Management Science

Publication details, including instructions for authors and subscription information:
http://pubsonline.informs.org

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MANAGEMENT SCIENCE
Articles in Advance, pp. 1–21
ISSN 0025-1909 (print) | ISSN 1526-5501 (online)

http://dx.doi.org/10.1287/mnsc.2014.2000

The Role of Equity, Royalty, and Fixed Fees in Technology Licensing to University Spin-Offs

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We develop a model based on asymmetric information (adverse selection) that provides a rational explanation for the persistent use of royalties alongside equity in university technology transfer. The model shows how royalties, through their value-destroying distortions, can act as a screening tool that allows a less-informed principal, such as the university's Technology Transfer Office (TTO), to elicit private information from the more informed spin-off. We also show that equity–royalty contracts outperform fixed-fee–royalty contracts because they cause fewer value-destroying distortions. Furthermore, we show that our main result is robust to problems of moral hazard. Beside the coexistence result, the model also offers explanations for the empirical findings that equity generates higher returns than royalty and that TTOs willing to take equity in lieu of fixed fees are more successful in creating spin-offs.

Keywords: university technology transfer; equity; royalty; fixed fees; contract design; screening games
History: Received October 31, 2011; accepted March 24, 2014, by David Hsu, entrepreneurship and innovation. Published online in *Articles in Advance*.

1. Introduction

University spin-offs are entrepreneurial companies founded to commercialize university-generated innovation (Shane 2004). These companies are often formed directly by university faculty or students, on the back of academic research that is promising but not immediately commercializable. They aim to take the necessary additional steps, such as further development, prototyping, establishing manufacturing feasibility, and improving the business plan, required to convert an academic idea into a profitable set of products and services. To do so, they usually require funding that goes beyond the financial resources of the founders, which they raise through public funds, friends and family, private investors, and venture capital (VC) firms (Lerner 1999a, b; Shane and Cable 2002). In FY2009 alone, 596 new start-up companies were formed based on technology developed through basic research at U.S. universities and teaching hospitals (Bloom 2011), and similar activity has also been observed in Europe (Geuna and Nesta 2006). Since the university-based research that constitutes the intellectual backbone of the spin-offs is almost universally the intellectual property (IP) of the university (e.g., in the United States this is the case by federal law—the Bayh–Dole Act of 1980 (Mowery et al. 2002)—and similar legislation exists in Europe (Geuna and Nesta 2006)), such companies are required to strike a licensing deal with the university's Technology Transfer Office (TTO). When granting the license the TTO aims to retain some of the value of the technology for the university.[1]

One notable example of a university spin-off is Google, founded in 1998 by Larry Page and Sergey Brin, two graduate students at Stanford University, to commercialize the PageRank algorithm for Internet search. The now phenomenally successful Internet giant raised money from angel investors, VC funds, and a public offering. Stanford granted the exclusive license for the PageRank algorithm in exchange for an equity stake, which by 2005 was liquidated for $336 M (Krieger 2005). Stanford also receives royalties from Google, which in 2011 were approximately $400,000 (GoogleDPS 2012). Although Google is an exceptionally successful spin-off, it is not an exception in the manner in which TTOs participate in the profits of their spin-offs. As reported in a number of empirical and survey studies (Bray and Lee 2000, Feldman et al. 2002, Thursby et al. 2001), and confirmed by the

[1] TTO managers and university administrators surveyed by Jensen and Thursby (2001) thought that generating revenue for the university was the most important objective of the TTO, whereas faculty considered this to be (only narrowly) the second most important objective after securing funding for sponsored research. Furthermore, the goal to "create discretionary income" features in the mission statement of many prominent Technology Licensing Offices, e.g., that of MIT (http://web.mit.edu/tlo/www/about/our_mission.html, last accessed January 20, 2014).

university TTOs we interviewed, licensing deal terms typically include royalties, equity stakes, and fixed fees. According to the STATT database, which collects comprehensive data from members of the Association of University Technology Managers (AUTM), of all the TTOs reporting licensing income for the year 2009, 25.4% reported income from sales of equity stakes in addition to royalty income, up from 14.2% in 1996, when the survey started collecting income data.

Both royalties, which are payments proportional to the sales of the spin-off, and equity stakes, which are a share of (future) profits, are deferred payments: royalties become payable upon future sales, whereas equity generates payments through dividends once the spin-off becomes profitable, or through selling the equity stake. Equity and royalties are also contingent payments because they depend on the spin-off's future performance. Although there exist strong theoretical results suggesting that up-front fixed-fee licensing generates a higher profit for the owner of the innovation than contingent payments (see review by Kamien 1992), two reasons may explain the prevalence of the latter in the case of university spin-offs. First, spin-offs are typically cash starved (Feldman et al. 2002): even VC-funded spin-offs try to stretch their limited funding as far as possible, which is not well served by up-front fixed-fee payments to the TTO. Second, contingent payments might help to resolve a moral hazard problem which arises especially when university staff who are not directly involved in the spin-off need to continue providing support for successful technology development (Jensen and Thursby 2001). However, when comparing royalty and equity in theoretical models, it is generally accepted that equity Pareto-dominates royalty because the latter reduces marginal revenue and therefore distorts the optimal production decision (Jensen and Thursby 2001). On the contrary, equity stakes do not create such a distortion because they offer the TTO a stake in the profits, and not just revenues, leaving the optimal production level unaffected. Since royalties appear to be Pareto dominated, the persistence of TTOs in continuing to use royalties alongside equity is a puzzle.

The use of royalties is even more puzzling as Bray and Lee (2000) show that equity generates more value for the university than royalties on average. One plausible explanation for this is offered by Feldman et al. (2002), who attribute the reluctance of the TTO to take on more equity instead of royalties to behavioral factors; TTOs are initially unwilling to experiment with new forms of payment, such as equity stakes, but as they become more experienced and more familiar with this new way of licensing technology they tend to increase the proportion of equity deals in their portfolio. Nevertheless, even the most experienced universities in their sample continue to take on royalties.

Our paper provides a model of licensing based on asymmetric information that provides a rational explanation for the persistent use of royalties alongside equity in university technology transfer. The model assumes that the management of the spin-off, which usually includes the inventors of the technology, along with their experienced VC backers, are better informed than the TTO about the demand curve of the new technology. In particular, since the management of the spin-off is actively involved in making decisions regarding product design, we assume that they are better able to estimate the consumers' heterogeneous willingness to pay for the spin-off's product, resulting in an adverse selection problem.[2]

We use this model to show that in equilibrium, it is optimal for the TTO to offer contracts that include royalties alongside equity. Because royalties cause distortions, and these distortions are increasing in the ex ante probability that the spin-off will generate a product appealing to a large number of consumers (which is the private information of the spin-off), we show that they can act as a screening mechanism. The TTO can use royalties to prevent spin-offs that have a higher ex ante probability of generating mass-market products from extracting full-information rents at the expense of the TTO. Furthermore, we find that the equilibrium contract intended for such high-value spin-offs contains lower royalties than the contract offered to spin-offs that have a lower probability of generating mass-market products. This result provides a potential explanation for the empirical observation that equity offers higher returns than royalty: equity is the licensing method of choice for high-value spin-offs.

Expanding the contract space to include fixed fees in addition to equity and royalty provides a further interesting insight. Our model provides a potential explanation as to why fixed fees are a less-favored mechanism for university technology transfer to spin-offs that goes beyond capital constraints. We show that in the presence of asymmetric information, it is more effective for the TTO to use equity–royalty rather than fixed-fee–royalty contracts as a screening mechanism. We show that the former achieves the desirable screening outcome at a lower royalty level than the latter, which in turn implies less value destruction through production distortions. In a sense, equity acts in a complementary way to royalty by enhancing its screening properties, something that fixed fees cannot do. In fact, we show that, as far as asymmetric information (i.e., adverse selection) is concerned, fixed fees are completely redundant—the TTO does not improve

[2] For convenience we refer to the commercialized output of the spin-off as the *product*. However, we note that this might not be a physical product and could instead be a service.

anything by expanding the contract space to include fixed fees alongside equity and royalty.

Finally, we present an extension in which the probability of technical success is endogenous. More specifically, we assume that it is a function of costly and unverifiable effort that needs to be exerted by the spin-off, thus leading to a moral hazard problem. In the absence of adverse selection (i.e., when the TTO and the spin-off are symmetrically informed) we show that there exists a pecking order of contracting terms: fixed fees dominate equity, which causes effort distortions, and equity dominates royalty, which causes both effort and production distortions. Nevertheless, we show that if there is also a problem of adverse selection, then the optimal contract contains not only fixed fees but also equity and royalty. Thus, our main result—that royalties should coexist with equity in the presence of asymmetric information—is robust to the presence of a moral hazard problem.

Before we proceed, we note that, beyond universities, technology transfer is a pertinent issue for many organizations interested in understanding how to best license technology. Research charities such as Cancer Research UK, a funding body for medical research in the United Kingdom, and private institutions such as the Cleveland Clinic, the leading cardiac surgery hospital in the United States, have also created TTOs with similar mandates to university TTOs.[3] Furthermore, innovative companies such as IBM are changing their business models to take advantage of technology transfer opportunities such as licensing to spin-offs. Such technology transfer agreements are a significant and growing part of global economic activity—Robbins (2009) estimates that U.S. corporations receive over $100 B p.a. for the use of their IP. Our research is relevant to all of the above organizations.

