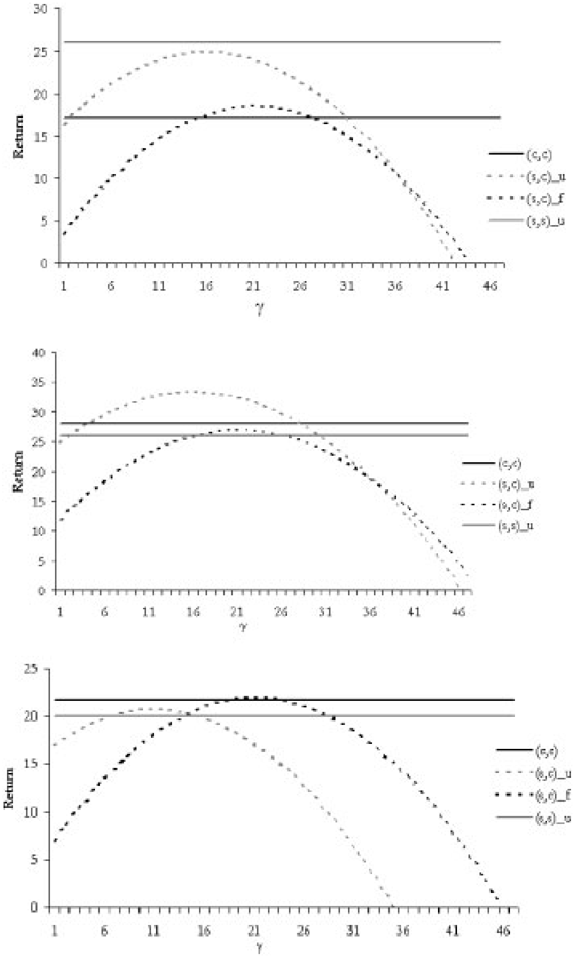

Figure 3. Graphical representation of Propositions 2.1–2.3, in the (γ, [expected] return) space. The continuous black line (*c*,*c*) gives the expected payoff from commercialization in both periods. The dotted gray curve (*s*,*c*)_*u* represents the expected return for the academic researcher from choosing *s* in $t = 0$ and *c* in $t = 1$. The dotted black curve (*s*,*c*)_*f* is the expected return for the industrial researcher from choosing *s* in $t = 0$ and *c* in $t = 1$. The continuous gray line (*s*,*s*)_*u* gives the return for the academic from choosing *s* in both periods. Notice that the academic scientist chooses $\gamma = 0$ if it plans not to commercialize at any period. The (*s*,*s*) line is therefore horizontal. The top diagram shows a case where the academic researcher never commercializes, while the company inventor does, in period 1. It is drawn for the following parameter values: $p = 0.7$; $\alpha = 30$; $K = 42$; $R = 65$; $B = 13$; $\lambda = 0.25$. The middle diagram is related to Proposition 2.2. The company scientist chooses *c* from $t = 0$, while the academic inventor invests in applicable research before commercialization. The following values are assumed: $p = 0.7$; $\alpha = 30$; $K = 42$; $R = 77$; $B = 13$; $\lambda = 0.25$. The bottom diagram represents the opposite situation, as in Proposition 2.3. The values of the parameters are: $p = 0.7$; $\alpha = 30$; $K = 42$; $R = 70$; $B = 10$; $\lambda = 0.5$. Notice that, in this last case, $B - \lambda\gamma^u = B - \lambda(1-\lambda)\alpha = 10 - 0.5(1 - 0.5)30 = 2.5$. The academic inventor would still receive positive net utility from performing additional research, given the optimal choice of γ^u and the value of the other parameters, but decides not to perform such additional research.

consequence, they have different incentives to undertake a given commercial opportunity. There is a set of commercial projects with positive profitability that the industrial inventor would undertake, and the university inventor would not. The university inventor is more selective the higher is *B*, i.e. the consumption value of basic research, and more so if λ, the parameter affecting the extra costs from applicable research, is high. Furthermore, academics choose a lower level of applicability of the content of their research ($\gamma^u < \gamma^f$), because of the extra cost they derive

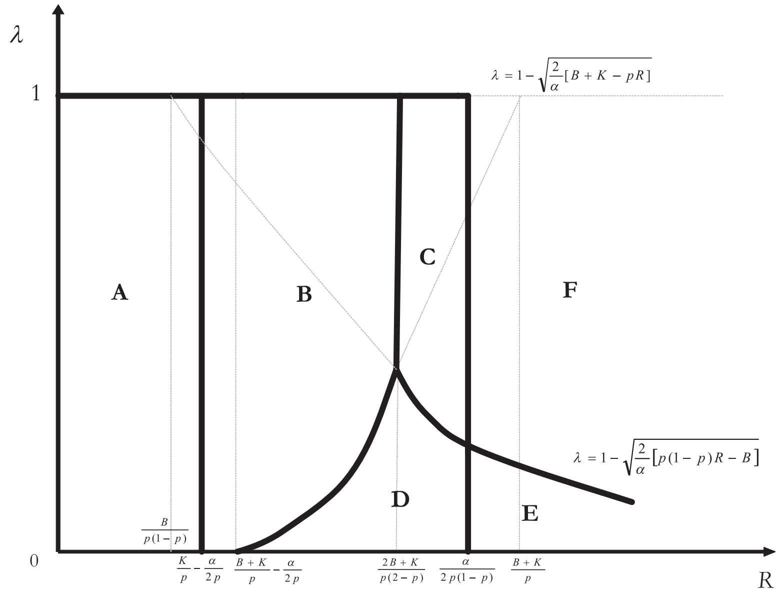

Figure 4. Qualitative representation of the cases in Propositions 2.1–2.3 in the (R,λ) space. In region A neither the company researcher nor the university researcher commercializes in any period. In region B (obtained from expressions (8), (9), (11) and (12)), the academic does not commercialize, and undertakes fundamental research (with $\gamma^u = 0$) in both periods 0 and 1. In regions D and E, the academic inventor performs applicable research in period 0, and commercializes in $t = 1$ (see inequalities (11) and (12)). In region D, also the company scientist performs research in $t = 0$ before commercializing, while in region E the firm has incentives to commercialize in period 0 with no additional research. In regions C and F the academic scientist commercializes in period 0 without performing any additional research. In region C the academic scientist commercializes earlier than the industrial inventor would—see inequalities (15) and (16) in Proposition 2.3. The diagram in this figure is drawn under the following additional assumption:

$$\frac{B}{p(1-p)} < \frac{K}{p} - \frac{\alpha}{2p} < \frac{B+K}{p} - \frac{\alpha}{2p} < \frac{2B+K}{p(2-p)} < \frac{\alpha}{2p(1-p)} < \frac{B+K}{p}$$

Values of $K = 7B$; $\alpha = 6.5B$ and $p = 0.5$ satisfy the conditions above. Notice that the condition excludes some scenarios from occurring, for example, the case in which $\{(a_0^u, a_1^u), (\gamma_0^u, \gamma_1^u)\} = \{(s,s), (0,0)\}$ and $\{(a_0^f, a_1^f), (\gamma_0^f, \gamma_1^f)\} = \{(c, c\,\text{if fail at}\,t = 0), (0,0)\}$ Further details on the construction of this graph are available from the author.

from it as compared with 'pure' basic research. In Figure 4, region A corresponds to a case in which the firm does not find it profitable to commercialize at any period, nor does the academic inventor move to commercialization. In region B, however, the firm has incentives to undertake commercially relevant activities, but the academic inventor does not (see also the top diagram in Figure 3). Scientists responding to academic rules in the performance of research choose among projects with higher expected revenues. Suppose, for example, that the distribution of projects' profitability (or probability of success) is skewed, with many marginal projects and a few very profitable ones. Because of the higher opportunity cost to move to commercialization, the academic scientist is unlikely to enter the marginal projects, and is more likely to enter only the very profitable ones. As long as also the marginal projects offer a non-negative expected return, the industrial researcher has incentives to move the research to the market. Therefore, on average the returns for an academic researcher may be higher. By contrast, conditional on both researchers moving to the same project commercialization at some period, the economic profits of the academic researcher (net of the private benefit B) are never higher than those of the industrial researcher. These intuitions are summarized in the following

Proposition 2.1:

The company researcher undertakes commercialization (at some period) if

$$pR > K - \frac{\alpha}{2} \tag{6}$$

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or

$$pR > \frac{K}{2-p} \tag{7}$$

the academic scientist commercializes if

$$pR > \frac{2B+K}{2-p} \tag{8}$$

or

$$pR > K - \frac{\alpha(1-\lambda)^2}{2} + B. \tag{9}$$

The *ex ante* revenue (or probability of commercial success) conditions for the academic scientist to commercialize are stricter than for the company scientist.

