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Citation: Banal-Estanol, A. & Macho-Stadler, I. (2008). Commercial Incentives in Academia (08/13). London, UK: Department of Economics, City University London.

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Commercial Incentives in Academia

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**Department of Economics
Discussion Paper Series
No. 08/13**

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Commercial Incentives in Academia*

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December 1, 2007

Abstract

This paper investigates the effects of monetary rewards from commercialisation on the pattern of research. We build a simple repeated model of a researcher capable to obtain innovative ideas. We analyse how academic and market incentives affect the allocation of the researcher's time between research and development. We argue, however, that technology transfer objectives also affect the choice of research projects. Although commercialisation incentives reduce the time spent in research, they might also induce researchers to conduct research that is more basic in nature, contrary to what the “skewing problem” would presage. Monetary rewards induce a more intensive search for (ex-post) path-breaking innovations, which are more likely to be generated through (ex-ante) basic research programs. These results are shown to hold even if development delays publication.

Keywords: Faculty behaviour, basic vs. applied research.

*An earlier version of this paper was circulated under the title “Financial Incentives in Academia: Research versus Development”. We are grateful to David Pérez-Castrillo and Reinhilde Veugelers for valuable discussions and helpful comments. We have also benefited from the comments of seminar participants at the Jornadas de Economía Industrial at IESE (Barcelona) and at the European Economic Association conference in Budapest. Financial support from Ministerio de Ciencia y Tecnología (SEJ2006-00538), Consolider-Ingenio 2010 (CSD 2006-00016), Generalitat (Barcelona Economics - xarxa CREA and 2005SGR00836) is gratefully acknowledged.

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1 Introduction

The industrial base of many advanced economies relies heavily on public science, i.e. knowledge that originates from universities and other public research institutions (Narin et al., 1997 and McMillan et al., 2000). The prominent role of universities implies that any change in the research environment is (and should be) widely debated. The Bayh-Dole Act, which gave American universities the right to own and license inventions emanating from federally funded research, has certainly been no exception. Since the enactment of this law more than twenty years ago, patenting by universities, together with licensing agreements and revenues, has increased dramatically. The 86 universities responding to the Association of University Technology Managers survey in 1991 and 1998, for example, reported an increase in patent applications of 176 percent and licenses executed of 131 percent (Jensen et al., 2003).¹

Many people have seen this surge in patenting and licensing as a great benefit to society. Others, however, worry about the long-term side-effects of the Bayh-Dole act. Voices have been raised in a variety of societal forums opposing changes that might endanger the “intellectual commons” and the practices of open science (see e.g., Nelkin, 1984). Because only private information can be patented, researchers might not be able to publish preliminary results until a patent application has been filed. This can be delayed further into the licensing process as firm contracts with universities often include delay of publication clauses.² Some other groups have expressed concerns about the possibility that commercial rewards might also be affecting the choice of research projects, “skewing” research from basic towards more applied (Florida and Cohen, 1999).³ After the costs are recovered, the royalty income is divided between the university’s transfer office, the faculty members listed as inventors and their departments. In many of these agreements

¹In recent years, in a large number of EU countries an increase in patenting has also been closely following the transfer of ownership of patents to universities (Geuna and Nesta, 2006).

²One half of the firms surveyed by Thursby and Thursby (2007) noted that they include delay of publication clauses in at least 90% of their university contracts.

³Survey results by Blumenthal et al. (1986) indicate that faculty members whose research is supported by the industry are four times more likely than faculty without such support to report that their choices of research topics have been affected by the chance that the results would have commercial application.

the faculty can receive as much as 50% of the total royalty revenue.⁴

Still, many directors of technology transfer offices believe that substantially less than half of the inventions with commercial potential are disclosed to their offices (Jensen et al., 2003). Some of them may not be disclosed because the inventor is not able to realise the potential commercial value but in many other cases the inventor does not want to take time away from research. Faculty involvement in commercial development is necessary for businesses to be interested in licensing university inventions, since most of the innovations licensed are at an early stage of development (Jensen and Thursby, 2001). And, researchers are not only driven by monetary rewards, as other non-academic entrepreneurs, but also by peer recognition and the “puzzle” joy (Stephan and Levin, 1992). Academic freedom to define research topics and methods has high importance for faculty members even if they lack applicability in the short run. Preferences for research are reinforced by the academic tenure process and the reward and merit systems that put the emphasis in scientific publications.

This paper proposes a framework to analyse the effects of monetary rewards from commercialisation on the pattern of research. We build a simple repeated model of a researcher capable to obtain innovative ideas. In each period, the researcher might decide to undertake new research, generating thus a new idea. Each idea has both academic and potential commercial value, in line with recent evidence that shows that a single piece of knowledge may contribute to both scientific research and useful commercial applications (the “Pasteur’s quadrant”).⁵ Alternatively, she may decide to work in collaboration with a firm and develop prior research into a commercially valuable innovation. If she does so, however, the researcher forgoes the opportunity of undertaking new research and therefore of receiving a new idea in that period. We analyse, in the first place, how

⁴Lach and Schankerman (2003) provide strong empirical support for the importance of inventor’s royalty shares for university performance in terms of inventions and license income.

⁵This line of research started with Stokes’ (1997) famous treatise, “Pasteur’s Quadrant”. The canonical example is the French chemist Louis Pasteur, who, acting as a consultant for the French wine industry, confirmed the germ theory of disease. Murray (2002) provides a more recent case study of the “onco-mouse”, a discovery that was both a product and fundamentally affected the pace and direction of genetic cancer research. Following Murray (2002) and Murray and Stern (2007) we posit that papers and patents encode the same piece of knowledge.

academic and market incentives affect the allocation of researcher's (fixed amount of) time between research and development. Not surprisingly, higher commercial rewards induce the researcher to develop more and therefore to spend less time on research.

We argue, however, that technology transfer objectives also affect the choice of research projects within the researchers' discipline. At least according to one measure, researchers should have incentives to conduct more basic research, contrary to what the "skewing problem" would suggest. Indeed, we show that the introduction of commercial rewards prompts researchers to increase the search for high-quality path-breaking (ex-post) ideas, which are more likely to be generated through (ex-ante) riskier research programs. Although risk is associated with all forms of research, high uncertainty is an inherent characteristic of basic research. As Nelson (1959) states in his seminal paper, "the line between basic scientific research and applied scientific research is hard to draw. There is a continuous spectrum of scientific activity. Moving from the applied-science end of the spectrum to the basic-science end, the degree of uncertainty about the results of specific research projects increases". Therefore our model shows that although commercial incentives induce faculty to spend less time doing research, they might also prompt researchers to select scientific projects that are more basic in nature.