2. Literature Review

The phenomenon of university entrepreneurship is an increasingly important topic of academic investigation (see the detailed literature review by Rothaermel et al. 2007). For the purposes of this paper we will focus on the two strands of literature to which our paper makes the most direct contribution: first, the literature on the economics of technology licensing and its application to university licensing; and second, the empirical literature on university technology transfer, which provides evidence that our model helps to explain.

Since the initial theoretical investigation on the merits of IP rights pioneered by Arrow (1962), a substantial body of research has developed with a focus on licensing. A large part of this literature starts with an innovator who needs to license a new technology to incumbent firms that operate in a monopoly (or oligopoly) setting and, in contrast to the innovator, have the complementary assets necessary to commercialize the technology (Teece 1986). The literature is concerned with examining the trade-offs between licensing based on a combination of fixed fees and royalties. A general finding of early research is that inventor rents are maximized through fixed fees (see review by Kamien 1992). Contingent payments such as royalties are dominated by fixed fees because they distort production (Jensen and Thursby 2001) or slow down adoption when network effects are important (Sun et al. 2004). The coexistence of royalties alongside fixed fees has been justified in a principal–agent framework by the presence of asymmetric information (Gallini and Wright 1990, Beggs 1992, Sen 2005b) or moral hazard (Choi 2001, Jensen and Thursby 2001) or both (Crama et al. 2008, Xiao and Xu 2012). In these papers, the contingent nature of royalties turns them into either an information extraction mechanism (via signalling or screening) or a motivational device that better aligns the interests (and efforts) of all parties involved. Various other reasons for the coexistence of royalties and fixed fees have also been identified in the literature. In a model with inventor moral hazard, Dechenaux et al. (2009) and Dechenaux et al. (2011) argue that royalties become optimal only when the licensee is risk averse. Erat et al. (2013) find that royalties should coexist with fixed fees to moderate downstream competition among licensees, while Sen and Stamatopoulos (2009) argue that royalties coexist with fixed fees to raise the market price back to monopoly prices.

Perhaps because the aforementioned work is motivated by licensing to incumbents, it does not explicitly consider equity. Indeed, for incumbent firms with a portfolio of revenue streams, equity stakes, in contrast to royalty payments, have little informational content because the value of equity is less well linked with the market performance of the specific technology being licensed. In contrast, the literature on university technology transfer, which is partly motivated by licensing to spin-offs, examines equity licensing explicitly. The main finding is that, because of moral hazard problems, contingent payments are necessary to incentivize university researchers to continue supporting the spin-off, but in general equity is superior to royalties (Jensen and Thursby 2001). Since the superiority of equity over royalties is well established in the literature, part of the extant literature has chosen to ignore royalties altogether as a viable means of technology transfer (Macho-Stadler et al. 2008). Our paper is similar in spirit to the models of technology licensing under asymmetric information, with an important distinction: We present, to the best of our knowledge, the first investigation into contracts that combine equity,

[3] http://www.cancertechnology.com/our-company and http://innovations.clevelandclinic.org/home.aspx (last accessed on January 20, 2014).

royalty, and fixed fees to show that in the presence of asymmetric information (adverse selection), the equilibrium outcome is to offer contracts that include both equity and royalty terms, and that equity–royalty contracts outperform fixed-fee–royalty contracts. We also examine how moral hazard, in combination with adverse selection, affects our results.

Turning to the empirical literature on the licensing terms of university technology to spin-offs we note four findings. First, there exists ample survey evidence to suggest that most TTOs license technology to spin-offs with a combination of equity, royalty, and fixed fees. For example, Jensen and Thursby (2001) report, based on a survey of the leading U.S. research universities, that 23% of all university licenses include equity. Of these equity-based licenses, 79% also include royalties and 67% include up-front fixed fees. Based on their interviews with TTO managers, the authors report that licenses with equity tend to be given to spin-offs rather than established firms. Similarly, Feldman et al. (2002) find that most TTOs included in their survey rely heavily on royalty-based licensing. Nevertheless they report an increasing trend in the use of equity: although only 40% of TTOs had equity deals in their portfolios in 1992, by 2000 this proportion had increased to 70%. Second, as reported in Feldman et al. (2002), the TTOs with the highest proportion of deals that include some element of equity in their portfolios are more likely to be based in more experienced universities. The authors interpret this as evidence for the superiority of equity over royalties and argue that, with experience, universities will overcome their behavioral bias against equity stakes and adopt them more frequently. Third, as reported by Bray and Lee (2000) based on a small sample survey, equity-based licensing is more profitable for the TTO in the long run than fixed fees or royalties. Although the return may be partially attributed to a few highly successful spin-offs that offer multimillion-dollar returns, even excluding these outliers, the authors find that equity returns are similar to the returns of fixed fees and royalties. Fourth, as shown in Di Gregorio and Shane (2003), based on data from 116 universities covered by AUTM from 1994 to 1998, TTOs that are willing to take equity in lieu of fixed fees are more successful in creating spin-offs. Our work provides an explanation, based on asymmetric information, and fully consistent with rational behavior that explains why royalties coexist with equity, predicts that equity stakes are more profitable than royalty, and explains why TTOs willing to take equity in lieu of fixed fees create more spin-offs.

3. Base Model

University technology transfer is a complex process with multiple stakeholders, some of which might be driven by nonpecuniary motivations such as generating knowledge. We do not cover all of the complexities of this problem. Instead, we aim to develop a model that investigates the implications of the spin-off's private information on the contract parameters chosen by the TTO.

3.1. Symmetric Information Without Uncertainty

We begin the modeling section with a simple deterministic and symmetric information model that aims to demonstrate why, at least in theory, it is more attractive to transfer technology through equity- or fixed-fee- and not royalty-based contracts. Throughout the analysis, we follow the standard assumption of the technology licensing literature that the spin-off, upon successful development of the technology, becomes a monopolist facing a market M of potential consumers who hold heterogeneous valuations for the product. For analytical tractability we assume that the customers' heterogeneous willingness to pay for the product follows the uniform distribution. To make this precise, for any price P we assume that the number of customers holding valuations less or equal to P is given by

$$F(P) = \begin{cases} 0 & \text{if } P > b, \\ M\dfrac{b-P}{b-a} & \text{if } P \in [a, b], \\ M & \text{if } P < a, \end{cases}$$

for $b > a \geq 0$. Without loss of generality, we can normalize $M = 1$. Furthermore, we find it convenient to define m as the mean customer willingness to pay and δ as the dispersion from this mean valuation; i.e., $a = m - \delta$ and $b = m + \delta$. Note that the condition $\alpha \geq 0$ implies that $\delta \leq m$. With these definitions, the quantity demanded at price $a \leq P \leq b$ is given by $Q(P) = (\delta - P + m)/(2\delta) = (\delta + m)/(2\delta) - P(1/(2\delta))$, which is the linear demand curve. The assumption of a linear demand curve is often made in the technology licensing literature (Giebe and Wolfstetter 2008, Sen and Tauman 2007, Sen 2005a).

One can think of $(\delta + m)/(2\delta)$ as the hypothetical demand for the new product had the price been zero and $1/(2\delta)$ as a measure of how price sensitive consumers are. Interestingly, for a fixed mean willingness to pay m, as the heterogeneity in consumers' willingness to pay measured by δ increases, the demand curve rotates counterclockwise; i.e., the product is appealing to inherently fewer, albeit less price-sensitive, customers (Johnson and Myatt 2006). Products with inherently low heterogeneity are commercialized with what can be called mass-market strategies; i.e., the firm sells at a relatively low price to a large number of price-sensitive consumers. In contrast, products with inherently high heterogeneity can be though of as "love it or hate it offerings" that are best commercialized with what can be called niche-market strategies; i.e., the firm sells at a relatively high price to a few loyal and not particularly price-sensitive customers. (See Johnson and Myatt 2006 for a more general discussion and implications.)

Under the assumption that the new technology will allow the spin-off to act as a monopolist, the value of a self-funded spin-off company that does not need to make any payments to the TTO is given by $(P-c)Q(P)-C$, where c denotes the variable production cost and C denotes the fixed development cost that the spin-off will incur before it can commence production. These costs are adjusted appropriately to account for the cost of capital and technical risk of the project. Therefore, assuming that $0 \le c < \delta + m$, the value of the spin-off company is maximized at production level $Q = (m+\delta-c)/(4\delta)$ and is equal to $(m+\delta-c)^2/(8\delta) - C$.

In the context of the problem we are studying, the spin-off has to license the technology from the TTO, which is the legal owner of the technology. Previous work in university technology transfer assumes that the TTO represents the interests of both the university's central administration and the university members that created the technology (Jensen and Thursby 2001; Dechenaux et al. 2009, 2011). This is a reasonable assumption in the context of licensing to incumbents because the creators of the technology are unlikely to have direct involvement with the licensee. In contrast, the creators of the technology typically have a direct and significant involvement in the management of the spin-offs, usually as cofounders. Therefore, in our setting we find it more reasonable to lump together the interests of the academics and those of the spin-off, which could also represent the interests of any outside investors, who we assume have come to an understanding on how to proceed with the development of the technology.[4]

Given our modeling assumptions, if financing constraints on the part of the spin-off were not an issue, such licensing could clearly occur frictionlessly on the basis of an up-front fixed fee. We will study fixed fees in §5, but assume that they are not a possibility for now. We continue by examining an equity-based license in which the TTO retains a share $1-e \ge 0$ in the spin-off's future profit. As in Jensen and Thursby (2001), we assume that equity is purely a profit-sharing device that is given to the TTO as payment for the exclusive license to use the technology. All decision rights remain with the spin-off. This is consistent with typical TTO policy of not being actively involved with the running affairs of its spin-offs. The remaining equity $e > 0$ is retained by the spin-off. The value of the spin-off, given by $e(P-c)Q(P)-C$, is maximized when the production quantity is set to $Q = (m+\delta-c)/(4\delta)$. The equity stake $(1-e)$ assigned to the TTO has no implications for the optimal production quantity; there is no production distortion and no value is destroyed.