Comment. A number of empirical findings are consistent with the 'reluctance/selection' result. Doutriaux (1987) shows that companies hiring scientists are likely to grow faster if the scientists give up on their commitments with the university. Audretsch (2000, 2001) finds that academic researchers tend to undertake entrepreneurial activities in later stages of their lives than do non-academics, thus potentially missing valuable economic opportunities. The delay is longer for academics who keep a formal link with both a university and a company. Hall *et al.* (2000) report that the involvement of university partners in research projects delays commercialization. Rothaermel and Thursby (2005) find that direct involvement of academic scientists into incubator firms delays the time it takes the firm to exit from the incubator and become an independent company.

History also offers examples consistent with this framework. The invention of the transistor in the late 1940s offer an interesting 'natural experiment'. A research team at Bell Labs, and a team at Purdue University, were performing very similar research on solid-state physics. It can be argued, from the existing accounts, that both groups had the knowledge and the abilities to reach the invention.[13] The scientists at Purdue were also aware of the economic and social impacts of their research, and of the possibility to profit from it (universities could file for patents in the 1940s, and in fact Purdue had already obtained some patents before entering semiconductor research). However, the academic team focused on single-disciplinary research paths with high 'pure' scientific value, but no immediate applicability. Research at Bell Labs, while having undoubtedly high scientific content, was multidisciplinary, and there was more intense communication between scientists with different backgrounds. Similar differences emerged between the industrial research team of Genentech and the groups at Harvard and at UC—San Francisco regarding of the synthesis of human insulin in the late 1970s. In both the transistor and the human insulin case, the industrial research teams completed (and commercialized) their research faster than the academic teams.[14] A further historical example is given by the case of Varian Associates, as described by Lenoir (1997). The development of nuclear magnetic resonance (NMR) instrumentation required the performance of research that was a 'disciplinary hybrid between engineering and physics' (Lenoir, p. 247). However, the Stanford scientists interested in NMR found it hard to conduct interdisciplinary research in their university.[15]

The reluctance result, finally, offers an explanation also for the difficulties of and resistances against university-led entrepreneurial ventures as described, among others, by Kenney (1986), Argyres and Liebeskind (1998) and Lerner (2004). In most of the cases described by these authors, a major reason for the poor performance of the ventures can be reconducted to the prevalence of other objectives and missions over the focus on economic returns.

The finding that academic and industrial researchers bring different types of projects to commercialization offers an alternative explanation for the positive performance of academic entrepreneurs, reported in several studies.[16] The positive impact of the direct involvement of academics into commercially relevant research may be driven by the fact that academics *choose* to participate only in those commercial projects which make it worthwhile for them to forego valuable academic activities, and not necessarily by the superiority of their knowledge and capabilities. Just as the success of a business venture may depend on the direct involvement of academicians, so the choice of academicians to join a company depends on the (expected) profitability of the venture, as compared with other sources of benefit for the scientists. Lenoir (1997), for example, reports that Felix Bloch, a leading theoretical physicist at Stanford, decided to get involved with Varian Associates only a few years after its foundation, when the company was already growing and in

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good health. Murray (2004) reports cases of academic biologists who decided to join the firms that had developed their research, only after the firms were able to raise considerable financial resources. It is hard to infer whether it was the direct involvement of these scientists that positively affected the firms' performance, or if they joined the companies only once their prospects began to look good. Comparing the outcomes of commercial ventures involving academics with those not involving academics may therefore not be appropriate, since these ventures are likely to be very different from the outset. The model also shows that the involvement of academics reduces the pure economic profit since the university scientist invests less in applicable research. But exactly for this reason the academic scientist may decide not to bring these 'economically marginal' projects out of the lab, and may instead keep doing basic research without concerns for commercial applications, thus obtaining higher scientific benefits.

Academic Slowness and Academic Rush

Not only do the academic and industrial actors have different incentives to bring a project to the market and select among different sets of projects: they also may commercialize a given project in different periods. Proposition 2.2 shows an expected result: the institutional and organizational features of universities make academic researchers slower than company scientists in undertaking research with commercial potential. The intuition is similar to that for the reluctance case. However, in this case the academic inventor has incentives to undertake commercial activities 'not too late'. In Figure 4, this case corresponds to regions D and E (in region D, both inventors would wait until period 1 before commercializing).

Proposition 2.3 defines the parameter space where a less intuitive scenario emerges: if applicable research is very costly for the academic scientist (small B, high λ), and if the return from commercialization is sufficiently (but not excessively) high, then an academic scientist will commercialize *earlier* than an industrial scientist. The bottom diagram in Figure 3 and region C in Figure 4 represent this case. The intuition behind this result is that, by performing additional research before commercialization, the scientist receives only a small consumption value from the research. Furthermore, since the recognition cost is high, the investment in applicability will be small: the level of γ^u, i.e. the degree of applicability of pre-commercial science or cost reduction, is negatively correlated to λ, the parameter affecting the recognition costs from applicable basic research. Performing additional pre-commercial research also delays the achievement of (uncertain) economic returns. Therefore, the academic scientist would prefer to move to commercially oriented activities right at the outset, giving up the private benefit from basic research. The absence of consumption motives and recognition issues for a firm eliminates this contrast, and makes the investment in additional research, with no immediate utility, still optimal.

Proposition 2.2:

If the parameter values are such that

$$pR > \frac{\alpha}{2(1-p)}$$ [10]

$$pR > \frac{2B + 2K - \alpha(1-\lambda)^2}{2} \tag{11}$$

$$0 \leqslant \lambda \leqslant 1 - \sqrt{\frac{2(1-p)pR - 2B}{\alpha}} \tag{12}$$

then

$$\{(a_0^u, a_1^u), (\gamma_0^u, \gamma_1^u)\} = \{(s, c), (\alpha(1-\lambda), 0)\} \tag{13}$$

and

$$\{(a_0^f, a_1^f), (\gamma_0^f, \gamma_1^f)\} = \{(c, c \text{ if fail } at\ t = 0), (0, 0)\}. \tag{14}$$

The expected return at period 0 for the industrial scientist will be $p(2-p)R-K$. The expected commercial return at period 1 for the academic scientist will be $pR-K+\alpha(1-\lambda)$.

Proposition 2.3:

If the following two conditions hold:

$$\frac{2B+K}{2-p} < pR < \frac{\alpha}{2(1-p)} \tag{15}$$

$$1 - \sqrt{\frac{2(1-p)pR - 2B}{\alpha}} < \lambda \leqslant 1 \tag{16}$$

then

$$\{(a_0^u, a_1^u), (\gamma_0^u, \gamma_1^u)\} = \{(c, c \text{ if fail } at\ t = 0), (0, 0)\} \tag{17}$$

and

$$\{(a_0^f, a_1^f), (\gamma_0^f, \gamma_1^f)\} = \{(s, c), (\alpha, 0)\}. \tag{18}$$

The expected return at period 0 for the academic scientist will be $p(2-p)R-K$. The expected return at period 1 for the industrial scientist will be $pR-K+\alpha$.