Although the choice of research projects cannot be measured directly, existing indirect evidence suggests that the much-feared switch from basic to applied research is not occurring. Thursby and Thursby (2002) conclude that changes in the direction of faculty research seem to be relatively less important than other factors in explaining the increased licensing activity. Using faculty-level data from six major universities, Thursby and Thursby (2007) find no systematic change in the proportion of publications in basic versus applied journals between 1983 and 1999.⁶ They also report that the total number of publications per faculty member more than doubled over the time period, indicating that the number of publications in basic journals has actually increased. A decrease in the quality of university patents could also be taken as an indication of a trend towards more applied research. Although Henderson et al. (1998) do find a decreasing trend in the quality of university patents (measured by the number of forward citations), Mowery

⁶Hicks and Hamilton (1999) also found that the percentage of basic research that was performed at American universities remained unchanged between 1981 and 1995.

et al. (2001), Mowery et al. (2002) and Mowery and Ziedonis (2002) argue that this is due to an increased number of new and inexperienced technology transfer offices rather than to a systemic change in the nature of academic research.

Our framework generates comparative statics results that are consistent with a variety of stylised facts related to individual characteristics such as age and tenure and other characteristics such as discipline. The model also allows us to examine further implications and suggest additional tests. We extend for example our basic model to analyse the effects of increased secrecy, the inability to publish results until the end of the development period. We compare how the allocation of time and the selection of research projects change with respect to the case in which development does not delay academic publication. We show that although the researcher develops less often than without secrecy, she might still select projects that are riskier. Therefore, the introduction of commercial incentives might induce research that is more basic in nature, even if development delays publication, albeit the effect should be weaker than without delay.

To the best of our knowledge, this is the first paper that models the impact of the introduction of commercial incentives on the choice of research projects. It is important to note that we are concentrating on early-stage academic research. Aghion et al. (2005), instead, study the respective advantages and disadvantages of academia and the private sector at different stages and show that university researchers are more effective at an early stage.⁷ Closer to our work, Lacetera (2006b) compares the incentives of academic and industrial researchers to perform additional research into a given project prior to commercialisation. In contrast, this paper concentrates on the choice between undertaking new research and spending time in development and commercialisation of existing research.⁸ Thursby et al. (2005) analyse the impact of licensing on the time spent on basic and applied research in a life cycle context. They show that basic research does not need to suffer from licensing if basic and applied research effort are complementary. In

⁷Using a closely related model Lacetera (2006a) studies firms' determinants to outsource research projects to academic organisations, focusing instead on duration and breadth.

⁸Several papers have analysed the relations between the university and the industry. Macho-Stadler et al. (1996) and Jensen and Thursby (2001) for example analyse the optimal contract between the university and the company. Our development period is a reduced form of this relationship. It bundles together development time, finding a buyer and so on.

our model, we show that even if applied research does not improve future basic research outcomes, researchers might choose projects that are more basic in nature.

The remainder of the paper is organised as follows. Section 2 introduces the basic model. Section 3 analyse the allocation of time and Section 4 the choice of research projects. Section 5 extends the basic model to accommodate the effects of increased secrecy. Finally, Section 6 concludes. The proofs of Section 5 are relegated to the Appendix.

2 Model

Consider the following repeated model of a risk-neutral researcher. In each period, she spends her time either doing research or being involved in further development of prior knowledge. If she pursues research she obtains, at the end of the period, an “idea” of random quality q , drawn from an independent and identical distribution $F(q)$ with density $f(q)$ and support $[0, Q]$.⁹ Our formulation thus emphasises the fact that the outcome of any research project is inherently uncertain. In line with the recent literature in the economics of science (Murray and Stern, 2007), the research output has both academic value and potential market value. The academic content is publishable in a scientific journal and it does not jeopardise further patent rights.¹⁰ The researcher derives a utility of αq , where α denotes the marginal benefit of the quality of the publication to the researcher. This parameter may reflect the tenure or recognition concerns or the possibility to obtain funding from public grants.

In the following period, the researcher may undertake a new research project and obtain, at the end of the period, a new idea. Alternatively, she might decide to spend time in the commercial development of the previous period’s output, which might involve patenting and finding and collaborating with a licensing firm to develop a commercially valuable innovation. At the end of the development period, the commercial value of an

⁹Effort and capacity issues are given and subsumed in the support and in the distribution. In the basic model, given the researcher’s specialisation and capabilities, the distribution of results is exogenous.

¹⁰We discuss in Section 5 what happens if academic publication is delayed by commercialisation. In our setup, publishing does not have any strategic effect. If, instead of a single university researcher, the producers of new technology were competing firms, publication could also be used as a strategic instrument to affect the R&D race (see for example Bar, 2006).

output of quality q is given by μq .^{11,12} The parameter μ may be linked to the discipline; engineering, for example, may have a higher μ than physical sciences. It may also reflect the difficulty of finding a company interested in licensing inventions at this early stage of development.

As the survey results of Jensen et al. (2003) confirm, faculty involvement in development (even after a license is executed) is necessary for commercial success. Therefore we assume that without this period of development, the idea does not have any commercial value. By being involved in development, however, the researcher forgoes the opportunity of undertaking new research and receiving a new idea in that period. In our setup, thus, the conflict between academic rewards and commercial gains only appears in terms of the time that development subtracts from conducting research. Research is motivated both for fundamental scientific interest and commercial gain (pertaining thus to the “Pasteur’s quadrant”). Moreover, the quality of the publications and the quality of the technology developed are positively correlated.

When selling the innovation the researcher receives a share s ($\in (0, 1)$) of the benefits that accrue to the company. These benefits depend on the market value of the innovation as well as on the costs of turning the innovation into a final commercial product. We denote by A the cost of making the innovation a commercial product, that is assumed to be paid by the firm. To make the problem interesting we need to assume that $\mu Q > A$ since, otherwise, it would never be interesting to develop any idea.¹³

¹¹We assume in the basic setup that the applicability factor is certain. It would be equivalent to assume that the commercial value is $\tilde{\mu}q$, with $\tilde{\mu}$ being an independently and identically distributed random factor with $E(\tilde{\mu}) = \mu$ whose realisation is not observed until the end of the development period. The realisation would not be relevant for the development decision. In Section 5 we extend the model to also allow for the possibility that the researcher observes the realised commercial value at the end of the research period.

¹²We assume that when sold the quality of the innovation is verifiable. The literature on markets for technology suggests the use of a menu of fixed fees and royalties or equity to signal the quality of the invention or to separate bad applications of the technology from good ones (Gallini and Wright, 1990, Macho-Stadler and Pérez-Castrillo, 1991, and Beggs, 1992).

¹³An alternative way to interpret our development period is having the researcher involved in a university spin-off. In that case, A can be interpreted as the sunk-cost of creating the spin-off and s as the shares received by the researcher. This is consistent with the contracts used for university spin-offs. See for example, Macho-Stadler et al. (2007).