Instead of being based on equity, the license could be based on royalty payments. These payments can be a fixed amount $r \ge 0$ per item sold or a percentage of total sales. For tractability purposes we take the former definition. The spin-off's value in a technology transfer contract that is based on such per item royalty payments is given by $(P-(c+r))Q(P)-C$, which is maximized when the production quantity is equal to $Q^*(r) = \max\{0, (m+\delta-c-r)/(4\delta)\}$. Clearly, this optimal production quantity is nonincreasing in the royalty rate r, hence there is production distortion. Effectively, the royalty payable to the TTO inflates the variable cost per item from c to $c+r$. Therefore, the spin-off that has to pay royalties will produce a smaller quantity and sell at a higher price than the equity-based spin-off. Assuming $0 \le r \le m+\delta-c$, the value of the spin-off company is given by $V(r) = (m+\delta-c-r)^2/(8\delta) - C$ and, more importantly, the value destroyed by the royalty is given by $r(2m+2\delta-2c-r)/8\delta$, which is positive for any $0 < r \le m+\delta-c$.

3.2. Demand Uncertainty and Information Asymmetry

The base model presented in the previous section, although helpful for illustrating the distortional effects of royalties and pointing out how they can be circumvented by either fixed-fee or equity-based contracts, is clearly a simplification. In particular, it makes two assumptions that are hard to justify. First, it assumes that both the management of the spin-off and the TTO know with certainty what the demand curve is going to be. This is unlikely to be the case because university spin-offs often commercialize new products for which customers' willingness to pay is unknown and hard to forecast. In particular, certain product features may turn out to be well liked by some consumers but not by others, leading to significant uncertainty regarding how heterogeneous preferences for the new product will be. To capture this uncertainty, we assume that while the average willingness to pay is known to be m, the dispersion of the willingness to pay δ will turn out to be either of type h with some probability α or l with probability $1-\alpha$, with respective dispersion parameters δ_h and δ_l. Furthermore, we assume that $m-c > \delta_h > \delta_l > 0$, which suggests that the consumer that likes the product the least has a valuation at least as high as the marginal cost of production. Under this condition, both the optimal production quantity and the value of projects are decreasing in δ, suggesting that low dispersion (δ_l) leads to mass-market products

[4] When the value of the spin-off is assumed to be exogenous and common knowledge, this distinction is not important; it becomes more important in the setting where there is asymmetric information and/or the value of the spin-off is endogenous.

(where the new product appeals to a large proportion of relatively homogenous consumers), whereas high dispersion (δ_h) leads to niche-market products (where the product appeals only to a few consumers who are at the right tail of the willingness-to-pay distribution). This formulation is a first step in capturing the highly uncertain market potential of early-stage innovation.

The second assumption made in the previous section that we would like to relax is that both parties are symmetrically informed. As Shane and Stuart (2002, p. 156) argue, "entrepreneurs are privy to more information about the prospects of their ventures and the abilities of and level of commitment of the founding team." In the context of spin-offs, although the inventors themselves may not have a great advantage over the TTO about predicting the eventual market characteristics of the product, the involvement of experienced investors in managerial decisions gives the spin-off an edge. Over 75% of university spin-offs receive funding from angel investors or VC firms (Shane 2004). Angel investors and venture capitalists, albeit to differing degrees, get involved with the management of the spin-off through managerial advice, provision of industry contacts, or by serving on the board. Working in consultation with seasoned business partners allows the spin-off to make better predictions about the future and make better decisions that affect the end product value. Since such decisions are not observable by the TTO, it is reasonable to assume that the spin-off's management is in a better position to estimate whether the product is more likely to be a mass-market hit or a niche product (i.e., how dispersed the willingness to pay of its target customers will be) than the TTO. To capture this asymmetry, we assume that the spin-off can be of either type N or type M. Spin-offs of type M (N) have a probability, θ_M (θ_N) of generating mass-market projects (i.e., of type l) and $\theta_M > \theta_N$. The management of the spin-off knows its type while the TTO does not. Instead, the TTO believes the spin-off to be of type M with probability $1-\beta$ and N with probability β.

It is perhaps helpful to think of the setting as follows: the TTO has a belief about the probability of demand dispersion being of type l, which is $\alpha = \beta\theta_N + (1-\beta)\theta_M = \theta_M + \beta(\theta_N - \theta_M)$, and of type h, with probability $1-\alpha = 1-\beta\theta_N - (1-\beta)\theta_M = (1-\theta_M) + \beta(\theta_N - \theta_M)$. This belief, although true on expectation for any spin-off, does not take into account some spin-off-specific information that the management is in a position to hold. Conditional on this information, the management can resolve some, but not all, of the uncertainty and is able to establish more accurately whether demand will be of type h or l.[5] We also find it useful to express $\theta_M = \theta_N + \gamma$, which allows us to use $\gamma > 0$ as a measure of the informational disadvantage of the TTO. Clearly, when $\gamma \to 0$, the beliefs of the TTO and the spin-off become symmetric. As the parameter γ increases so does the informational disadvantage of the TTO. The TTO knows that the spin-off has superior information, and all parameters are common knowledge. The information structure is summarized in Figure 1.

Note that both the spin-off of type M and type N have the potential of generating projects of type h or l; they differ only in the probability of generating such a scenario. This specification renders it impossible to verify the type of spin-off, even if the demand is observable and verifiable ex post. After all, an M-type spin-off can always claim to be an N-type and if the project turns out to be of type h it can always claim to have been lucky. This inherent uncertainty in the demand of the end product, which allows the spin-off to mask its true type even ex post, renders the TTO unable to offer spin-off type-dependent contracts.

4. Equity and Royalty Contracts

In this section we will focus on contracts that belong in the set $(e, r) = [0, 1] \times [0, m + \delta_h - c]$, where e is the equity stake offered to the spin-off and r is the royalty per quantity sold payable to the TTO. Under such a contract, the production quantity is given by $Q_j(r) = (m + \delta_j - c - r)/(4\delta_j)$ for $j \in \{h, l\}$ and the expected value of the spin-off of type $i \in \{M, N\}$, excluding development costs C, is given by $\pi_i(r) = \theta_i V_l(r) + (1-\theta_i)V_h(r)$, with $V_j(r) = (m + \delta_j - c - r)^2/(8\delta_j)$ for $j \in \{h, l\}$. The value appropriated by the TTO when the spin-off is of type $i \in \{M, N\}$ is given by

$$U_i(e, r) = (1-e)\pi_i(r) + r[\theta_i Q_l(r) + (1-\theta_i)Q_h(r)]. \quad (1)$$

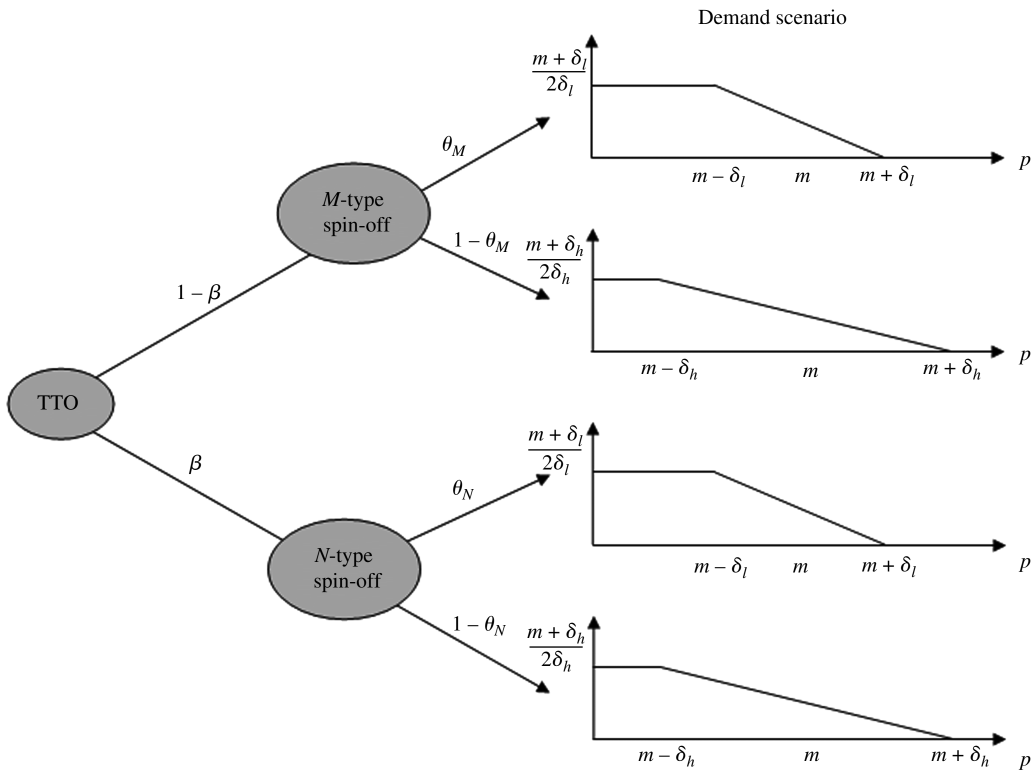
The first term is the expected value of the TTO's equity share, and the second is the expected cashflow from royalties. Because at the time the contract is signed the TTO knows the type of project only in distribution, the expected value of the TTO over the possible project types is given by $U(e, r) = \beta U_N(e, r) + (1-\beta)U_M(e, r)$.