Comment. The slowness result in Proposition 2.2 helps to interpret a number of empirical findings. The survey of Franklin *et al.* (2001) shows that one of the major concerns of Technology Transfer Officers in universities is that academics tend to focus on the scientific aspects of a project, thus neglecting or delaying commercially related activities. Rothaermel and Thursby (2005), while finding that incubator firms with an active involvement of academicians have lower rates of failure, also find that these firms take longer to exit from the incubator and become independent companies. Hall *et al.* (2000), finally, find that in collaborative projects with universities, firms experience difficulties in assimilating knowledge useful for the completion of the project. This can be due to the fact that university researchers have incentives to generate less applicable knowledge—another implication of the model presented here.

The rushing result of Proposition 2.3, in turn, offers interpretations for some evidence on the behavior of academics when they move to commercialization, such as the findings of Jensen and Thursby (2001) and Lowe (2002). They find that academic researchers tend to start their companies or licence their findings very early, i.e. when some additional research may still need to be performed. Finally, the result that firms have incentives to do research is also consistent with the evidence of outstanding research performed in industrial labs through history. Interestingly, an exclusive orientation to economic profits leads a company to appreciate fully the investment value of research, while the simultaneous presence of multiple motives inhibits the investment in research by the academic scientist.

Two additional issues need to be considered with regard to the rushing result. First, one could ask whether the academic scientist is actually behaving like a pure profit-seeking actor, since she is not performing any additional research. Recall that the academic and the industrial inventors are characterized as responding to different incentives when they perform *research* activities. Development and commercialization activities are activities for which there are no academic rewards, e.g. rewards in the form of recognition, publications, promotions and the like. This does not mean that universities (or individual scientists) do not care about commercialization, since they can get monetary returns out of it. Commercialization activities, *per se*, do not imply that universities are not behaving as universities, since the differences between the academic and the industrial environment are confined to the research phase. The peculiarity of the academic environment is the pursuit of *multiple missions*, with different activities, research and commercialization, being rewarded, respectively, by peer recognition and by market-based mechanisms. In the industrial setting, any activity is subject only to market-based rules. This implies that behavioral differences between the two scientists, if any, will be in the amount and type of research. Recall, finally, that we look at the performance of *additional* research for a single project. Therefore, it may well be that some academic research has already been performed, and that scientists are performing research for other projects.

A second question is whether the academic researcher, by rushing to commercialization, is potentially giving up the higher payoff that the industrial scientist is receiving (see the bottom diagram in Figure 3): the academic scientist might instead prefer to 'behave like a firm' and not follow the rules of the scientific community. However, this is precisely the case in which we are treating the academic scientist as just a company scientist. What we are interested in is instead the analysis of the behavior and performance of a scientist when she responds to the rules and incentives of the scientific community. This is what characterizes the scientist (and the entrepreneurial activity she engages in) as *academic*.

INSIGHTS FOR EMPIRICAL ANALYSES AND MANAGERIAL AND POLICY IMPLICATIONS

In addition to offering a comprehensive framework to analyze and interpret seemingly contrasting

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evidence, the model proposed in this paper lends itself to several types of empirical tests. In addition, the model can also inform managers as well as policymakers. This section discusses these additional insights.

Empirical Implementations

A first direction of empirical analysis of the model would be to study other cases of 'parallel' research by industrial and academic laboratories, in addition to those mentioned above. One could think of detailed, case-based comparisons of such contexts as company-based and university-based business incubators. Think of Xerox's PARC, for example, as opposed to university-based incubators, possibly in that same area, e.g. at Stanford. It would be possible to assess how university-based and company-based labs behave when faced with similar research projects, with economic potential.

A second direction of empirical research would be an econometric assessment of the existence of the selection effect regarding the involvement of academics in commercial ventures. One case on which to focus would be the participation of individual academicians in joint projects with commercial entities, while keeping their academic positions. Another case would be the presence of an academic professor in the founding team of a firm. One might re-run some of the regressions performed in the existing papers treating these issues, with the appropriate endogeneity and self-selection corrections.[17]

Third, one could define empirical analyses to study the timing of commercialization by academic and industrial actors. The model identifies some key parameters that drive firms and universities to choose different transition times for a given project, given the assumptions on the different missions and governance modes. Ideal data to be collected would concern a large number of industrial and academic research laboratories, and would give information about the timing of transition to development and commercialization phases. Similarly, data on business incubators offer a good empirical setting. We could assess, for example, whether and when university-led incubator firms tend to move to commercialization slower than commercial firms do, or whether and when they move faster. It would also be interesting to see if higher profitability coincides with slow completion. Studies similar to the ones proposed are Hall *et al.* (2000) and Rothaermel and Thursby (2005). These studies, however, do not control for the phase of the project, and it therefore does not allow to assess whether academic scientists tend to be slower, keeping the stage of the project constant. One could also collect information about research agreements between companies and universities, and analyze which phases of a given project are done in the university and which phases are done by the firm directly. The common wisdom would predict that early phases, having a high content of 'basicness', will be performed by the university scientists. However, an implication of the model is that, in certain circumstances, a firm has stronger incentives to perform certain types of research, while the university may prefer to perform different types or to move early to commercialization. Therefore, in some situations we might assist to less conventional divisions of labor.

A fourth avenue for empirical tests of the model is the analysis of the life cycle of academic and non-academic entrepreneurs. Junior professors may be more sensitive to the rules of the scientific community in order to obtain recognition and tenure. Senior faculty, by contrast, may be more willing to undertake types of research with no immediate academic recognition, since they have already a reputation among peers, and may be more eager to cash in. We might therefore expect academics to undertake commercial enterprises later in their life cycle than non-academics. Some evidence has already been provided by Audretsch (2000, 2001).

Managerial and Public Policy Insights

The reluctance result formalizes the arguments and evidence that cast doubts on the viability of academic entrepreneurship on a large scale and as a solution to problems of lack of innovativeness. Involving academics and academic organizations implies the involvement of peculiar missions and incentive systems, which may take priority over the completion and commercialization of projects. Research-intensive companies like Bell Labs and Genentech, to continue with the examples made above, have often been considered successful because they were able to replicate an academic environment. A careful analysis of these and other similar companies, and of the contemporaneous, similar research activities occurring in actual academic laboratories, however, reveals that the organization of research in these firms was rather different from comparable academic settings at their times. In particular, managerial direction and authority over research projects, as well as secrecy, were the norm (Shockley, 1956; Nelson, 1962; Braun and Macdonald, 1978; Hoddeson, 1980; Bray, 1982, 1997). These more 'standard' R&D organizational rules might explain the greater success of Bell Labs and Genentech, and their anticipation of the discovery of the transistor and of the synthesis of human insulin, respectively, over academic laboratories engaged in the same research at the same times.

The selection result implies that any strategic, organizational, and policy implication from empirical tests of the impact of academic entrepreneurs on the viability and success of a commercial activity (and in bringing research to market successfully) should be taken with caution, unless the selectivity problem is appropriately corrected for and the causal directions disentangled. The reluctance and selection results, taken together, tell us that we might observe both success stories of academic entrepreneurs, and missed opportunities. From a managerial standpoint, moreover, these results imply that attracting talented academic scientists may be very costly, given the additional opportunity costs that would need to be covered.