This model is infinitely repeated and time is discounted by $\delta \in (0, 1)$.¹⁴ An advantage of this formulation is that our results are not distorted by the existence of a final date. The model, however, is not dynamic in the sense that there are no differences between periods, i.e. there is neither learning from past research nor accumulation of capabilities over time. While these dimensions are important, this paper aims, as a first step, at studying the simplest situation where the university researchers are confronted with the research versus development decision for an exogenous sequence of ex-ante identical research projects (next section) and with the prior selection of projects (section thereafter).

3 Time Allocation

After obtaining an idea q in the previous period the researcher decides, at the beginning of the new period, whether to develop this idea further into a potentially commercially valuable innovation or to work on a new research project. This decision depends on the expected market value of the idea and on the opportunity cost of the time to develop it. To characterise the optimal allocation of time as a function of the exogenous parameters we proceed in two steps. We first state the optimal decision as a function of any exogenous “research continuation value” V , defined as the discounted present expected value of the utility stream of a researcher at the beginning of a period in which she does research.

Lemma 1 *For any research continuation value V , there is a unique $q^\circ(V)$ such that the researcher will not develop if and only if $q \leq q^\circ(V)$.*

Proof. The researcher will be able to sell the innovation if the value for the firm is larger than the costs. This defines two intervals, $[0, \frac{A}{\mu})$ and $[\frac{A}{\mu}, Q]$, depending on the value of q . If $q < \frac{A}{\mu}$ then the researcher will not develop for any V since she will never be able to sell anyway, $\alpha q + \delta V \geq \alpha q + \delta^2 V$. If $\frac{A}{\mu} \leq q \leq Q$ then she will be able to sell the innovation if she develops and therefore she will develop whenever $\alpha q + \delta s [\mu q - A] + \delta^2 V \leq \alpha q + \delta V$, or equivalently, when $(1 - \delta)V \geq s [\mu q - A]$.

¹⁴Infinite horizon models are indeed appropriate if after each period the player believes that the game will continue for an additional period with some probability.

Denoting $m(q) \equiv s[\mu q - A]$, the previous discussion implies that, for all V , $q^\circ(V)$ is given by $m(q^\circ(V)) = (1 - \delta)V$ when $m(Q) > (1 - \delta)V$ and $q^\circ(V) = Q$ when $m(Q) \leq (1 - \delta)V$. Given that $m(Q) > 0$ (by assumption $\mu Q - A > 0$), in order to show that there exists a unique $q^\circ(V)$, we need to show that $m(q)$ is an increasing function and $m(0) < 0$. Indeed, $m'(q) = s\mu > 0$ and $m(0) = -sA < 0$. ■

For any exogenous continuation value, the researcher switches to a new research project unless the output of the previous period has enough commercial prospects. We are now ready to characterise the cutoff q° and present value V as a function of the exogenous parameters of the model. Denote as \bar{q} the expected value of q .

Proposition 2 *The optimal decision of the researcher is not to develop research output whose quality $q < q^\circ$, where q° is defined as follows:*

- (a) $q^\circ = Q$ when $\alpha\bar{q} \geq s(\mu Q - A)$.
- (b) $s(\mu q^\circ - A) = \alpha\bar{q} + \delta s\mu \int_{q^\circ}^Q (x - q^\circ) dF(x)$ when $\alpha\bar{q} < s(\mu Q - A)$.

The discounted present expected value V for the researcher is,

$$V = \frac{1}{1-\delta} \left[\alpha\bar{q} + \delta s\mu \int_{q^\circ}^Q (x - q^\circ) dF(x) \right].$$

Proof. Suppose firstly that the cut-off chosen by the researcher is $q^\circ = Q$. The researcher never develops and never sells. Hence $V = \int_0^Q \alpha x dF(x) + \delta V$, which simplifying gives $V = \frac{1}{1-\delta} \alpha\bar{q}$. The decision $q^\circ = Q$ is optimal if and only if $(1 - \delta)V \geq s[\mu Q - A]$, which substituting gives $\alpha\bar{q} \geq s(\mu Q - A)$, which corresponds to the region in part (a).

Suppose secondly that the cut-off chosen by the researcher is $q^\circ < Q$. We have that

$$V = \int_0^{q^\circ} \alpha x dF(x) + \delta F(q^\circ)V + \delta s \int_{q^\circ}^Q (\mu x - A) dF(x) + [1 - F(q^\circ)] \delta^2 V,$$

which simplifying gives

$$(1 - \delta)(1 + \delta[1 - F(q^\circ)])V = \alpha\bar{q} + \delta s \int_{q^\circ}^Q (\mu x - A) dF(x).$$

On the other hand, $q^\circ(V)$ should be defined here as $(1 - \delta)V = s[\mu q^\circ - A]$. Hence,

$$(1 + \delta[1 - F(q^\circ)])s[\mu q^\circ - A] = \alpha\bar{q} + \delta s \int_{q^\circ}^Q (\mu x - A) dF(x).$$

Simplifying we have that q° is implicitly defined by

$$j(q^\circ) \equiv s(\mu q^\circ - A) - \delta s\mu \int_{q^\circ}^Q (x - q^\circ) dF(x) = \alpha\bar{q}.$$

Since $j'(q) = s\mu + \delta s\mu(1 - F(q)) > 0$, the cut-off q° is unique. Finally, we need to check that $q^\circ \leq Q$. Since $j(q^\circ) = \alpha\bar{q}$ and $j'(q) > 0$, we need that $j(Q) \geq \alpha\bar{q}$ or $s(\mu Q - A) \geq \alpha\bar{q}$, which corresponds to the region in part (b). ■

The intuition behind Proposition 2 is simple. First, if the (academic) value of the average publication is, in monetary terms, higher than the payment from the best innovation, the researcher will never develop an idea (part a). If this is not the case, then the researcher will develop her best ideas while dropping the worse ones (part b). The quality in which the researcher is indifferent is such that the monetary reward after development is equal to the expected opportunity cost of a period's time; namely, the academic reward of the average publication plus the expected monetary reward from an innovation derived from a research output of higher quality.

From the previous equations, it is easy to show which changes of the exogenous parameters induce the researcher to develop more often; that is, when the region of part (a) of Proposition 2 (in which the researcher never develops) shrinks and/or the threshold within the region in part (b) (in which she might develop) is lower.

Corollary 3 *The researcher develops more often, when*

- (a) *the applicability factor, μ , increases;*
- (b) *the costs of turning an innovation into a commercial product, A , decreases;*
- (c) *the share of the benefits received by the researcher, s , increases;*
- (d) *the marginal utility of the quality of the publication, α , decreases;*
- (e) *the discount factor, δ , decreases.*

As one would anticipate, a higher marginal commercial value of the innovation, μ , and a lower cost of turning the innovation into a commercial product, A , induce more development. Indeed, the empirical results by Thursby and Thursby (2007) confirm that the probability that a researcher discloses in a given year is higher in more applied fields such as engineering and in fields in which the results are in strong demand by the industry such as biological sciences. Assuming that the marginal utility of academic publication α decreases with tenure and age, part (c) is consistent with the fact that disclosure increases with tenure and age, at least until the middle ages.