4.1. Equity-Only Contract

When information about the project type at the time the contract is signed is common knowledge, the TTO can extract all rents simply by setting the royalty to zero to avoid distortions and set a type-dependent equity that is high enough to allow the spin-off to

[5] Our assumption of asymmetric information on customer heterogeneity is in contrast to extant literature, which, motivated by technology transfer from innovators to incumbent firms, usually assumes that the asymmetric information is on the production cost c. We make this assumption because we believe that production costs are less important for spin-offs, many of which focus on digital or service-like products with relatively low production costs. Nevertheless, we can show that our results are qualitatively unaffected under different information assumptions such as an isoelastic demand function with asymmetric information on production costs.

Figure 1 **Information Structure**



Notes. Both M- and N-type spin-offs may face demand scenario l or h. Demand scenario l occurs with probability $\theta_M > \theta_N$ for the M- and N-type, respectively, with $m - c > \delta_h > \delta_l$.

recoup its investment costs but no more than that: $e_M = C/\pi_M(0)$, $e_N = C/\pi_N(0)$.

Under asymmetric information and demand uncertainty, if the TTO were to offer the two contracts described above, the M-type spin-off would always pretend to be an N-type, thus appropriating all information rents. The TTO is left with two options: either offer e_N and allow the commercialization of both types of projects at the expense of giving up all information rents to the M-type spin-off, or offer $e_M < e_N$ and appropriate all rents from the M-type spin-off but at the expense of preventing further commercialization by N-types. Which of the two is preferable will depend on whether the difference in value between type M and type N spin-offs is greater than the value of type N spin-offs, appropriately adjusted for how likely a spin-off is to be type M versus type N. The exact value is summarized in the proposition below, whose proof is straightforward and which we omit for brevity.

Proposition 1. *The optimal equity-only contract is given by*

$$e = \begin{cases} \dfrac{C}{\pi_M(0)} & \text{if } \dfrac{\pi_N(0)}{\pi_M(0)} \le 1 - \beta, \\[2ex] \dfrac{C}{\pi_N(0)} & \text{if } \dfrac{\pi_N(0)}{\pi_M(0)} > 1 - \beta. \end{cases}$$

Since there is no element of the contract that can be made contingent on the distribution of customer valuations, there is no way for the TTO to offer a contract that would differentiate between the two types without excluding the N-types. Because university TTOs have a number of other objectives besides purely maximizing profit (Thursby et al. 2001), it is unlikely that they would be purposely preventing viable technology from being licensed. However, we should point out that if equity-only contracts are offered, this might well be the optimal behavior. We further note that licensing using only a fixed fee is very similar to licensing using only equity. In fact the TTO would be indifferent between the equity contract described in the proposition above and any contract with a combination of fixed fees and equity that generate the same overall value.

4.2. Equity and Royalty Contract: A Separating Equilibrium

As we have seen, an equity-only contract does not allow the TTO to license technology to both spin-off types without giving up all information rents. It is worth investigating whether a joint equity and royalty contract can fare better. Here we focus on separating equilibria, which allow the TTO to license to both types. Appealing to the revelation principle (Myerson 1979), and without loss of generality, we can assume that the TTO will offer a menu of two contracts, (e_M, r_M) and (e_N, r_N), the first intended for the M-type spin-off and the second for the N-type spin-off. The TTO will choose the contract terms that solve the following constrained optimization problem,

$$\underset{e_M, e_N, r_M, r_N \geq 0}{\text{maximize}} \; U = (1-\beta)U_M(e_M, r_M) + \beta U_N(e_N, r_N)$$

$$\begin{aligned} \text{s.t.} \quad & e_M \pi_M(r_M) \geq e_N \pi_M(r_N), && \text{(ICM)} \\ & e_N \pi_N(r_N) \geq e_M \pi_N(r_M), && \text{(ICN)} \\ & e_M \pi_M(r_M) \geq C, && \text{(IRM)} \\ & e_N \pi_N(r_N) \geq C, && \text{(IRN)} \\ & e_N, e_M \leq 1, \end{aligned}$$

where $U_i(e, r)$ is given by (1). The first two constraints (ICM and ICN), often referred to as incentive compatibility constraints, ensure that a spin-off of type M will prefer the equity–royalty contract designed for type M over that designed for type N and vice versa. The next two constraints (IRM and IRN), often called individual rationality or participation constraints, ensure that both types of spin-off receive a nonnegative expected payoff. Subject to these constraints, the TTO would like to maximize its own payoff from the licensing agreement. Royalties are assumed to be positive, because we do not want to consider contracts where the university subsidizes spin-offs—such contracts are not observed in practice.

For the results that follow we find it useful to define two quantities, $\underline{r}$ and $\bar{r}$. The former is the royalty level that makes the value of the M-type spin-off equal to the value of the N-type spin-off (i.e., $\pi_N(\underline{r}) = \pi_M(\underline{r})$), and the latter is the royalty level that makes the participation constraint of the N-type that retains 100% equity binding (i.e., $\pi_N(\bar{r}) = C$). Analytically, $\underline{r}$ and $\bar{r}$ can be written as

$$\underline{r} = m - c - \sqrt{\delta_h \delta_l},$$

$$\bar{r} = m - c + \frac{\delta_h \delta_l - \sqrt{\delta_h \delta_l \Delta}}{\delta_l(1-\theta_N) + \delta_h \theta_N},$$

where $\Delta = 8C((1-\theta_N)\delta_l + \delta_h\theta_N) - (\delta_h - \delta_l)^2(1-\theta_N)\theta_N)$. The optimal contract is summarized with the following proposition.

Proposition 2. *Under equity–royalty contracts, a unique separating equilibrium exists and is characterized by*

$$r_N = \min\{\underline{r}, r^*, \bar{r}\}, \qquad e_N = \frac{C}{\pi_N(r_N)},$$
$$r_M = 0, \qquad e_M = \frac{C\pi_M(r_N)}{\pi_N(r_N)\pi_M(0)},$$

where r^* is the root to the equation

$$r_N \frac{\beta(\theta_N \delta_h + (1-\theta_N)\delta_l)}{4\delta_h \delta_l} = (1-\beta)\frac{C(\delta_h - \delta_l)Q_l(r_N)Q_h(r_N)(\theta_M - \theta_N)}{\pi_N^2(r_N)}.$$

All proofs are presented in the appendix. Proposition 2 shows that when there is asymmetric information about customers' heterogeneous willingness to pay, royalties coexist with equity. In this case the TTO can extract information from the more informed spin-off by offering two contracts: one with equity e_M and no royalties intended for the M-type and one with higher equity $e_N > e_M$ and high enough royalties $r_N > 0$ intended for the N-type.

To understand the intuition behind Proposition 2, it is important to emphasize that royalties have an asymmetric impact on the two types of spin-off. As the production quantity is decreasing in the heterogeneity of customers' willingness to pay (δ), the value destroyed by royalties is greater for projects with low demand dispersion δ_l (mass-market strategy) than for projects with high demand dispersion δ_h (niche strategy).[6] Therefore, the lost value due to royalty distortions is greater for the M-type spin-off, which has a higher probability of creating the mass-market product, than for the N-type spin-off. This asymmetric distortion can be exploited by the TTO to increase its payoff compared to the equity-only case (where both types are offered the equity stake that makes the participation constraint of the N-type binding). It can do so by adding a small fraction ϵ of royalties to the contract intended for the N-type and at the same time increasing the N-type's equity stake just enough that the participation constraint is still binding. The M-type will not want to misrepresent its type and get the higher equity stake because the royalties would harm it more than the N-type and the extra equity allocated to the N-type would not be enough to cover this loss. In fact, since royalties are so undesirable for the M-type, the TTO can even decrease the equity stake of the M-type by a little. The TTO can continue adding royalties and increasing the equity stake of the N-type while decreasing the equity stake of the M-type until one of the following happens:

1. either it extracts all of the rents from the M-type, in which case there is no need to continue increasing royalties ($r_N = \underline{r}$); or
2. the equity allocated to the N-type has reached 100%, and therefore it cannot increase the royalty and equity offering any further ($r_N = \bar{r}$); or
3. the value destroyed by further increasing royalties of the N-type is greater than the extra value the TTO appropriates by further decreasing the equity stake of the M-type ($r_N = r^*$).

[6] More formally, our setting satisfies the Spence–Mirrlees single-crossing property (Bolton and Dewatripont 2005); i.e., if $P(r, e, \theta)$ denotes the payoff of the spin-off that has to pay royalty r, retains an equity stake e, and has a probability θ of generating a mass-market product (which, since it is the private information of the spin-off, can be thought as the spin-off's type), then the following condition holds: $(\partial/\partial\theta)[(\partial P/\partial r)/(\partial P/\partial e)] = e((Q_h(r)Q_l(r))/(2\pi(r)^2))(\delta_h - \delta_l) > 0$.