As for the slowness result derived in Proposition 2.2, most of the previously cited literature that has documented commercialization delays by academics has interpreted these delays as a downside of academic entrepreneurship. A delay, however, implies that the academic inventor produces a higher amount of research. If, at a given point in time and for a given amount of knowledge in the system, the performance of some additional research has a higher social value than the costs from the delay of commercialization, then a university researcher will have the 'right' incentives to perform this additional research. Similarly, if a company expects to benefit from the performance of additional research in a given project in the form, say, of spillovers of knowledge into other current or future activities, the company might benefit from tying the financial rewards of its scientists to their standing in the scientific community (Henderson and Cockburn, 1994), or from partnering with a university research team and delegating decision power to it over the conduct of research (Lacetera, 2007).

Finally, the rush result can be seen as a warning for the organization of research activities by companies as well as for policy interventions. From a managerial standpoint, there are cases in which, if a firm wants to commit to a higher effort in research, partnering with organizations responding to the incentives of the scientific community, or providing academic incentives to its own scientists are not the right ways to go: researchers who respond to academic incentives may be even more eager than their industrial partners to bring their research to the market, potentially at high costs given the state of knowledge. Scientific and commercial incentives, if juxtaposed in their 'pure' form, may collide instead of reinforcing each other. From a university policy perspective, if the aim of promoting academic entrepreneurship is to increase both the scientific and the commercial value of research, then in some cases academicians are not the appropriate agents of such policy. Reforms of reward criteria for academic scientists, and the promotion of multidisciplinary research, for example, may help to avoid too early commercialization, and reach a balance between science and commercialization. David (2005) proposes to create 'bridging institutions' with rules different from both the industrial and the academic environments. Bozeman (2002) shows that in University Science and Technology (S&T) Centers, often funded by both public and private entities, scientists are rewarded according to partially different rules than those prevailing in pure academic laboratories. For example, peer review is not the only metric, and multidisciplinary work is promoted. The development of these hybrid organizations, partially autonomous even if not totally separated from the academic environment, might represent a viable strategy for the promotion of science-based entrepreneurship. The benefits of these organizational and institutional changes, however, need to be weighed against a few potential costs. For example, it may be difficult for an academic organization to sustain different rules and incentive systems within its boundaries.

CONCLUSION

Despite the vast attention directed toward the role, features and impact of academic entrepreneurship, still little is known about whether academic entrepreneurship is *different* from private-firm entrepreneurship. This paper has proposed a model of the choice and timing of commercialization of research by academic entrepreneurs, and has analyzed the returns and costs of these activities. The behavior and performance of an academic actor was compared with an industrial actor. Before moving to commercialization, a scientist can decide to invest in cost-reducing research activities. In the model it is assumed that, unlike the industrial researcher, the academic scientist also receives direct benefit from performing research, in the form of publication and peer recognition in the scientific community. However, the type of research that is more effective in reducing development and commercialization costs may not be the one generating the highest scientific benefit for the academic scientist.

The model implies that, while in some cases academic scientists are more reluctant to commercialize research—because they find it too costly to abandon the research activities that generate the highest peer recognition in the scientific community—in other cases they may commercialize faster than profit-seeking firms would, and perform less basic research. A trade-off between timing and cost effectiveness is therefore present, and different organizations solve it differently. In addition, academic researchers will tend to forsake commercial projects with positive but small commercial value, and will pursue the purely scientific alternative. By contrast, company scientists would be willing to undertake also these marginal projects with economic and potentially social value. Therefore, a self-selection mechanism is present, and the observed success of academic entrepreneurs may therefore derive from the fact that, on average, university researchers move to commercialization only if the prospects are very good.

The model offers a unifying interpretation of the contrasting empirical evidence on the role and performance of academic entrepreneurs. The analysis also uncovers some potential problems in existing empirical analyses of the performance of academic entrepreneurs that do not account for project selections and the ensuing endogeneity problems. A number of implications of academic organization and policy, as well as for the management of R&D in companies, were also derived, with a focus on the challenges of academic institutions in undertaking commercial activities while not renouncing to the original missions, and on the challenges for companies that provide ‘academic’ incentives to its scientists and engage in cross-institutional collaborations.

We conclude with an outline of potential avenues for further theoretical research on the topic. A major extension of the model would be the inclusion of interactions between the academic and the company scientist, instead of having them operating separately. Interactions would take place in the form of knowledge spillovers among the parties and/or in the form of competition for priority in the discovery of the commercializable results. Both knowledge spillovers and competition between academic and industrial research labs do occur in science-based sectors. Given their different incentives, it would be interesting to study whether and how an industrial and academic research researchers react differently to spillovers and competition. For the industrial researcher, knowledge spillovers would generate a typical free-riding response, with a reduction in the research performed internally. The academic researcher, conversely, has stronger incentives to perform research, and, in addition, knowledge spillovers from the firm would further reduce the costs of commercially oriented activities, thus making them more appealing than the performance of research with no applicability and only consumption value. Some openness of research and free flow of knowledge might therefore stimulate academic entrepreneurship. We might also expect asymmetric effects from the presence of competition. Both the university and the industrial scientists will have incentives to preempt the rival and anticipate commercialization. However, since the academic scientist has the positive utility option to keep performing basic research with no commercial applications, the reduction in the expected commercial returns from competition would make the option to just perform research more appealing. This incentive would contrast the tendency to anticipate commercialization.[18]

APPENDIX A: NOTATION

Summary of the notation used in the model is given in Table A1.

Table A1. Summary of the Notation used in the Model

Agents	
u,f	Superscript indicating, respectively, the academic and the company scientist
Choice variables	
s	Perform research
c	Undertake commercialization
$\emptyset$	Stay idle
γ^u, γ^f	Level of applicability of research
Probabilities	
P	Probability of success of commercialization, in each period
Payoffs parameters	
$B \geqslant 0$	Per-period benefit for the academic scientist from performing research
$R \geqslant 0$	Gross return from (successful) commercialization
$K \geqslant 0$	Highest level of commercialization costs
$\lambda \in (0,1)$	Degree of additional costs from performing applicable research for the academic inventor
$\alpha \in (0,K]$	Scaling parameter in the cost of research function

APPENDIX B: PROOF OF PROPOSITIONS 2.1–2.3

Consider the following remarks:

Remark B.1:
The academic and the industrial scientist invests in applicable research (i.e. in γ^u) in period 0 only if they plan to commercialize in period 1. The company scientist always invests in γ^f in period 0, if she plans to commercialize in period 1. Neither the academic scientist nor the industrial scientist invests in γ in the second and last period, since there is no benefit from doing this, while there are costs.

Remark B.2:
When the scientists invest in applicable research, they choose

$$\gamma^u = \alpha(1-\lambda) \tag{B1}$$

$$\gamma^f = \alpha \tag{B2}$$

Therefore, $\gamma^u < \gamma^f$. These values are obtained from maximizing, with respect to γ, the *ex ante* expected returns from performing research in period 0, and commercializing in period 1:

$$B - \lambda\gamma - \frac{(\gamma)^2}{2\alpha} + [pR - (K-\gamma)] \quad \text{s.t.}\, \gamma \geqslant 0 \tag{B3}$$

$$-\frac{(\gamma)^2}{2\alpha} + [pR - (K-\gamma)] \quad \text{s.t.}\, \gamma \geqslant 0 \tag{B4}$$

Remark B.3:
The condition for the company scientist to commercialize in period 0 or 1 is

$$\text{Max}\left\{[p(2-p)R - K],\ \left[pR - K + \frac{\alpha}{2}\right]\right\} > 0 \tag{B5}$$

and for the academic scientist is

$$\text{Max}\left\{[p(2-p)R - K],\ \left[B + pR - K + \frac{\alpha}{2}(1-\lambda)^2\right]\right\} > 2B \tag{B6}$$

Re-arranging the terms of expressions (B6) and (B5), we obtain conditions (6) or (7), and conditions (8) or (9). Since $B > 0$ and $\lambda > 0$, conditions for the academic scientist to commercialize are stricter than for the company scientist.