More interestingly, if the future is little valued (δ low), then researchers do not lose much from developing in this period and foregoing the possibility of obtaining a better research outcome. As a result, they develop more often. An alternative interpretation of the discount rate δ is the rate at which ideas are obtained. The corollary implies that a more prolific researcher (with a high δ) should be more reluctant to develop a given idea. Although she might end up developing more or less in total, the commercial value of her average innovation should definitely be higher.

Also intuitively, stronger commercial incentives (a higher s) and a lower emphasis in publications (a lower α) induce more development. The combination (α, s) would be determined by the university and would depend on the university objectives, a matter that is beyond the aim of this paper. Nevertheless, it is important to stress that for the incentive to commercialise inventions to be effective, it is necessary that the parameters satisfy $\alpha\bar{q} \geq s[\mu Q - A]$ or $\frac{\bar{q}}{[\mu Q - A]} < \frac{s}{\alpha}$. Still there might be a minimum α established by competition for researchers and/or a maximum s coming from the relationship with the market. Hence, whenever $\frac{\bar{q}}{[\mu Q - A]}$ is very high, either because the quality of the area of research is very high or because the discipline has not marketable applications, it may not be possible to provide incentives to commercialise.

So far we have assumed that all researchers were obtaining ideas from the same pool. However, better researchers might have access to better pools. In order to understand whether better researchers develop more or less often we briefly suppose that different researchers have access to pools that differ in the support of the distribution, $[\Delta, Q + \Delta]$ for some $\Delta \geq 0$. Better researchers should have a higher Δ , i.e. they obtain ideas from a pool that first-order stochastically dominates the pool of worse researchers. For simplicity, for any Δ , the distribution of quality is assumed to be uniform.

Corollary 4 *Assume that the research output is uniformly distributed over $[\Delta, Q + \Delta]$ for $\Delta \geq 0$. Better researchers (higher Δ) develop more often if and only if $\frac{\alpha}{2} < s\mu$.*

Proof. The optimal cutoff in part (b) in Proposition 2 for a uniform distribution function between $[\Delta, Q + \Delta]$ is given by $G(q^\circ, Q, \Delta) = 0$ where

$$G(q, Q, \Delta) \equiv s(\mu q - A) - \alpha \frac{Q + \Delta}{2} - \frac{s\delta\mu}{2Q} (Q + \Delta - q)^2.$$

The researcher develops more often when getting better results as long as $\frac{\partial}{\partial \Delta}(Q + \Delta - q^\circ) > 0$ or as long as $\frac{\partial}{\partial \Delta}q^\circ < 1$. Applying the implicit function theorem, we have that $\frac{\partial G}{\partial \Delta} = -\frac{s\delta\mu}{2Q}2(Q + \Delta - q) - \alpha\frac{1}{2}$ and $\frac{\partial G}{\partial q} = s\mu + \frac{s\delta\mu}{2Q}(Q + \Delta - q)$ and therefore $\frac{\partial q^\circ}{\partial \Delta} = -\frac{\partial G/\partial \Delta}{\partial G/\partial q} < 1$ as long as $\frac{s\delta\mu}{2Q}2(Q + \Delta - q) + \alpha\frac{1}{2} < s\mu + \frac{s\delta\mu}{2Q}(Q + \Delta - q)$, which is equivalent to $\frac{\alpha}{2} < s\mu$. ■

Gifted with research outputs of higher academic value, a researcher should on the one hand have more incentives to do more research and therefore develop less because her ideas have a higher academic value. On the other hand, she should have more incentives to develop because patents would also be more lucrative. The academic and commercial marginal values determine which effect is stronger. Indeed, in an institution with a low emphasis in publications and a high in development (case $\alpha/2 < s\mu$ in Corollary 4), better researchers develop more.¹⁵ In contrast in an institution more prone to reward academic excellence, better researchers should be those that develop less.

The previous corollary also hints at the dynamic consequences of working in a research or business oriented university. If one assumes that more senior researchers obtain better research output, the previous proposition predicts that researchers in research-oriented institutions will devote more and more time to research as time goes by. In contrast, senior researchers in more business oriented institutions or in more applied fields should devote more time to development than junior ones. We are not aware of any empirical test along these lines, although there is evidence that scientists become on average less productive as they get older (Stephan and Levin, 1992 and Jones, 2005).

4 Basic or Applied Research Projects

We now turn to the controversial question of how the introduction of commercial remuneration affects the choice of research projects. As argued in the introduction one of the main differences between basic and applied projects is that basic projects are riskier than applied projects. Although there is a continuous spectrum of scientific activity, moving

¹⁵Debackere and Veugelers (2005) show that top generators of new technology ventures and industrial contract volumes in the KU of Leuven in Belgium also tend to be among the top performers in terms of academic research. Similar results are obtained by Calderini et al. (2007) and Stephan et al. (2007).

from the applied-science end of the spectrum to the basic-science end, the degree of uncertainty about the results of specific research projects increases (Nelson, 1959). In what follows, we will show that according to this distinction, researchers will be more willing to choose projects that are more basic in nature. In order to isolate the effects of this difference, suppose that the researcher can costlessly choose the level of risk of her research projects, assuming that the mean and the support of the distribution are identical. In the next section, we consider other potential differences between basic and applied research.

Proposition 5 *The introduction of remuneration for commercial inventions induces researchers to select riskier projects (“more basic”). By choosing riskier projects, researchers are more reluctant to develop a given outcome, although they might develop more or less in expected terms.*

Proof. To prove this result, consider two distributions, $F_1(q)$ and $F_2(q)$, with the same support $[0, Q]$ and with the same mean (\bar{q}), and $F_2(q)$ being a mean preserving spread of (i.e. riskier than) $F_1(q)$. By definition, $\int u(x)dF_2(x) \geq \int u(x)dF_1(x)$ for any $u(x)$ defined in R^+ , non-decreasing and non-concave. Given that $u(x) = 0$ if $x \in [0, q]$ and $u(x) = x - q$ if $x \in [q, Q]$ satisfies these conditions, we have that $\int_q^Q (x - q) dF_2(x) \geq \int_q^Q (x - q) dF_1(x)$. In other words, $F_1(x)$ second-order stochastically dominates $F_2(x)$.