Therefore, the optimal contract of Proposition 2 is of similar structure to the standard results in the literature (see Bolton and Dewatripont 2005); i.e., the optimal contract does not cause any distortion to the more valuable M-type, the participation constraint of the less valuable N-type is binding, and so is the incentive compatibility constraint of the M-type, with the additional constraint on the equity stake $e \leq 1$.

It is worth making a few observations here. First, we find that there exist spin-offs of sufficiently low value (N-type) for which it is optimal for the TTO to retain no equity but to license the technology with royalties (equal to $\bar{r}$) only. This is consistent with the empirical observation that some spin-offs license technology exclusively through royalties without the TTO having any equity participation. Second, we find that sufficiently high-value (M-type) spin-offs are offered a contract with zero royalties. This is consistent with the observation that, on average, equity licensing generates a higher revenue for the TTO than royalty licensing (Bray and Lee 2000). Proposition 2 suggests that this effect may be due not to equity being an inherently better way of licensing university technology, but to selection bias: *ceteris paribus,* technology that is more likely to generate high-value (mass-market) products is more likely to be licensed with equity, and technology that is more likely to generate low-value (niche-market) products is more likely to be licensed through a contract that relies heavily (or exclusively) on royalties.

We continue by investigating how the level of royalties offered to the N-type spin-off is affected by the amount of capital investment (C) incurred by the spin-off and the extent of asymmetric information present between the TTO and the spin-off (γ) where $\theta_M = \theta_N + \gamma$.

Proposition 3. *If the sufficient condition* $\delta_h \delta_l \geq ((6(m-c) - \delta_l)/7)^2$ *holds, then*

- *the royalty rate* r_N *is nondecreasing in asymmetric information* γ, *and*
- *the equity stake* e_N *is nondecreasing in asymmetric information* γ *and in capital cost* C.

The above proposition shows that if customers are sufficiently heterogeneous in their willingness to pay, then both the royalty rate given to the N-type and the equity stake the N-type is allowed to retain in the spin-off are in general increasing as the problem of asymmetric information becomes more pronounced. Although the royalty rate r_N is nonmonotone in the capital investment C required by the spin-off, the equity stake is nondecreasing. This happens because the increase in the investment cost C necessitates that the spin-off retain a larger share of the profits to offset these higher costs. When the costs are increasing from a low basis, this is best achieved by allowing the N-type to retain a higher equity stake e_N, coupled with a higher royalty rate r_N, to prevent the M-type from mimicking. However, as the costs continue to increase to the point where the equity stake retained by the N-type cannot increase further (i.e., $e_N = 1$), then the TTO finds it necessary to start reducing the royalty payments of the N-type (i.e., $\bar{r}$ is decreasing in C) to allow the N-type to recover its investment cost C. The sufficient condition of Proposition 3 is not very restrictive—for example, it is always satisfied if $\delta_h > \delta_l > \frac{3}{4}(m-c)$; i.e., the consumer that values the l-type product the least places no more than $(m+3c)/4$ value to the product. Furthermore, this is only a sufficient condition; numerically we find that the result of Proposition 3 holds for almost all of the parameter values we tried. The results of Proposition 3 are interesting because they can be tested empirically.

4.3. Numerical Investigation

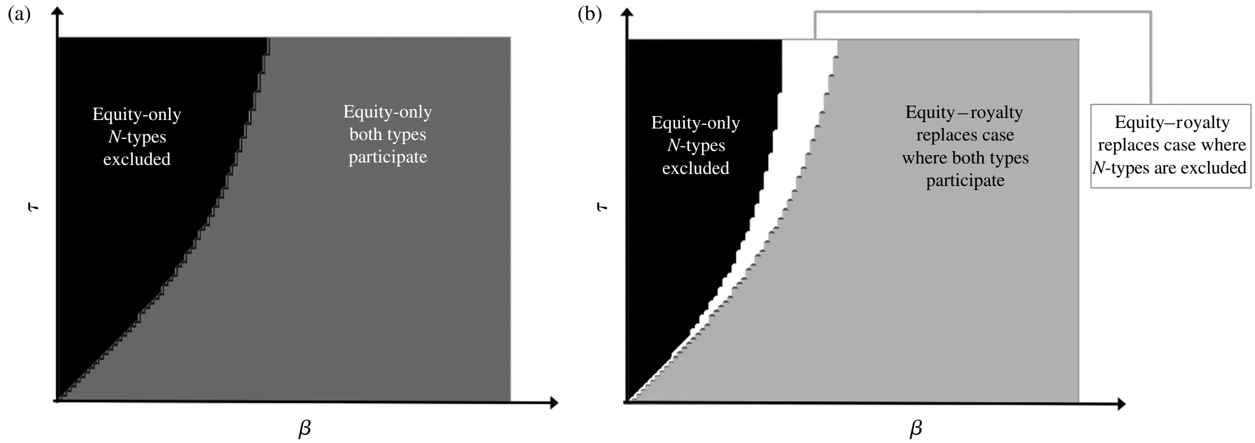
To gain a better understanding of how the combination of equity and royalty terms perform, we conduct a detailed numerical analysis. We vary the proportion of N-type spin-offs in the population (β), the gap between the high- and low-demand dispersion scenarios ($\tau = \delta_h - \delta_l$), and the severity of informational asymmetry ($\gamma = \theta_M - \theta_N$). A summary of all parameters used in the figures throughout the paper is given in Table 1.

Figure 2(a) depicts the two regions of Proposition 1. The TTO can offer the pooling contract and license to both types, leaving the M-type with full information rents (gray region), or exclude the N-type by offering the contract that extracts all rents from the M-type (black region). Intuitively, the latter region occurs when there is a low probability that the spin-off is an N-type (low β) or when the gap between the expected values of the two types of spin-off is substantial (high τ).

As shown in Proposition 2, expanding the contract space to allow for royalties alongside equity allows for separation without excluding the N-type spin-off. This is optimal in the white and the gray regions of Figure 2(b). In the black region of the same figure the TTO continues to find it optimal not to license to the N-type. The white region is of interest because, for the model parameters that fall in this region, the TTO would have preferred to exclude the N-type had royalty not been an option. We can therefore conclude that the use of royalties with equity not only allows the TTO to extract more rents but perhaps more importantly also permits the licensing of technology to N-type spin-offs that would otherwise have been optimal to exclude. In this white region royalties may still be regarded as inefficient from a production decision perspective. However, they may be dubbed welfare improving from a system perspective, because the N-type is no longer excluded.

We also take a closer look at the optimal royalty charged by the TTO. We do so to observe what effect

Figure 2 Equity-Only and Equity–Royalty Contract Regions



the severity of the asymmetric information problem (γ) has on the royalty rate charged and on the value extracted by this royalty. As shown in Proposition 3, the optimal royalty r^* is (weakly) increasing in γ. This can be observed from the dashed line in Figure 3. The solid lines in Figure 3 represent the percentage of the total value appropriated by the TTO that is attributed to royalties. This can be read off the primary y-axis. The solid gray line shows the expected income generated directly by royalties, and the solid black line gives the indirect value generated by royalties defined as the excess value extracted from the M-type spin-off, when compared to the pooling equilibrium of Proposition 1. As the asymmetric information problem becomes more severe, a larger proportion of the value generated by royalties is indirect. In Figure 3 the proportion of the indirect value from royalties to the total value from royalties is as high as 45%.

Table 1 Parameter Values

	Parameters used	Parameters varied
Figures 2 and 4(b)	$\theta_M = 0.9$, $\theta_N = 0.1$ $m = 10$, $c = 0.5$ $C = 2.5$, $\delta_l = 1.4$	$\tau \in \{0.05, 4.00\}$, steps of 0.05 $\beta \in \{0.01, 0.99\}$, steps of 0.01
Figure 3	$\delta_h = 11$, $\delta_l = 1$, $m = 12$ $\beta = 0.4$, $c = 0.5$ $C = 1$, $\theta_N = 0.1$	$\gamma \in \{0.01, 0.89\}$, steps of 0.01
Figure 4(a)	$\delta_h = 2.4$, $\delta_l = 1.4$, $m = 10$ $\beta = 0.3$, $c = 0.5$ $C = 2.5$, $\theta_N = 0.1$	$\gamma \in \{0.01, 0.10\}$, steps of 0.01
Figure 5(a)	$\delta_h = 6$, $\delta_l = 4$, $m = 10$ $\beta = 0.5$, $c = 0.5$ $C = 1.4$, $\theta_N = 0.3$, $\theta_M = 0.7$	$\kappa \in \{0.01, 1.89\}$, steps of 0.01
Figure 5(b)	$\delta_h = 6$, $\delta_l = 4$, $m = 10$ $\beta = 0.5$, $c = 0.5$ $C = 1.4$, $\theta_N = 0.3$, $\kappa = 0.05$	$\gamma \in \{0.01, 0.69\}$, steps of 0.01