Remark B.4:
If the academic or the company scientist commercialize in period 0, and they are not successful, they will both choose $a_1^i = c$. This choice is obvious for the firm. As for the university, the choice is between $a_1^u = c$ and $\{a_1^u = s,\ \gamma^u = 0\}$ (as for the choice of γ^u in period 0, see Remark B.2). Now, the academic scientist chooses $a_1^u = s$ only if $B > pR$ (at this point the commercialization cost is sunk). If this is the case, then the scientist would have chosen s also in the first period, because, *a fortiori*, $B > pR - K$. Therefore, having chosen to go commercial in the first period implies that the parameter values are such that it is optimal to go commercial also in the second period.

Remark B.5:
No party stays idle in period 0 if it plans not to stay idle also in period 1. The company scientist would retard the payoffs by one period without enjoying reduction in commercialization costs. The academic scientist would also forsake the net benefit B. In fact, the academic scientist never stays idle, since she can always guarantee itself a benefit of $B > 0$ in each period. If $pR > K - \alpha/2$,

the firm does not stay idle in the second period either.

Given these remarks, the decision trees for the academic and company scientists reduce to what reported in Figure B1.

Consider conditions (B6) and (B5) in Proposition 2.1. If the academic scientist moves to commercialization, it means that either $p(2-p)R-K>2B$ or $B+pR-K+(\alpha/2)\times(1-\lambda)^2>2B$ (or both). If $p(2{-}p)R{-}K{>}2B$, then *a fortiori* $p(2{-}p)R{-}K{>}0$, and also a company scientist would find it profitable to enter the project. If $B+pR-K+(\alpha/2)(1-\lambda)^2>2B$, then $pR-K+(\alpha/2)(1-\lambda)^2>B>0$. Now, since $\lambda\in(0,1)$, also $pR-K+(\alpha/2)>0$. Any project that the academic scientist would commercialize, would also be commercialized by the company scientist, while the opposite is not necessarily true.[19]

As for Proposition 2.2, consider the problem of the academic scientist. Commercialization in period 1 is optimal if

$$B-\lambda\gamma^u-\frac{(\gamma^u)^2}{2\alpha}+[pR-(K-\gamma_u)]>2B \tag{B7}$$

and

$$\begin{aligned}B-\lambda\gamma^u-\frac{(\gamma^u)^2}{2\alpha}+[pR-(K-\gamma^u)]&>pR+p(1-p)R\\ &=p(2-p)R-K\end{aligned} \tag{B8}$$

Similarly, for the firm, commercialization is optimally undertaken in period 1 if

$$\begin{aligned}-\frac{(\gamma^f)^2}{2\alpha}+[pR-(K-\gamma^f)]&<pR+p(1-p)R\\ &=p(2-p)R-K\end{aligned} \tag{B9}$$

Given the optimal determination of γ^u and γ^f from (19) and (20), we get the conditions (10), (11) and (12). By a similar procedure we obtain the conditions in Proposition 2.3.

APPENDIX C: AN INFINITE-TIME VERSION OF THE MODEL IN THE FIRST SECTION

This section presents an infinite (discrete) time extension of the model that nests the two-period basic framework described in the first section. Some clarifications and modifications are necessary to adapt the model to the infinite period case. Consider first, as before, the academic scientist. In each period $t=0,1,2,\ldots$, the scientist chooses $\{a_t^u,\gamma_t^u\}$, where $a_t^u\in\{s,c,\emptyset\}$ and γ_t^u is the level of applicability of research. Once the scientist commercializes ($a_t^u=c$), then there is a probability p in each period to receive an amount R. Occurrences are independent across periods. The investment in γ_t^u is separate in each period, and the impact on the reduction of commercialization costs is additive. So for example, if in time t the scientist invests an amount γ^*, and she commercializes in period $z>t$, the cost reduction in z will be equal to γ^*. Recall that the cost of commercialization is paid only once, the first time the scientist tries commercialization. There is discounting across periods; the discount factor is $\delta\in(0,1)$. We derive the following.

Proposition C.1:
Define

$$\begin{aligned}\Pi_0&=pR+\delta(1-p)pR+\delta^2(1-p)^2pR+\cdots\\ &=\frac{pR}{1-\delta(1-p)}-K\end{aligned} \tag{C1}$$

$$\begin{aligned}SC^u(\tau)=&\frac{1-\delta^\tau}{1-\delta}B+\frac{\alpha\lambda^2}{2}\frac{1-\delta^\tau}{1-\delta}-\tau\delta^\tau\alpha\lambda\\ &+\frac{\alpha\delta^\tau}{2}\frac{(\delta-\delta^{\tau+1})}{(1-\delta)}+\delta^\tau\Pi_0\end{aligned} \tag{C2}$$

and

$$\begin{aligned}NND^u(\tau,t)=&\frac{1-\delta^{\tau-t}}{1-\delta}B+\frac{\alpha\lambda^2}{2}\frac{1-\delta^{\tau-t}}{1-\delta}\\ &+\alpha\lambda(t-\tau\delta^{\tau-t})\\ &+\frac{\alpha\delta^{\tau-t}}{2}\frac{(2\delta^{t+1}+\delta^{\tau+1-t}-2\delta^{\tau+1}-\delta)}{(1-\delta)}\\ &-(1-\delta^{\tau-t})\Pi_0\\ &\forall\, t=1,2,\ldots,\tau-1\end{aligned} \tag{C3}$$

(i) If $\exists\tau^u\in(0,\mathrm{In}\,\lambda/\mathrm{In}\,\delta)$ such that

$$\tau^u=\arg\max_{\{\tau\}}SC^u(\tau)\ \text{s.t.}\ 0<\tau<\frac{\ln\lambda}{\ln\delta} \tag{C4}$$

$$SC^u(\tau^u)>\mathrm{Max}\left\{\frac{B}{1-\delta},\Pi_0\right\} \tag{C5}$$

and

$$NND^u(\tau^u)>0\quad\forall\, t=1,2,\ldots,\tau^u-1 \tag{C6}$$

then the academic scientist performs research for τ^u periods, from period 0 to period $\tau^u - 1$, start commercialization in period τ^u, i.e. $a^u_{\tau^u} = c$, and keeps trying until success. In each period $t = 0, 1, \ldots, \tau^u - 1$, the scientist invests an amount $\gamma^u_t = \alpha(\delta^{\tau^u - t} - \lambda)$ in 'applicable' basic research: $\{a^u_t = s,\ \gamma^u_t = \alpha(\delta^{\tau^u - t} - \lambda)\}\ \forall\, t = 1, 2, \ldots, \tau^u - 1$; $a^u_t = c$ at $\forall t = \tau^u$ and in any further period, until success.

(ii) If $\Pi_0 > \mathrm{Max}\{B/(1-\delta), SC^u(\tau^u)\}$, then the scientist undertakes commercially relevant in the first period $t = 0$ and tries until success: $a^u_t = c$ (until success) $\forall t = 0, 1, \ldots$.

(iii) If $B/(1-\delta) > \mathrm{Max}\{\Pi_0, SC^u(\tau^u)\}$, then the scientist never undertakes commercially relevant activities: $a^u_t = s \forall t = 0, 1, \ldots$.

Proof:

The proof is performed in three steps.