If s is small, the parameters of the model are in the region of part (a) of Proposition 2. In this region, the researcher is indifferent between the two distributions. If s is high enough, the parameters are in the region of part (b). Given $F_1(q)$, the threshold quality q_1^o is defined as:

$$s(\mu q_1^o - A) - \delta s \mu \int_{q_1^o}^Q (x - q_1^o) dF_1(x) = \alpha \bar{q}.$$

Since $F_2(\cdot)$ is a mean preserving spread of $F_1(\cdot)$, we have that

$$s(\mu q_1^o - A) - \delta s \mu \int_{q_1^o}^Q (x - q_1^o) dF_2(x) < \alpha \bar{q}.$$

Given that the derivative of the left hand with respect to q_1^o is positive and that

$$s(\mu q_2^o - A) - \delta s \mu \int_{q_2^o}^Q (x - q_2^o) dF_2(x) = \alpha \bar{q},$$

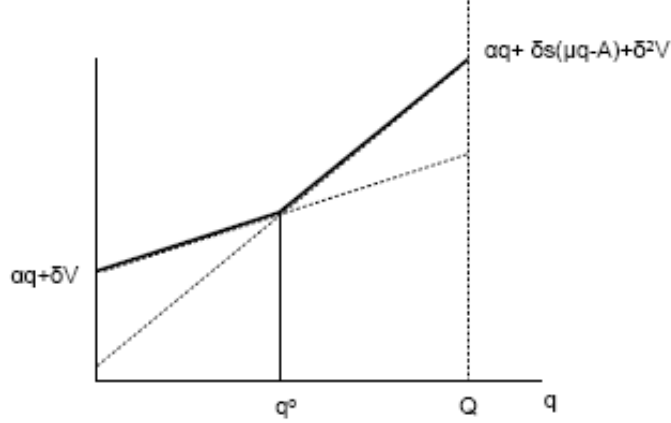


Figure 1: Researcher's utility in a given period (for a given V) as a function of the quality of the idea.

we have that $q_2^o > q_1^o$. As shown in the proof of the previous proposition, this implies that $V_2 > V_1$ and therefore the researcher prefers the risky research project. ■

The intuition behind the preference for the risky project follows from the fact that the researcher acts as if she was risk-loving with respect to the quality of the output. As we can see in Figure 1, researcher's utility as a function of the output quality is a convex function. Indeed, for a given V , the utility is the maximum of two affine functions that represent the value from continuing doing research ($\alpha q + \delta V$) and the value from development ($\alpha q + \delta s[\mu q - A] + \delta^2 V$). The latter is steeper because better output have higher development value. The former has a higher intercept because the researcher obtains a new idea sooner. As shown in Proposition 2, as long as the remuneration for the best innovation is high enough, the two lines cross at some point q^o .

By choosing riskier projects, researchers are more reluctant to develop a given idea. Indeed, they are more likely to obtain a better idea in the next period and therefore they are more willing to drop the current one. As shown in Figure 2, though, they might end up developing more ideas in expected terms. Although $F_2(x)$ is a mean preserving spread of $F_1(x)$ and therefore the threshold for the former is higher ($q_2^o > q_1^o$), the ex-ante probability of developing is higher for the former than it is for the latter ($F_2(q_2^o) < F_1(q_1^o)$).

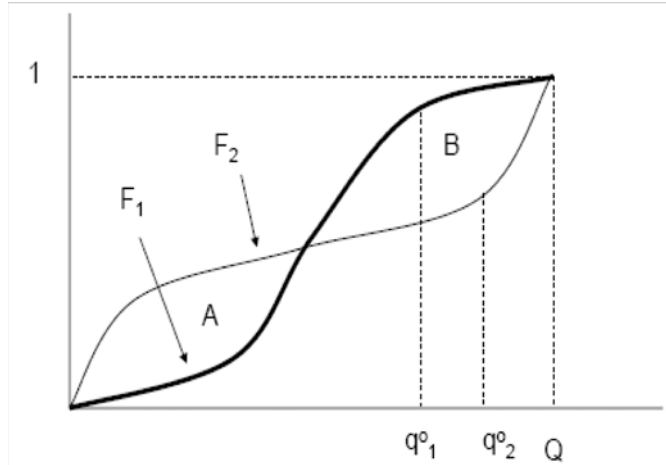


Figure 2: Distribution $F_1(\cdot)$ and a mean preserving spread, $F_2(\cdot)$ (Area A =Area B).

Although the academic and commercial rewards were assumed to be linearly increasing in the quality of the output, this result should hold more generally. Indeed, the introduction of commercial rewards induce the researcher to select between two increasing functions. Assume that the commercial value of an idea of quality q is $\mu(q)q$. Given that the best innovations have much higher value than intermediate ones, $\mu(q)$ would typically be not constant as in our model but increasing. This would make the researcher even more risk-loving than with no rewards from technology transfer. Further, the fact that the researcher selects riskier projects than with no commercial rewards should hold if the value of publications has the form $\alpha(q)q$ for any $\alpha(q)$ and not only when $\alpha(q)$ is constant. Indeed, although she might not always act as if she was risk-loving she would exhibit more risk-loving behaviour than before the introduction of commercial rewards.

5 Extensions

5.1 Increased Secrecy

There is evidence that a delay in scientific publication has occurred on results that have been the subject of a patent application (see e.g. Geuna and Nesta, 2006). To analyse how this dimension might affect our results, we assume in this subsection that if the research

outcome is to be developed, the researcher cannot publish it in a scientific journal until the end of the development period. To make things interesting, we need to assume here that the loss from delaying publication until the next period is lower than the monetary value from development (i.e., $\delta s\mu > (1 - \delta)\alpha$). Otherwise, the researcher would never develop. Following the same procedure as before, we have the following proposition.

Proposition 6 *The optimal decision of the researcher is not to develop research output whose quality $q < q^s$, where q^s is defined as follows:*

$$(a) \quad q^s = Q \text{ when } \delta\alpha\bar{q} \geq s\delta(\mu Q - A) - (1 - \delta)\alpha Q.$$

$$(b) \quad s[\mu q^s - A] = \alpha\bar{q} + \frac{(1-\delta)}{\delta}\alpha q^s + \int_{q^s}^Q (\delta s\mu - (1 - \delta)\alpha)(x - q^\circ) dF(x) \text{ when } \delta\alpha\bar{q} < s\delta(\mu Q - A) - (1 - \delta)\alpha Q.$$

The discounted present expected value V for the researcher is,

$$V = \frac{1}{(1-\delta)} \left[\alpha\bar{q} + \int_{q^s}^Q (\delta s\mu - (1 - \delta)\alpha)(x - q^s) dF(x) \right].$$

That is, the marginal idea is such that the monetary value at the end of the period is equal to the opportunity cost of time, equal to the average value of a research output, the lost value of publishing later, and the lost possibility of having a better output, which can be developed but of course at the cost of delaying publication one period.

The following corollary shows that although the researcher develop less than if development does not delay publication, she still prefers a riskier (i.e. more basic) project.

Corollary 7 *The researcher develops less often and she is worse off when there is increased secrecy. She would still choose to select riskier rather than safer projects.*

As we can see in the dashed lines in Figure 3, publication delay makes development less attractive. As a result the researcher develops less often ($q^s > q^\circ$). Further, she would still select riskier rather than safer projects because the utility is still convex (remember that $s\delta\mu > (1 - \delta)\alpha$). However, she acts as she was less risk-loving than before. Although the introduction of commercial incentives still induces research that is more basic in the presence of delay, the effect is weaker than without delay. More generally, if the researcher were risk-averse, she might be more prone to select safer or more applied projects than in the case of no secrecy.