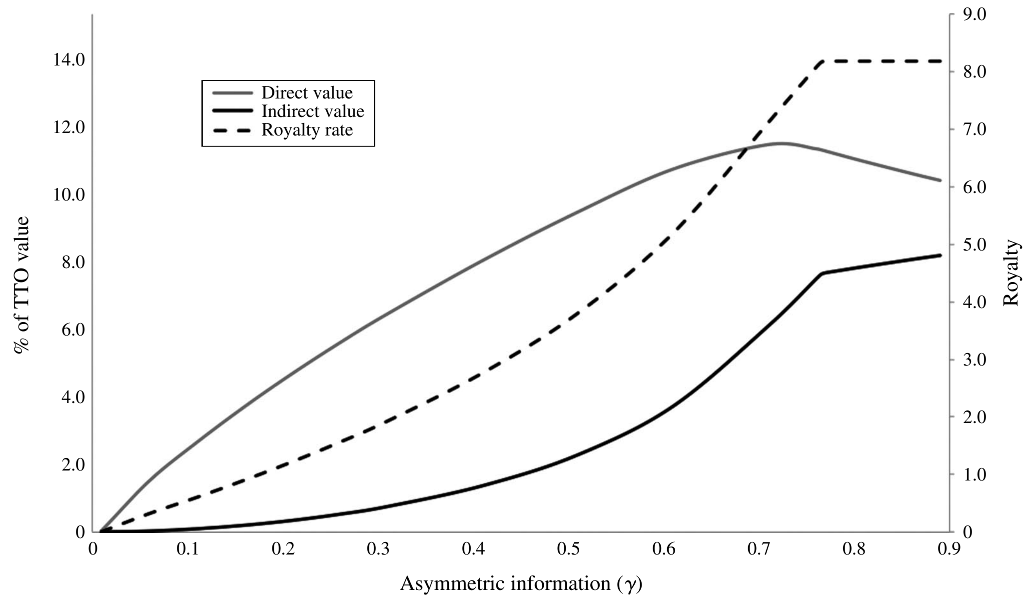
5. Contracts with Fixed Fees

Although we have concentrated on the use of royalties alongside equity until now, the prior licensing literature has primarily focused on the use of royalties alongside fixed fees. The main finding is similar to ours in that the principal is successful in extracting information from (or signaling information to) the licensee by offering a contract with fixed-fee payments only intended for the "high-value" licensee and a contract with a combination of royalties and fixed fees intended for the "low-value" licensee (Gallini and Wright 1990, Macho-Stadler and Perez-Castrillo 1991, Sen 2005b). The use of fixed fees instead of equity in university technology transfer is limited practically because small entrepreneurial companies such as university spin-offs are typically cash starved (Feldman et al. 2002). This "funding gap" has been well documented and a number of market imperfection hypotheses have been proposed to explain its prevalence (Himmelberg and Petersen 1994, Hall and Lerner 2010). In this section we seek to understand whether there is anything special about the use of equity in technology transfer to spin-offs that goes beyond funding constraints. We do so by first examining fixed-fee–royalty contracts and compare them with the equity–royalty contracts of the previous section. We subsequently expand the contract space to allow the inclusion of all equity, fixed fees, and royalties.

5.1. Fixed-Fee and Royalty Contracts

We begin our analysis by examining contracts that belong in the set $(F, r) = [0, C] \times [0, m + \delta_h - c]$, where F is the fixed fee payable up front and r is the royalty per quantity produced payable to the TTO. The TTO can offer a menu of two contracts with F_i and r_i intended for spin-off $i \in \{M, N\}$, respectively. The production decision of the spin-off is not affected by fixed fees, and the value of the spin-off having to pay royalties r in demand scenario $j \in \{l, h\}$ is once again given

Figure 3 **Effect of Asymmetric Information**



by $V_j(r) = (m + \delta_j - c - r)^2/(8\delta_j)$. The expected value of a spin-off of type i excluding development costs and fixed fees payable to the TTO is given by $\pi_i(r_i) = \theta_i V_l(r_i) + (1 - \theta_i)V_h(r_i)$, and the value appropriated by the spin-off is given by $\pi_i(r_i) - F_i - C$. The TTO's payoff from a spin-off of type i is given by $U_i(r_i, F_i) = F_i + r_i(\theta_i Q_l(r_i) + (1 - \theta_i)Q_h(r_i))$, and the optimization problem of the TTO is given by

$$\underset{r_M, r_N, F_M, F_N \geq 0}{\text{maximize}} \quad U = (1 - \beta)U_M(r_M, F_M) + \beta U_N(r_N, F_N)$$

$$\text{s.t.} \quad \pi_M(r_M) - F_M \geq \pi_M(r_N) - F_N, \tag{ICM}$$

$$\pi_N(r_N) - F_N \geq \pi_N(r_M) - F_M, \tag{ICN}$$

$$\pi_M(r_M) - F_M \geq C, \tag{IRM}$$

$$\pi_N(r_N) - F_N \geq C. \tag{IRN}$$

The separating equilibrium contract is characterized by the following proposition.

Proposition 4. *Under fixed-fee–royalty contracts, a unique separating equilibrium exists and is characterized by*

$$r_N = \min\{r^*, \underline{r}, \bar{r}\}, \quad F_N = \pi_N(r_N) - C,$$

$$r_M = 0, \quad F_M = \pi_M(0) - (\theta_M - \theta_N)(V_l(r_N) - V_h(r_N)) - C,$$

where

$$r^* = \frac{(1 - \beta)(\theta_M - \theta_N)(\delta_h - \delta_l)(m - c)}{(1 - \beta)(\theta_M - \theta_N)(\delta_h - \delta_l) + \beta(\theta_N \delta_h + (1 - \theta_N)\delta_l)}.$$

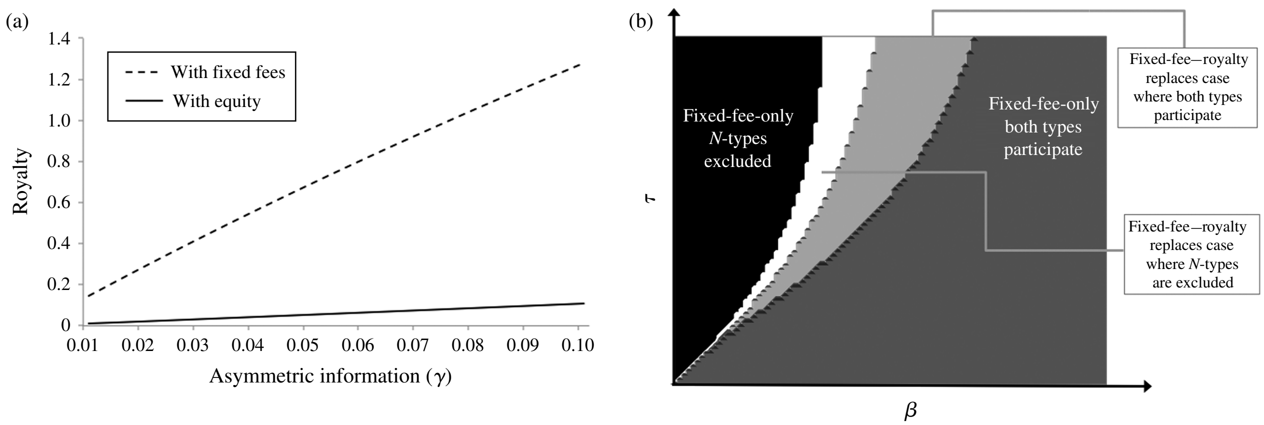
Proposition 4 implies that fixed-fee–royalty contracts can be used in a similar way to equity–royalty contracts to create a separating equilibrium. The TTO can offer two contracts: one that includes relatively low fixed fees and positive royalties intended for the N-type spin-off and another with relatively high fixed fees and no royalties intended for the M-type spin-off. Similarly to the equity–royalty case, this fixed-fee–royalty contract achieves separation because the royalties destroy more value for the M-type spin-off, which is willing to pay a higher fixed fee than the N-type to avoid royalties. The following proposition compares the level of royalties required to achieve separation in the equity–royalty case to the fixed-fee–royalty case.

Proposition 5. *The optimal royalties r_N of the separating equity–royalty contract are lower (or equal) to the royalties of the fixed-fee–royalty contract.*

This result shows that although both equity–royalty and fixed-fee–royalty contracts allow the TTO to extract information from the spin-off, for *any* model parameters, the former does so with lower royalties than the latter. Because production distortions caused by royalties destroy value for *both* the spin-off and the TTO, this result suggests that equity–royalty contracts are superior to fixed-fee–royalty contracts for licensing between a less-informed principal and a better-informed agent.

To understand why a lower royalty level is sufficient to separate the two types in the equity–royalty case than in the fixed-fee–royalty case, recall that any given level of royalty creates more severe distortions for the M-type spin-off than for the N-type, which discourages the M-type from misrepresenting its type in order to take the lower fixed fee or higher equity stake intended for the N-type. Furthermore, for any given level of royalty, the value taken away by royalties as far as the spin-off is concerned is decreasing in the equity retained by the spin-off. In the case of fixed-fee–royalty contracts, both types of spin-off receive the

Figure 4 Fixed-Fee and Fixed-Fee–Royalty Contract Regions



same equity stake (100%); therefore, the difference in distortion between the two types of spin-off is caused solely by the difference in royalties. In the case of equity–royalty contracts, the M-type spin-off retains a smaller share of the equity than the N-type spin-off, and therefore the M-type would experience even more distortions if it were to misrepresent its type. The way in which equity and royalties interact to enhance the distortions experienced by the M-type spin-off vis-à-vis the N-type spin-off allows the TTO to extract information at a lower royalty level, thereby causing less severe production distortions.