Step 1: The options reported in the previous proposition—performing s in each period with no investment in applicability, commercializing in the first period and trying c until success, and performing applicable research in the first x periods before commercialization—are the only rational ones. The reasoning is similar to the one offered for the proof of Propositions 2.1–2.3, and is expressed through the following three remarks:

(a) Once the scientist chooses c in some period z, there are no incentives to switch to any other activities thereafter. Conditional on having began to commercialized in a given period z and having failed to complete, there is no reason to invest in applicable research afterwards since the one-shot commercialization cost has already been paid, and further expenses in γ^u_t will not translate in cost reduction. Moreover, choosing c in a period z implies that the expected return from commercial research ($pR-(K-$cost savings$)$) is greater than the return from choosing pure basic research (i.e. $\{a^u_z = s,\ \gamma^u_z = 0\}$). Consider period $z+1$. Suppose that, instead of trying c again, the scientist makes a one-time deviation to $\{a^u_{z+1} = s,\ \gamma^u_{z+1} = 0\}$, and gains B. From period $z+2$, the scientist is back to the 'c path'. This deviation is profitable if

$$B + \delta pR + \delta^2(1-p)pR + \cdots = B + \frac{\delta pR}{1-\delta(1-p)} > \frac{pR}{1-\delta(1-p)}$$

or, rearranging, if

$$\frac{B}{1-\delta} > \frac{pR}{1-\delta(1-p)}$$

If this is the case, then *a fortiori*

$$\frac{B}{1-\delta} > \frac{pR}{1-\delta(1-p)} - (K - \text{cost savings})$$

so never commercializing dominates commercialization. This contradicts the assumption of entry into commercialization at a finite date z.

(b) A path in which the scientist chooses c at some finite period, and has chosen inapplicable basic research in at least one previous period (i.e. $\{a^u_t = s,\ \gamma^u_t = 0\}$) is not an equilibrium path. Suppose that, in some period t, the scientist finds it optimal to choose $\{a^u_t = s,\ \gamma^u_t = 0\}$, and gets a payoff of B. Take the path (or plan) after t (i.e. from $t+1$ to entry into commercialization) as given, and as yielding an expected sum of discounted payoffs of A_{t+1}. Now, at t, if the scientist chooses $\{a^u_t = s,\ \gamma^u_t = 0\}$, this means that $B + \delta A_{t+1} > A_{t+1}$: the scientist is better off retarding the payoff A from the established policy by one period, and getting B in the current period. A and B are time independent: choosing $\{a^u_t = s,\ \gamma^u_t = 0\}$ 'today' does not change the number of periods in which the scientist will perform applicable research from tomorrow on before moving to action c, and therefore retards entry into commercialization by one period. Hence, at each subsequent period, the scientist faces the choice between $B+\delta A$ on the one hand and A on the other hand. If $B + \delta A_{t+1} > A_{t+1}$ (or equivalently $B/(1-\delta) > A_{t+1}$), then in each period the scientist is better off doing inapplicable research in any subsequent stage, rather than undertaking the path that leads to commercialization at some point. This contradicts the assumption that the scientist would choose c at some finite time.[20]

(c) The scientist chooses $\gamma^u_t > 0$, at a given period t, only if the scientist chooses $a^u_z = c$ at some finite date $z > t$. If the scientist never chooses c, obviously she would be better off by performing $a^u_t = s$ with $\gamma^u_t = 0$ at any period t, since $\gamma^u_t > 0$ entails a cost and the benefit is enjoyed only if the scientist moves to commercialization at some finite time.

Step 2: Consider the choice of the investment levels $\{\gamma^u_t\}, t = 0, 1, \ldots, \tau^u - 1$, taking τ^u, i.e. time in which c is first chosen, as given. Consider the first period $t = 0$ (see the three parts of

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the previous step). The payoff function for the academic scientist, at period $t=0$, can be expressed as[21]

$$SC^u(\tau^u) = B - \lambda^u\gamma_0^u - \frac{(\gamma_0^u)^2}{2\alpha} + \delta\left(B - \lambda^u\gamma_1^u - \frac{(\gamma_1^u)^2}{(2\alpha)}\right) + \cdots + \delta^{\tau^u-1}\left(B - \lambda^u\gamma_{\tau^u-1}^u - \frac{(\gamma_{\tau^u-1}^u)^2}{(2\alpha)}\right) + \delta^{\tau^u}\left(\Pi_0 + \sum_{t=0}^{\tau^u-1}\gamma_t^u\right) \tag{C7}$$

This means that, when the scientist has to choose the level of investment γ_0^u, she expects this investment to generate a cost reduction equal to γ_0^u in τ^u+1 periods from the present period. Therefore, while the cost $\lambda_u\gamma_1^u + (\gamma_1^u)^2/2\alpha$ is borne in the present period, the benefit is discounted by a factor δ^{τ^u}. When the scientist has to choose the level of investment γ_1^u, the cost $\lambda_u\gamma_1^u + (\gamma_1^u)^2/2\alpha$ is borne in the current period, while the benefit is discounted by a factor δ^{τ^u-1}. And so on. Therefore, maximizing the present-valued intertemporal payoff in each period t with respect to γ_t^u yields a sequence $\{\gamma_t^u\} = \{\alpha(\delta^{\tau^u-t} - \lambda)\}$, $t = 0, 1, \ldots, \tau^u - 1$. Notice that $\gamma_t^u > 0$ if and only if $\delta^{\tau^u-t} - \lambda > 0$ or, equivalently, $t > \tau^u - \ln\lambda/\ln\delta$. As from steps 1(b) and 1(c), the scientist will perform at most $\ln\lambda/\ln\delta$ periods of applicable research, and, if she decides to do applicable research, she will start from $t=0$.

Step 3: Now, take the sequence $\{\gamma_t^u\} = \{\alpha(\delta^{\tau-t} - \lambda)\}$, $t = 0, 1, \ldots, \tau - 1$,, as a function of τ, and consider the choice of the optimal τ which we call τ^u, In point 2 of the proof, we took τ^u as given and found the optimal sequence $\{\gamma_t^u\}$ (given also steps 1(a), 1(b), and 1(c)). In this point 3, we instead consider the sequence $\{\gamma_t^u\}$ for any value of τ (the time activity c is undertaken), and then find the optimal $\tau = \tau^u$. The scientist is choosing both $\{\gamma_t^u\}$ and τ^u, and the two choices have to be consistent. Substituting $\{\gamma_t^u\}$ into (C7), we obtain

$$SC^u(\tau) = \frac{1-\delta^\tau}{1-\delta}B - \alpha\lambda\sum_{t=0}^{\tau-1}\delta^t(\delta^{\tau-t} - \lambda) - \frac{\alpha}{2}\sum_{t=0}^{\tau-1}\delta^t(\delta^{\tau-t}-\lambda)^2 + \delta^\tau\left[\Pi_0 + \alpha\sum_{t=0}^{\tau-1}(\delta^{\tau-t} - \lambda)\right] \tag{C8}$$

or equivalently

$$SC^u(\tau) = \frac{1-\delta^\tau}{1-\delta}B + \frac{\alpha\lambda^2}{2}\frac{1-\delta^\tau}{1-\delta} - \tau\delta^\tau\alpha\lambda + \frac{\alpha\delta^\tau}{2}\frac{(\delta - \delta^{\tau+1})}{(1-\delta)} + \delta^\tau\Pi_0. \tag{C9}$$