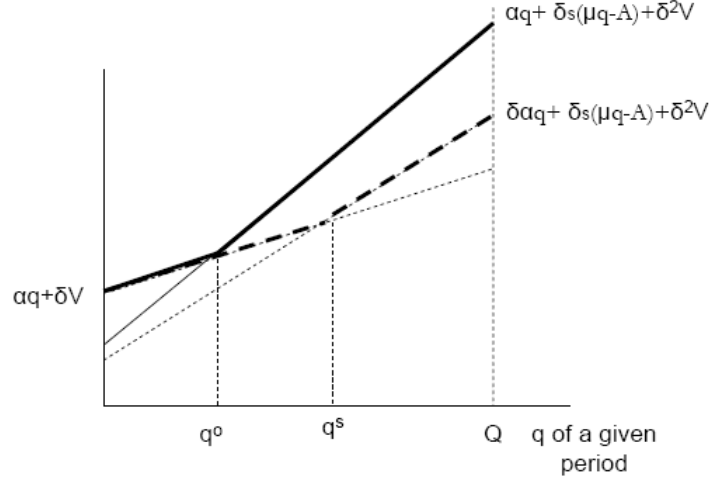


Figure 3: Researcher’s utility in a given period with (dashed line) and without secrecy.

5.2 Further differences between basic and applied research

Another potential difference between basic and more applied research projects is that the outcomes of applied projects can be more easily commercialised or, in other words, the costs A of turning the innovation into a commercial product are lower. Also, peer recognition and the expected value of publication (measured by the parameter α) can be lower for more applied projects. The next proposition confirms that, according to this distinction, researchers will be more likely to choose applied projects in the presence of commercial incentives.

Proposition 8 *The introduction of remuneration for commercial inventions is conducive to a selection of projects with lower costs of development and lower academic value (“more basic”). By choosing these projects, researchers spend more time in development and less in research.*

Propositions 5 and 8 identify two opposite effects of commercial incentives on the choice of research projects. Commercial rewards induce a shift towards more applied or towards more basic depending on which of these two effects is stronger. Of course, if more applied projects have much lower development costs, then researchers choose more applied research projects even if they are less risky. On the other hand, researchers choose

research projects that are riskier if the difference in development costs is not large. That is, commercial incentives should not necessarily “skew” research towards more applied projects, as the recent evidence mentioned in the introduction also seems to suggest. In the next section, we investigate whether this depends on the fact that we have so far assumed that commercialisation does not delay publication.

5.3 Random development value

Our basic model assumes that the development factor is certain. As mentioned in footnote 11, however, it would also allow for the possibility that the development factor is random, as long as the realisation is not observed until the end of the period of development. Both are equivalent given that only the expectation (and not the realisation) is relevant for the development/research decision. It might be, however, that the researcher realises the commercial value of a piece of knowledge at the end of the research period, when she also realises its quality. In this subsection, we assume that the development factor is random but determined at the end of the research period. We consider, for simplicity, the binary case: the development factor μ is equal to μ_l with probability p and equal to μ_h with probability $1 - p$, where $\mu_l < \mu_h$. Also for notational simplicity, we restrict the set of exogenous parameter values to ensure that at least some ideas are developed (part b in proposition 2).

Proposition 9 *The optimal decision of the researcher is not to develop output of quality $q < q_h^\circ$ if $\mu = \mu_h$ and $q < q_l^\circ$ if $\mu = \mu_l$ where q_h° and q_l° are such that $\mu_h q_h^\circ = \mu_l q_l^\circ$ and*

$$s(\mu_l q_l^\circ - A) = \alpha \bar{q} + p \delta s \mu_l \int_{q_l^\circ}^Q (x - q_l^\circ) dF(x) + (1 - p) \delta s \mu_h \int_{q_h^\circ}^Q (x - q_h^\circ) dF(x) .$$

The discounted present expected value V for the researcher is,

$$V = \frac{1}{1-\delta} \left[\alpha \bar{q} + p \delta s \mu_l \int_{q_l^\circ}^Q (x - q_l^\circ) dF(x) + (1 - p) \delta s \mu_h \int_{q_h^\circ}^Q (x - q_h^\circ) dF(x) \right] .$$

From the definition of the threshold quality values, it is easy to see that $q_h^\circ < q_l^\circ$. Intuitively, the researcher tends to develop ideas that turn out to have higher commercial value. It might be that a piece of knowledge of a given quality q is developed if it turns out to have a high commercial value ($\mu = \mu_h$) but not if it has a low one ($\mu = \mu_l$). This occurs if $q_h^\circ < q < q_l^\circ$.

In order to analyse the effects of an increase in the commercialisation risk, as in the previous section, we concentrate on the case where $p = 1/2$ and $\mu_h = \bar{\mu} + \varepsilon$ and $\mu_l = \bar{\mu} - \varepsilon$ so that $E(\mu)$ is constant and equal to $\bar{\mu}$ for any ε .¹⁶ While keeping the expectation constant, a greater ε would imply a riskier commercialisation value and therefore a more basic project. Intuitively, the commercial value of more basic projects is more difficult to predict, while for more applied projects it is easier to anticipate.

Corollary 10 *The introduction of remuneration for commercial inventions induces researchers to select riskier projects in terms of their commercial value (“more basic”).*

6 Concluding Remarks

Many firms and industries rely heavily on knowledge originating from universities and other public research institutions. In order to foster the transfer of knowledge, the governments of many advanced economies have recently transferred the ownership of patents emanating from public funds to the universities and part of the proceeds to the inventors. Although this has increased the number and the value of university patents, many people worry about the long-term side effects of commercial incentives in academia. Some groups have expressed concerns about the possibility that academic faculty “skews” the nature of their research, selecting applied rather than basic research projects, and therefore putting the future of the industrial base at stake. This paper analyses some of the “unintended” effects of government policies that increase the incentives to transfer university research into the market, such as the Bayh-Dole Act, in particular we discuss whether financial incentives aimed at promoting commercialisation affects the choice of research projects.

To understand the behaviour of university researchers, we build a simple repeated model to study the allocation of time as a function of the individual characteristics and of the academic and market incentives. We show that the researcher should pursue a new research project unless the quality of the outcome has enough commercial prospects to compensate a delay in undertaking new research. The opportunity costs of development

¹⁶Other papers have also analysed project selection when projects differ on their variance. In Cabral (2003), for example, two firms competing in R&D have to choose between two projects, one of which is a mean-preserving spread of the other.

and commercialisation include not only scientific output but also the opportunity to obtain a more lucrative innovation. Consistent with the empirical evidence, our comparative statics results indicate that a researcher spends more time developing if her discipline has greater applicability and if the marginal utility of academic publications is lower.