5.2. Numerical Investigation

Having established analytically that the royalty required to achieve separation is higher for fixed-fee–royalty than equity–royalty contracts, in this section we present a numerical examination of this difference and its implications for technology licensing. Figure 4(a) confirms the result of Proposition 5 and also allows us to observe the magnitude of the difference between the royalty rates required to achieve separation when combined with fixed fee versus. equity. Even for modest values of asymmetric information γ the gap is substantial, and this was the case for most of the model parameters we tried. Perhaps more importantly, the gap is increasing as asymmetric information becomes more prevalent. Since the value destroyed by royalties is increasing in the royalty rate, this finding suggests that fixed-fee–royalty contracts may be substantially more inefficient than equity–royalty contracts. In fact, as we show next, this inefficiency sometimes outweighs the benefits of extracting information.

As in Figure 2(b) of §4.3, in Figure 4(b) we vary the proportion of N-type spin-offs in the population (β) and the gap between the high- and low-demand dispersion scenarios ($\tau = \delta_h - \delta_l$). If the TTO were *only* allowed to charge fixed fees, then the black and the white regions of Figure 4(b) would denote the regions of the model parameters where the TTO would have found it optimal to license only to the M-type (i.e., exclude the N-type) by offering a fixed fee that is too high for the N-type. Conversely, the light and dark gray regions denote the model parameters for which the TTO would have found it optimal to choose the pooling equilibrium, which licenses to both types by charging a relatively low fixed fee and allows the M-type to extract full information rents.

Analogous to the case of equity–royalty contracts shown in Figure 2(b), the white region of Figure 4(b) denotes the model parameters for which the introduction of royalties alongside fixed fees makes it optimal for the TTO to license technology to both spin-off types as opposed to just the M-type. In this case, using royalties alongside fixed fees may well improve welfare despite the production distortions, because the N-type is not prevented from commercializing the technology. More interestingly, in the dark gray region of the same figure, although a fixed-fee–royalty separating equilibrium exists, it is no longer optimal for the TTO to use it to extract information from the spin-off, because the royalties required to achieve separation would have simply destroyed too much value. Therefore, the TTO prefers the pooling equilibrium where the M-type appropriates all information rents. Note that such a region does not exist in the equity–royalty case; under equity–royalty the pooling equilibrium is always less profitable than the optimal equity–royalty separating equilibrium.

This observation provides an important argument for the use of equity instead of fixed fees as a means of transferring technology by a less-informed principal to a more-informed agent that goes beyond financial frictions and cost-of-capital issues. Using equity–royalty as opposed to fixed-fee–royalty allows the TTO to screen for information for more model parameters (i.e., the dark gray region of Figure 4(b)) as well as to cause fewer production distortions (i.e., the white and light gray regions of Figure 4(b)). This, in turn, motivates TTOs to license to spin-offs rather than established firms. Perhaps this result provides an explanation as to why universities that accept equity in lieu of fixed fees create more spin-offs, as observed by Di Gregorio and Shane (2003).

In fact, we would argue that as far as adverse selection problems are concerned, equity–royalty contracts dominate fixed-fee–royalty contracts—an argument that we make exact in the next section, where we examine more complex contracts that include fixed fees, equity, and royalties.

5.3. Equity, Fixed Fee, and Royalty Contracts

In this section we expand the contract space to include all contract terms studied in the previous sections; i.e., we consider contracts that belong to the set $(F, e, r) = [0, C] \times [0, 1] \times [0, m + \delta_h - c]$, where F is the up-front fixed fee, e is the equity stake retained by the spin-off, and r is the royalty per unit of production. Without loss of generality, the TTO can offer a menu of two contracts with F_i, r_i, e_i for $i \in \{M, N\}$. The expected value of a spin-off of type i ignoring fixed costs C and fixed fees F_i is given by $\pi_i(r_i) = \theta_i V_l(r_i) + (1 - \theta_i) V_h(r_i)$, and the value remaining with the spin-off is given by $e_i \pi_i(r_i) - F_i$. The TTO's payoff from a spin-off of type i is given by $U_i(e_i, r_i, F_i) = F_i + (1 - e_i)\pi_i(r_i) + r_i(\theta_i Q_l(r_i) + (1 - \theta_i) Q_h(r_i))$. The problem of the TTO can be written as

$$\begin{aligned}
\underset{\substack{e_M, e_N, r_M, r_N,\\ F_M, F_N \geq 0}}{\text{maximize}}\ & U = (1-\beta) U_M(e_M, r_M, F_M) + \beta U_N(e_N, r_N, F_N) \\
\text{s.t.}\quad & e_M \pi_M(r_M) - F_M \geq e_N \pi_M(r_N) - F_N, && \text{(ICM)} \\
& e_N \pi_N(r_N) - F_N \geq e_M \pi_N(r_M) - F_M, && \text{(ICN)} \\
& e_M \pi_M(r_M) - F_M \geq C, && \text{(IRM)} \\
& e_N \pi_N(r_N) - F_N \geq C, && \text{(IRN)} \\
& e_N, e_M \leq 1.
\end{aligned}$$

The separating equilibria are characterized by the following proposition.

Proposition 6. *Under equity, fixed-fee, and royalty contracts there exist multiple payoff-equivalent separating equilibria. These are characterized by the following menus of two contracts, one intended for the N-type and one for the M-type. When $\underline{r} \geq \min\{r^*, \bar{r}\}$,*

$$r_N = \min\{r^*, \bar{r}\}, \quad r_M = 0, \quad e_N = \frac{C}{\pi_N(r_N)},$$
$$1 \geq e_M \geq 0, \quad F_N = 0, \quad F_M \geq 0,$$

such that $e_M \pi_M(0) - F_M = C(\pi_M(r_N)/\pi_N(r_N))$. When $\underline{r} <$ $\min\{r^*, \bar{r}\}$,

$$r_N = \underline{r}, \quad r_M = 0, \quad e_N \geq 0,$$
$$1 \geq e_M \geq 0, \quad F_N \geq 0, \quad F_M \geq 0,$$

such that $e_N \pi_N(\underline{r}) - F_N = C$ and $e_M \pi_M(0) - F_M = C$, where r^* is defined in Proposition 2.

This proposition shows that, depending on model parameters, the TTO either strictly prefers equity over fixed fees or is indifferent between retaining equity versus an equally valuable fixed fee (or any combination of the two with the same total value). This result provides a more formal confirmation of the intuition of the previous subsection: fixed-fee contracts are dominated by equity contracts. The use of royalties remains identical to the equity–royalty contract case, and fixed fees are optional in the sense that there always exists a separating equilibrium contract with zero fixed fees that cannot be improved upon.

6. Moral Hazard: The Case of Endogenous Effort

So far, in an attempt to illustrate the merits of including royalty terms in university technology transfer, we have chosen to abstract from moral hazard problems by assuming that the value of the spin-off is exogenously specified and fixed at the time of licensing. Clearly, this is a simplification, because the university technology being transferred is often too embryonic for immediate commercialization. In a survey of leading TTOs, Jensen and Thursby (2001) report that 88% of technologies licensed required further development, with over 75% of them no more advanced than lab-scale prototypes requiring substantial effort to overcome hurdles such as manufacturing feasibility (Dechenaux et al. 2011). This effort, which must be exerted by the management and the scientists of the spin-off, is costly both in terms of capital costs incurred and the time required for further development. Furthermore, since it is unobservable by the TTO, how much of it will be exerted is at the sole discretion of the spin-off. This leads to the classic moral hazard problem (Bolton and Dewatripont 2005): will the contract terms imposed on the spin-off distort effort, and does this distortion render royalties undesirable for university technology transfer?

In this section, we expand the analysis of the base model presented in §3 to understand how this costly endogenous effort affects our results. We introduce an endogenous probability of technical success $p(f)$, which is a function of costly and unobservable (or unverifiable) effort $f \geq 0$ that needs to be exerted by the spin-off. To simplify the analysis, we employ a specific functional form for the probability of success $p(f) = 1 - \exp(-f)$. This assumption, which is similar to that in Dechenaux et al. (2011), ensures that $p(f)$ is indeed a probability (i.e., $0 \leq p \leq 1$), and that it is increasing and strictly concave in effort, f. More specifically, the payoff of the spin-off that exerts effort f, produces quantity Q, pays a fixed fee F and royalties r, and retains an equity stake e becomes

$$p(f) e Q(m + \delta - c - r - 2\delta Q) - C - \kappa f - F - C,$$

where κ is the cost of unit effort. Assuming that the royalties (equity) are not too high (low), i.e., $r \le m+\delta-c$ ($e \ge 8\delta\kappa/(m+\delta-c-r)^2$), the payoff is jointly concave in effort f and quantity Q. The profit-maximizing quantity–effort pair is given by $Q^* = (m+\delta-c-r)/4\delta_i$ and $f^* = \log(e(m+\delta-c-r)^2/8\delta\kappa)$. The payoffs of the spin-off and the TTO at the optimal production quantity and level of effort are given by

$$V^S(F,e,r) = e\frac{(m+\delta-c-r)^2}{8\delta} - \kappa \cdot\left(1+\log\left(\frac{(m+\delta-c-r)^2}{8\delta\kappa}e\right)\right) - F - C, \quad (2)$$

$$V^{\mathrm{TTO}}(F,e,r) = (1-e)\left(\frac{(m+\delta-c-r)^2}{8\delta} - \frac{\kappa}{e}\right) + r\left(\frac{m+\delta-c-r}{4\delta} - \frac{2\kappa}{e(m+\delta-c-r)}\right) + F. \quad (3)$$

Reassuringly, as the cost of effort $\kappa \to 0$, the payoffs reduce to that of §3.