Consider $\tau^u = \operatorname{argmax}_{\{\tau\}} SC^u(\tau)$ s.t. $0 < \tau < \ln\lambda/\ln\delta$. If τ^u maximizes (C9) with respect to τ under the constraint that $0 < \tau < \ln\lambda/\ln\delta$, and condition (C6) is satisfied, then it is optimal to choose $\{a_t^u = s, \gamma_t^u = \alpha(\delta^{\tau^u-t} - \lambda)\}, \forall t = 1,2,\ldots,\tau^u - 1$, and $a_t^u = c$ at $t = \tau^u$ and in any further period, until success. Condition (C6) ensures that, in each period before τ^u, commercializing (with the cost reduction accumulated up to that point) is not profitable if compared with staying on the path that implies investments in γ up to $\tau^u - 1$, and first attempt to commercialize at τ^u, given the path $\{\gamma_t^u\} = \{\alpha(\delta^{\tau-t} - \lambda)\}, t = 0,1,\ldots,\tau - 1$. Suppose, for example, that $\tau^u > 1$. Consider the choices available to the scientist at period 1, and recall we keep the sequence $\{\gamma_t^u\}$ constant. The scientist can choose between staying on the 'equilibrium path', i.e. investing a sequence $\{\gamma_t^u\}$ up to period $\tau^u - 1$, or begin commercialization $a_t^u = c$ in period 1. Notice that in period 1 the scientist has already sunk the cost of investing in γ_0^u, and expects to gain $\Pi_0 + \alpha(\delta^{\tau^u} - \lambda)$ from deviating. If instead the scientist stays on the path, the expected return is

$$ND^u(\tau^u, t)\,|_{t=1} = \frac{1-\delta^{\tau^u-1}}{1-\delta}B - \alpha\lambda\left[\sum_{i=0}^{\tau^u-2}\delta^i(\delta^{\tau^u-1-i} - \lambda)\right] \frac{-\alpha}{2}\left[\sum_{i=0}^{\tau^u-2}\delta^i(\delta^{\tau^u-1-i}-\lambda)^2\right] + \delta^{\tau^u-1}\left[\Pi_0 + \alpha\sum_{i=0}^{\tau^u-1}(\delta^{\tau^u-i} - \lambda)\right] \tag{C10}$$

or equivalently

$$ND^u(\tau^u,t)|_{t=1}=\frac{1-\delta^{\tau^u-1}}{1-\delta}B+\frac{\alpha\lambda^2}{2}\frac{1-\delta^{\tau^u-1}}{1-\delta}-\tau\delta^{\tau^u-1}\alpha\lambda-\frac{\alpha\delta^{\tau^u-1}}{2}\frac{\delta-\delta^{\tau}}{1-\delta}+(\alpha\delta^{\tau^u-1})\frac{\delta-\delta^{\tau^u+1}}{1-\delta}+\delta^{\tau^u-1}\Pi_0. \tag{C11}$$

More generally, the expected return from deviating at a given period $t<\tau^u$ is

$$D^u(\tau^u,t)=\Pi_0+\alpha\sum_{i=0}^{t-1}(\delta^{\tau^u-i}-\lambda)$$

and the expected return from staying on the path is

$$ND^u(\tau^u,t)=\frac{1-\delta^{\tau^u-t}}{1-\delta}B-\alpha\lambda\sum_{i=0}^{\tau^u-t-1}\delta^t(\delta^{\tau^u-t-i}-\lambda)-\frac{\alpha}{2}\sum_{i=0}^{\tau^u-t-1}\delta^t(\delta^{\tau^u-t-i}-\lambda)^2+\delta^{\tau^u-t}\left[\Pi_0+\alpha\sum_{i=0}^{\tau^u-1}(\delta^{\tau^u-i}-\lambda)\right] \tag{C12}$$

or equivalently

$$ND^u(\tau^u,t)=\frac{1-\delta^{\tau^u-t}}{1-\delta}B+\frac{\alpha\lambda^2}{2}\frac{1-\delta^{\tau^u-t}}{1-\delta}-\tau\delta^{\tau^u-t}\alpha\lambda-\frac{\alpha\delta^{\tau^u-t}}{2}\frac{(\delta-\delta^{\tau^u+1t)}}{1-\delta}+(\alpha\delta^{\tau^u-t})\frac{\delta-\delta^{\tau^u+1}}{1-\delta}+\delta^{\tau^u-t}\Pi_0 \tag{C13}$$

In order for no deviation to be profitable, we need $ND^u(\tau^u,t)-D^u(\tau^u,t)=NND^u(\tau^u,t)>0, t=1,\ldots,\tau^u-1$ (see condition (C3)). Notice that $SC^u(0)=\Pi_0$. Moreover, if $\tau^u>\ln\lambda/\ln\delta$, there will be some periods of inapplicable basic research performed ($\gamma_t^u=0$) However, from the previous steps in this proof we know that either the scientist performs applicable research in any period before commercializing, starting from $t=0$, or the scientist always chooses $\gamma_t^u=0$ and does s in any period. Therefore, we can write $SC^u(\tau)=(1/(1-\delta))B$ for $\tau>\ln\lambda/\ln\delta$. □

As for the industrial scientist, the following is obtained:

Proposition C.2:
Define

$$\Pi_0=\frac{pR}{1-\delta(1-p)}-K \tag{C14}$$

$$SC^f(\tau)=\frac{\alpha\delta^\tau}{2}\frac{(\delta-\delta^{\tau+1})}{(1-\delta)}+\delta^\tau\Pi_0 \tag{C15}$$

and

$$NND^f(\tau,t)=\frac{\alpha\delta^{\tau-t}}{2}\frac{(2\delta^{t+1}+\delta^{\tau+1-t}-2\delta^{\tau+1}-\delta)}{(1-\delta)}-(1-\delta^{\tau-t})\Pi_0 \quad \forall\, t=1,2,\ldots,\tau-1 \tag{C16}$$

(i) If $\exists\,\tau^f$ such that

$$\tau^f=\arg\max_{\{\tau\}} SC^f(\tau)$$

$$SC^f(\tau^f)>\Pi_0$$

and

$$NND^f(\tau^f)>0 \quad \forall\, t=1,2,\ldots,\tau^u-1, \tag{C17}$$

then the company scientist performs research for τ^f periods, from period 0 to period τ^f-1, enters commercially relevant activities in period τ^u, i.e. $a^u_{\tau^f}=c$, and keeps trying until success. In each period $t=0,1,\ldots,\tau^f-1$, the scientist invests an amount $\gamma_t^f=\alpha\delta^{\tau^u-t}$ in ‘applicable’ basic research.

(ii) If $\Pi_0>SC^f(\tau^f)$, then the scientist undertakes commercially relevant in the first period $t=0$ and tries until success.

Proof:
Follows from the proof of Proposition 3, once we recall that $B^f=\lambda^f=0$. □

We see how the results derived and discussed in the basic, two-period model can all be derived also from this more general formulation. The reluctance and selection results, which state that the parameter space for which the academic scientist enters commercialization at some finite time is a subset of the parameter space for which the company scientist enters, can be seen as follows. If $\Pi_0>\left[1/(1-\delta)\right]B$, then *a fortiori* $\Pi_0>0$, so for sure the company scientist does find it profitable to enter commercialization, at least a

$t = 0$. Suppose now that $\Pi_0 < 0$ and

$$SC^u(\tau) = \frac{1-\delta^\tau}{1-\delta}B + \frac{\alpha\lambda^2}{2}\frac{1-\delta^\tau}{1-\delta} - \tau\delta^\tau\alpha\lambda + \frac{\alpha\delta^\tau}{2}\frac{(\delta-\delta^{\tau+1})}{(1-\delta)} + \delta^\tau\Pi_0 > \frac{1}{1-\delta}B \tag{C18}$$

or equivalently

$$\frac{\alpha\lambda^2}{2}\frac{1-\delta^\tau}{1-\delta} - \tau\delta^\tau\alpha\lambda + \frac{\alpha\delta^\tau}{2}\frac{(\delta-\delta^{\tau+1})}{(1-\delta)} + \delta^\tau\Pi_0 > \frac{\delta^\tau}{1-\delta}B(>0) \quad \text{at some } \tau \in \left(0, \frac{\ln\lambda}{\ln\delta}\right) \tag{C19}$$

This implies that the academic scientist will commercialize at some point. If assumption (C19) is true, then the company scientist could always choose an investment level and commercialization time so as to achieve a positive return, and therefore will enter. The opposite case (with the academic scientist commercializing at some finite period and the industrial scientist never commercializing), in contrast, will not occur. The following examples report different possible scenarios.