We also analyse how the coexistence of publications and technology transfer rewards affects the choice between basic and applied research programs. We show that the introduction of researcher remuneration for commercial inventions pushes the researcher to prefer riskier projects. Given that higher levels of uncertainty are related to more basic research, the introduction of commercial rewards might not only preserve but also enhance the choice of more basic research projects. As a result, although less time might now be spent on research, this research might be more basic in nature than before.

Our model is not only consistent with a variety of stylised facts but it also generates a number of additional testable predictions. On the development side, by choosing riskier projects, researchers should be more reluctant to develop research of a low quality. Instead, they are more willing to continue undertaking research because they are more likely to obtain results of higher quality in the future. As a result, it might be that they end up developing less as commercial rewards increase. Indirect evidence from this can also be found in Thursby and Thursby (2007), who state that “the much publicized increase in licensing activity appears to be concentrated among a minority of faculty”. We predict however that the commercial value of the projects that are actually developed is higher. Again, indirect evidence suggests that most of the patenting revenues are concentrated among a reduced number of patents. Although the level of invention disclosures, patent applications and licenses executed increased by 84%, 238% and 161% respectively from 1991 until 2000, the royalty revenue increased by 520% in the same period.

On the research side, a selection of riskier projects should lead to a more spread distribution of the quality of the publications. Empirically, one could analyse whether the quality of the publications, measured for example in citations, of researchers in departments in which commercial rewards are larger is more spread.

Appendix

Proof of Proposition 6

Again, the researcher never expects to sell the innovation if $q < \frac{A}{\mu}$. If $\frac{A}{\mu} \leq q \leq Q$ she will develop whenever $\delta\alpha q + \delta s[\mu q - A] + \delta^2 V \geq \alpha q + \delta V$, or equivalently, when $\delta(1 - \delta)V \leq s\delta[\mu q - A] - (1 - \delta)\alpha q$.

For any continuation value V , there is again a unique $q^s(V)$ such that the researcher will not develop. This is the case if and only if $q \leq q^s(V)$. Indeed, denoting $m(q) \equiv s\delta[\mu q - A] - (1 - \delta)\alpha q$, for any V , $q^s(V)$ is given by $m(q^s(V)) = \delta(1 - \delta)V$ when $m(Q) > \delta(1 - \delta)V$ and $q^s(V) = Q$ when $m(Q) \leq \delta(1 - \delta)V$. Given that $m'(q) = s\delta\mu - (1 - \delta)\alpha > 0$ and $m(0) = -sA < 0$ there exists a unique $q^s(V)$.

Now, suppose firstly that the cut-off chosen by the researcher is $q^s = Q$. The researcher never develops and never sells. Hence, $V = \int_0^Q \alpha x dF(x) + \delta V$, which simplifying gives $V = \frac{1}{1-\delta}\alpha\bar{q}$. The decision $q^s = Q$ is optimal if and only if $\delta(1 - \delta)V \geq s\delta[\mu Q - A] - (1 - \delta)\alpha Q$, which substituting gives $\delta\alpha\bar{q} \geq s\delta(\mu Q - A) - (1 - \delta)\alpha Q$, which corresponds to the region in part (a).

Suppose secondly that the cut-off chosen by the researcher is $q^s < Q$. Since she sells if and only if she develops, we have that

$$V = \int_0^{q^s} \alpha x dF(x) + \delta \int_{q^s}^Q \alpha x dF(x) + \delta F(q^s)V + \delta s \int_{q^s}^Q (\mu x - A) dF(x) + [1 - F(q^s)] \delta^2 V,$$

which simplifying gives

$$(1 - \delta)(1 + \delta[1 - F(q^s)])V = \int_0^{q^s} \alpha x dF(x) + \delta \int_{q^s}^Q \alpha x dF(x) + \delta s \int_{q^s}^Q (\mu x - A) dF(x).$$

On the other hand, the optimal $q^s(V)$ should be defined as $\delta(1 - \delta)V = s\delta[\mu q^s - A] - (1 - \delta)\alpha q^s$. Substituting in the previous equation and simplifying,

$$s[\mu q^s - A] = \alpha\bar{q} + \frac{(1 - \delta)}{\delta}\alpha q^s + \int_{q^s}^Q (\delta s\mu - (1 - \delta)\alpha)(x - q^s) dF(x).$$

In other words, q^s is implicitly defined by $g(q^s) = 0$, where

$$g(q^s) \equiv s[\mu q^s - A] - \alpha\bar{q} - \int_{q^s}^Q \delta s\mu(x - q^s) dF(x) - \frac{(1 - \delta)}{\delta}\alpha q^s + \int_{q^s}^Q (1 - \delta)\alpha(x - q^s) dF(x) = 0.$$

We have that $g'(q) > 0$ and $g(0) < 0$. Indeed,

$$g'(q) = \frac{1}{\delta} [\delta s\mu + \delta^2 s\mu(1 - F(q^s)) - \alpha(1 - \delta) + \delta(1 - \delta)\alpha [1 - F(q^s)]] > 0$$

and

$$g(0) = s(-A) - \alpha\bar{q} - \int_0^Q \delta s\mu x dF(x) + \int_0^Q (1 - \delta)\alpha x dF(x) < 0,$$

because of our initial assumption ($s\delta\mu - (1 - \delta)\alpha > 0$). In order to have a unique cutoff q^s we need that

$$g(Q) = \frac{1}{\delta} (\delta s [\mu Q - A] - \delta\alpha\bar{q} - (1 - \delta)\alpha Q) > 0,$$

which corresponds to the region in part (b).

Substituting,

$$V = \frac{1}{(1 - \delta)} \left[\alpha\bar{q} + \int_{q^s}^Q (\delta s\mu - (1 - \delta)\alpha) (x - q^s) dF(x) \right].$$

Proof of Corollary 7

The cut-off point of our baseline case q° satisfies

$$s [\mu q^\circ - A] - \alpha\bar{q} - \int_{q^\circ}^Q \delta s\mu (x - q^\circ) dF(x) = 0,$$

and therefore, in particular,

$$q^\circ - \int_{q^\circ}^Q \delta (x - q^\circ) dF(x) > 0.$$

We have that $g(q^\circ) < 0$, where $g(\cdot)$ is defined in the previous proof, because

$$g(q^\circ) = \frac{(1 - \delta)}{\delta} \alpha \left[-q^\circ + \delta \int_{q^\circ}^Q (x - q^\circ) dF(x) \right] < 0.$$

Therefore, given that g is increasing and at q° is negative and at q^s is 0, we have that $q^\circ < q^s$.

We have that $V^s < V^\circ$ if and only if

$$\int_{q^s}^Q (\delta s\mu - (1 - \delta)\alpha) (x - q^s) dF(x) < \int_{q^\circ}^Q \delta s\mu (x - q^\circ) dF(x),$$

which is true if and only if

$$\int_{q^s}^Q \delta s\mu (x - q^s) dF(x) - \int_{q^\circ}^Q \delta s\mu (x - q^\circ) dF(x) - \int_{q^s}^Q (1 - \delta)\alpha (x - q^s) dF(x) < 0.$$

Defining $n(q) \equiv \int_q^Q \delta s \mu(x - q) dF(x)$ and given that $n'(q) = -\delta s \mu(1 - F(q)) < 0$, we have that the first two terms are negative and so is the third.

To prove that researchers still prefer riskier projects, consider as before two distributions, $F_1(q)$ and $F_2(q)$, with the same support and the latter being a mean preserving spread of the former. In the region of part (a), the researcher is indifferent between the two distributions. In the region of part (b), given $F_1(q)$, the threshold quality q_1^s is defined as:

$$s [\mu q_1^s - A] - \alpha \bar{q} - \frac{(1 - \delta)}{\delta} \alpha q_1^s - \int_{q_1^s}^Q (\delta s \mu - (1 - \delta) \alpha) (x - q_1^s) dF_1(x) = 0.$$

Since $F_2(\cdot)$ is a mean preserving spread of $F_1(\cdot)$, we have that

$$s [\mu q_1^s - A] - \alpha \bar{q} - \frac{(1 - \delta)}{\delta} \alpha q_1^s - \int_{q_1^s}^Q (\delta s \mu - (1 - \delta) \alpha) (x - q_1^s) dF_2(x) < 0.$$

Given that the derivative of the left hand side is equal to

$$s \mu - \frac{(1 - \delta)}{\delta} \alpha + (\delta s \mu - (1 - \delta) \alpha) (1 - F_2(q_1^s)) > 0,$$

and that

$$s [\mu q_2^s - A] - \alpha \bar{q} - \frac{(1 - \delta)}{\delta} \alpha q_2^s - \int_{q_2^s}^Q (\delta s \mu - (1 - \delta) \alpha) (x - q_2^s) dF_2(x) = 0,$$

we have that $q_2^s > q_1^s$. From Proposition 6, $V = \frac{1}{(1 - \delta)} \left[s [\mu q^s - A] - \frac{(1 - \delta)}{\delta} \alpha q^s \right]$, and hence we have that $V_2 > V_1$ and therefore the researcher prefers the risky pool.

Proof of Proposition 8

To prove this result, suppose that there are two projects characterised by the parameters (α_1, A_1) and (α_2, A_2) , with $A_1 > A_2$ and $\alpha_1 > \alpha_2$, but otherwise identical. Project 1 is more basic than project 2. According to Proposition 2, we can write the discounted present expected value for each project $i = 1, 2$ as

$$V_i(s) = \frac{1}{1 - \delta} [s (\mu q_i^\circ(s) - A_i)],$$

where V_i and q_i° are functions of the share s . The researcher prefers the applied project (project 2) if and only if

$$q_1^\circ(s) - q_2^\circ(s) < \frac{A_1 - A_2}{\mu}.$$

From Proposition 2 and Corollary 3, one can show that $\frac{\partial^2 q^\circ}{\partial s \partial \alpha} < 0$ and $\frac{\partial^2 q^\circ}{\partial s \partial A} < 0$. As a consequence, $q_1^\circ(s') - q_2^\circ(s') < q_1^\circ(s'') - q_2^\circ(s'')$ whenever $s' > s''$. This implies that the researcher is more inclined to choose the applied project the larger is the share s . Indeed, if she chooses project 2 when the share is s'' , she will keep preferring that project for the larger share s' . However, the increase in s can make the researcher switch from project 1 to project 2. The second part of the Proposition follows directly from Corollary 3.

Proof of Proposition 9

Following a similar procedure to the proof of Proposition 6, we can find q_h° , q_l° , and V as described in the text.

Proof of Corollary 10

By taking the derivative of V (as defined in the proposition) with respect to ε and substituting $p = 1/2$, $\mu_h = \bar{\mu} + \varepsilon$ and $\mu_l = \bar{\mu} - \varepsilon$, we obtain

$$\begin{aligned} \frac{2(1-\delta)}{s\delta} \frac{dV}{d\varepsilon} = & - \int_{q_l^\circ}^Q (x - q_l^\circ) dF(x) + \int_{q_h^\circ}^Q (x - q_h^\circ) dF(x) - (\bar{\mu} - \varepsilon) [1 - F(q_l^\circ)] \frac{dq_l^\circ}{d\varepsilon} \\ & - (\bar{\mu} + \varepsilon) [1 - F(q_h^\circ)] \frac{dq_h^\circ}{d\varepsilon} \end{aligned} \quad (2)$$

From the other definition of V , $V = \frac{s}{1-\delta} (\mu_l q_l^\circ - A)$ we have

$$\frac{1-\delta}{s} \frac{dV}{d\varepsilon} = -q_l^\circ + (\bar{\mu} - \varepsilon) \frac{dq_l^\circ}{d\varepsilon} \quad (3)$$

and therefore

$$\frac{2(1-\delta)}{\delta s} \frac{dV}{d\varepsilon} = -\frac{2}{\delta} q_l^\circ + \frac{2}{\delta} (\bar{\mu} - \varepsilon) \frac{dq_l^\circ}{d\varepsilon}$$

Denoting $B = - \int_{q_l^\circ}^Q (x - q_l^\circ) dF(x) + \int_{q_h^\circ}^Q (x - q_h^\circ) dF(x) > 0$ and equalizing the derivatives (1) and (3) we have

$$\frac{dq_l^\circ}{d\varepsilon} = \frac{\delta B (\bar{\mu} + \varepsilon) + 2q_l^\circ [[1 - F(q_h^\circ)] \bar{\mu} \delta + (\bar{\mu} + \varepsilon)]}{[2 + \delta [2 - F(q_h^\circ) - F(q_l^\circ)]] (\bar{\mu} - \varepsilon) (\bar{\mu} + \varepsilon)}$$

From the definition of q_h° in the proposition, and differentiating with respect to ε , we have also that

$$\frac{dq_h^\circ}{d\varepsilon} = \frac{-2\bar{\mu}q_l^\circ + (\bar{\mu} - \varepsilon)(\bar{\mu} + \varepsilon) \frac{dq_l^\circ}{d\varepsilon}}{(\bar{\mu} + \varepsilon)^2}$$

By substituting $\frac{dq_i^\circ}{d\varepsilon}$ by the derivative above, and then substituting $\frac{dq_h^\circ}{d\varepsilon}$ and $\frac{dq_l^\circ}{d\varepsilon}$ in (1) and simplifying, we conclude that the sign of (1) is the same as the sign of

$$(\bar{\mu} + \varepsilon) \left[- \int_{q_i^\circ}^Q x dF(x) + \int_{q_h^\circ}^Q x dF(x) \right] = (\bar{\mu} + \varepsilon) \int_{q_h^\circ}^{q_i^\circ} x dF(x) > 0.$$

Hence, V increases with ε which gives our result.

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