Example C.1:
For $p = \delta = 0.5$, $R = 6000$, $B = 500$, $\alpha = 810$, $K = 3000$, $\lambda = 0.1$, we have $\tau^u = 1$ and $\tau^f = 0$.

Example C.2:
For $p = \delta = 0.5$, $R = 5000$, $B = 500$, $\alpha = 1500$, $K = 3000$, $\lambda = 0.1$, we obtain $\tau^u = \infty$ (the university scientist never commercializes) and $\tau^f = 1$.

Example C.3:
If $p = \delta = 0.5$, $R = 7000$, $B = 250$, $\alpha = 3000$, $K = 4000$, $\lambda = 0.28$, then $\tau^u = 0$ and $\tau^f = 1$.

Example C.4:
For $p = 0.7$, $\delta = 0.9$, $R = 10000$, $B = 400$, $\alpha = 1900$, $K = 6000$, $\lambda = 0.4$, we have $\tau^u = 5$ and $\tau^f = 3$.

NOTES

1. Academic entrepreneurship takes several forms: industry–university collaborations, university-based incubator firms, start-ups by academicians, double appointments of faculty in firms and universities, etc. This paper abstracts from any specific form in the theoretical development. Just like the expression 'Academic entrepreneurship' will be use to indicate different cases, so the terms 'Entrepreneur', 'Scientist', 'Researcher' and 'Inventor' will be used interchangeably in the paper.
2. The interventions include the 1980 Bayh-Dole Act and the 1986 Federal Technology Transfer Act. Similar initiatives have been undertaken more recently in Europe and Japan. See Geuna *et al.* (2003) and David (2005).
3. See Merton (1957, 1973), Dasgupta and David (1994), Gittelman and Kogut (2003) and Stern (2004).
4. The model, therefore, does not explore *why* the objectives and incentive systems in business and academia differ. Somewhat less ambitiously, but not without insight, the objective of this study is to analyze the *consequences* on entrepreneurial decisions of the presence of different missions and incentives in different institutional contexts.
5. Equivalently, one could consider a research *team* as the relevant unit of analysis, assuming that the members of the team agree on the same course of actions.
6. Commercial activities include, for example, the time spent writing a business plan to market the product, and the performance or supervision of development and marketing activities. These commercially related activities are assumed to be directly performed, at least to some extent, by the scientist herself. Both in the academic and industrial setting, the scientist is assumed to have decision power over the course of action. See Gee (2001).
7. See, among others, Rosenberg (1994), Stern (1995), Brewer (1999), Llerena and Meyer-Krahmer (2003), Rinia *et al.* (2001), Carayol and Thi (2003), Boardman and Bozeman (2004), Page (2007). Also, several practitioners interviewed for this project stressed the importance of multidisciplinary research for the industrial application of basic knowledge.
8. The assumption that there are no actions in the last period, if commercialization is undertaken in $t = 0$ and is successful, is a restrictive one. One could expect, for example, the academic scientist to perform some additional research after the project is completed. Jensen *et al.* (2003) make a similar assumption: if the academic inventor discloses her invention in the first stage of the game, and the Technology Transfer Office finds an acquirer, then the game ends. In this model, just as in theirs, the unit of analysis is a single project (apart from the presence of an alternative project in their model, and of the choice to stay idle in mine). Once the project is completed, no other projects are available. We can imagine that the project has no additional commercial value after the first date in which it is successfully commercialized, say because others can soon imitate it, nor it has any additional scientific novelty content after commercialization of the final product, say because of loss of novelty content. Furthermore, the academic inventor has also the

choice not to commercialize at all, and to perform research instead. In some sense, we can interpret this option as the performance of an alternative project.

9. The role of research as a cost-reducing investment is present in other works, for example Klepper (1996). Instead of reducing costs, the performance of additional research can increase the probability successful commercialization (see Jensen *et al.*, 2003). Results are similar if this alternative modeling strategy is adopted.
10. This assumption can be relaxed to $B^u > B^f \geqslant 0$.
11. One could think of $\lambda^u \gamma^u$ as a (negative) component of the direct benefit that academics receive from basic research. The direct benefit from fundamental research can be expressed as $(B^u - \lambda^u \gamma^u)$, and the cost as $\left[(\gamma^u)^2/2\alpha\right]$. A possibly less arbitrary way to capture the lower cost for the company inventor (for a given γ) is to exclude the linear term $\lambda\gamma$ from the academic inventor's cost function, and assume that the parameter α takes two different values, α^u and α^f, with $\alpha^u < \alpha^f$. This parameterization conveys qualitatively the same results and intuitions as the form used here.
12. Brewer (1999) offers a typology of obstacles to interdisciplinary research. Some of these difficulties, e.g. the differences in methods and language across disciplines, can be said as referring to the nature itself of interdisciplinary research. Other sources of costs depend on the institutional rules and incentive systems of the environment where the research is performed. These costs include the funding rules (and whether they give priority to disciplinary research), and scientists' concerns about their status and careers. Williamson (2006) describes the difficulties of academic scientists to adapt to the research environment in company labs, where teamwork and cross-disciplinary projects are the norm.
13. For example, Bardeen, Brattain and Shockley, who led the project at Bell Labs, shared the Nobel prize in 1956, and Karl Lark-Horovitz, who led solid-state research at Purdue, was an authority in solid-state physics in the 1940s.
14. See Nelson (1962), Braun and Macdonald (1978), Hoddeson (1980) and Bray (1997) on the transistor; and Hall (1987), Stern (1995) and McKelvey (1996) on synthetic insulin. The author is also very grateful to Professor Ralph Bray, who was a doctoral student in the Lark-Horovitz's group at Purdue in the late 1940s, for agreeing to be interviewed.
15. A strict disciplinary organization of research at Stanford is confirmed by Jong (2006) in a study of the biochemistry departments in the San Francisco Bay Area.
16. See, for example, Zucker and Darby (1995), Cockburn and Henderson (1998), Torero *et al.* (2001), Nerkar and Shane (2003), Shane (2004), Stephan *et al.* (2004), Rothaermel and Thursby (2005), Toole and Czarnitzki (2005) and Agrawal (2006).
17. A plausible instrument for the selection equation may be given by changes in a university's guidelines regarding conflict of interests and of commitment for professors.
18. In the previously mentioned case of the synthesis of human insulin, there was some competition between Genentech and the two academic teams (at Harvard and UC San Francisco; see Hall, 1987). Competition was even more evident in the research on the human genome (see Davies, 2001), between Celera Genomics and a public consortium that included the NIH, the Whitehead Institute and the Wellcome Foundation. See Werth (1995), and Evans (2004) for further examples. In the human insulin case this competition did not seem to have changed the behavior of the parties, with the academic teams still preferring a longer, scientifically more relevant and commercially less applicable path of research. In the human genome case, by contrast, the entry of Celera into the 'race' caused the public consortium to change their path of research toward a shorter, less scientifically relevant method.
19. Equivalently, if the probability p of commercial success of a given project is such that the academic scientist is willing to commercialize, then also the industrial team is. The opposite is not necessarily true.
20. Note the implicit assumption that the path that leads to commercialization in a finite period includes some periods of applicable research (in fact, this remark proves that all of the periods preceding commercialization will be spent in applicable research). Clearly, performing basic research with $\gamma = 0$ and then moving to commercialization is not optimal: if no applicable research is being performed, in each period the alternative is between getting $pR - K$ and getting B, independent of time. So if one is greater than the other, it is so in any period.
21. Assume that K is always greater than the sum of cost-reducing investments, in order to ensure that commercialization costs be non-negative.

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