6.1. Moral Hazard Without Adverse Selection

In a setting of symmetric information where the spin-off needs to exert unverifiable and costly effort f_i, both royalty payments to the TTO and equity stakes retained by the TTO cause distortions. In particular, as can be seen from the expressions for the optimal quantity Q^* and effort f_i^*, royalties cause both quantity and effort distortions. However, equity causes effort distortion but does not affect production. Since fixed fees F do not feature in the expressions for the optimal quantity or effort, they do not cause any kind of distortion. We study the optimal technology transfer contract in this case with the following proposition.

Proposition 7. *In the presence of endogenous effort and symmetric information, technology transfer with fixed fees is preferable to either equity or royalties and equity is preferable to royalties.*

Proposition 7 shows that in the presence of endogenous effort, if the TTO and the spin-off are symmetrically informed, then there exists a clear pecking order of licensing terms: fixed fees dominate equity and equity dominates royalties. Even if the spin-off is cash constrained and the TTO has to choose between royalties and equity, the presence of moral hazard alone cannot explain the use of royalties alongside equity—if anything it makes it even more puzzling because royalties in this case cause both effort and production distortions.

6.2. Moral Hazard and Adverse Selection

In this section we extend the model described above to account for both uncertainty in demand and asymmetry of information, as described in §3.2. We examine contracts that belong to the set $(F,e,r) = [0,C]\times[0,1]\times[0,m+\delta_h-c]$. The TTO can offer a menu of contracts F_i, e_i, r_i, with $i\in\{M,N\}$. The TTO's payoff from a spin-off of type i is given by $U_i(e_i,r_i,F_i) = F_i + (1-e_i)\times p_i(e_i,r_i)(\pi_i(r_i) + r_i(\theta_i Q_l(r_i) + (1-\theta_i)Q_h(r_i)))$, where $p_i(e,r) = 1-\kappa/(e\pi_i(r))$ and $Q_j(r) = (m+\delta_j-c-r)/(4\delta_j)$ for $j\in\{h,l\}$. The problem of the TTO can be written as

$$\underset{\substack{e_M,e_N,r_M,r_N,\\ F_M,F_N\ge 0}}{\text{maximize}}\; U = (1-\beta)U_M(e_M,r_M,F_M) + \beta U_N(e_N,r_N,F_N)$$

s.t.

$$e_M\pi_M(r_M) - F_M - e_N\pi_M(r_N) + F_N \ge \kappa\log\left(\frac{e_M\pi_M(r_M)}{e_N\pi_M(r_N)}\right), \quad \text{(ICM)}$$

$$e_N\pi_N(r_N) - F_N - e_M\pi_N(r_M) + F_M \ge \kappa\log\left(\frac{e_N\pi_N(r_N)}{e_M\pi_N(r_M)}\right), \quad \text{(ICN)}$$

$$e_M\pi_M(r_M) - \kappa\left(1+\log\left(\frac{e_M\pi_M(r_M)}{\kappa}\right)\right) - F_M \ge C, \quad \text{(IRM)}$$

$$e_N\pi_N(r_N) - \kappa\left(1+\log\left(\frac{e_N\pi_N(r_N)}{\kappa}\right)\right) - F_N \ge C, \quad \text{(IRN)}$$

$$e_N, e_M \le 1.$$

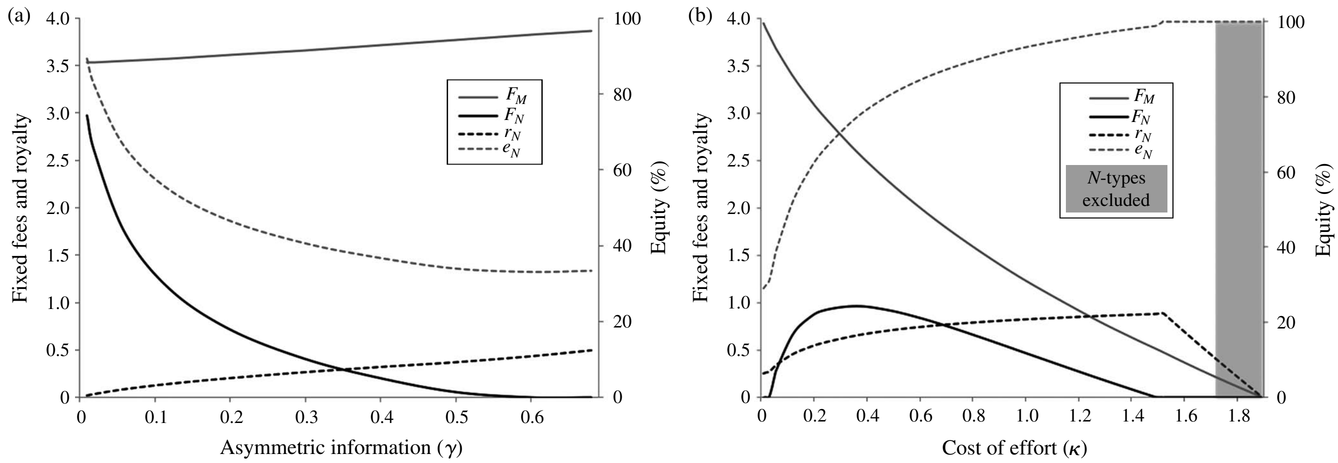
A complete analytical characterization of the optimal contract is possible but too complicated to be useful. Nevertheless, we can prove some of the structural properties of the optimal contract.

Proposition 8. *Any separating equilibrium contract must satisfy $r_M = 0$, $e_M = 1$, $F_M \ge 0$ and $r_N > 0$, $e_N \le 1$, $F_M \ge 0$.*

Proposition 8 shows that in the presence of both unobservable effort (i.e., moral hazard) and adverse selection, the optimal contract for the N-type spin-off contains all three elements: equity, royalties, and fixed fees. Importantly, r_N is strictly positive in any separating equilibrium (even if the moral hazard problem is severe).

We also investigate the structure of the optimal solution numerically in Figure 5. As can be seen in this figure, equity always coexists with royalty for the N-type spin-off, and fixed fees are usually also needed. We can therefore conclude that moral hazard does not invalidate the optimality of royalties or the coexistence of equity and royalties in university technology transfer. Furthermore, the presence of a moral hazard problem can explain the coexistence of all three contractual terms, which is often observed in university technology transfer. Consistent with §6.1, we see from Figure 5 that as the problem of asymmetric information becomes less prominent (i.e., $\gamma \to 0$), the equity retained by the TTO and the royalties are both reduced to zero. Conversely, as the moral hazard problem becomes less prominent

Figure 5 **Contract Terms Under Moral Hazard and Adverse Selection**



(i.e., $\kappa \to 0$), fixed fees are reduced to zero and the optimal contract contains a combination of equity and royalties, consistent with §4.1. Although the curves show the optimal contracts for a separating equilibrium, when the moral hazard problem is extreme it may be optimal not to screen and exclude N-types by offering the fixed fee that binds the participation constraint of the M-type (shaded region of Figure 5(b)).

Finally, we conclude this section by noting that, in this setting, royalty payments are not the only mechanism through which the TTO can separate the two types. Indeed, there exists a fixed-fee–equity separating equilibrium that exploits the asymmetric effort distortion caused by equity to ensure incentive compatibility (proof available from the authors). Nevertheless, it follows from Proposition 8 that such a contract underperforms compared to the more general fixed-fee–equity–royalty contract.

7. Discussion and Conclusion

University spin-offs are increasingly important in translating university-based research to commercial application (Shane 2004). As a result, a substantial body of research has been developed in an attempt to describe the spin-off phenomenon and understand their creation process (see §4.3 of the review by Rothaermel et al. 2007). To the extent that universities aim to retain some of the economic value of the university-created IP, they find it necessary to negotiate licensing agreements with their spin-offs. Therefore, contracts play a critical role in fostering spin-off creation. Among the contractual terms (fixed fees, equity, or royalty) to include in such contracts, economic theory suggests that royalties should be avoided because they have a detrimental effect on value. Nevertheless, in practice, royalties are used in conjunction with equity. Our paper offers an explanation driven by the natural assumption that TTO managers are less well informed about the market potential of the new product vis-à-vis the entrepreneurs who are actively involved in the daily running of the spin-off. We show that under this assumption royalties are an effective screening mechanism that allows the TTO to retain a larger share of the value created by the spin-off. Furthermore, royalties are more effective when used in conjunction with equity rather than fixed fees; equity–royalty contracts lead to lower value distortion and allow for technology to be licensed over a wider range of parameters than fixed-fee–royalty contracts. The sequence of models we present provides insights on the coexistence of equity, royalty, and fixed fees by characterizing the different roles played by the three contract terms with respect to moral hazard and adverse selection. We present a summary of these roles in Table 2.

Our analysis sheds light on some empirical observations. First, we show that adverse selection (with or without moral hazard) provides a rational explanation for the persistent use of royalties alongside equity (and fixed fees) by TTOs. Second, our work suggests that selection bias may be an alternative explanation for the empirically documented superior performance of equity over royalties (Bray and Lee 2000)—ceteris paribus, equity-only contracts are intended for spin-offs of the highest quality whereas royalty-only contracts are intended for spin-offs that are most likely only going to generate niche-market products. Third, our findings may explain why TTOs that are willing to take equity in lieu of fixed fees create more spin-offs (Di Gregorio and Shane 2003): equity–royalty contracts allow the TTO to screen for information for more model parameters and cause fewer production distortions than fixed-fee–royalty contracts.

In addition to explaining existing empirical observations, our work generates hypotheses that can be tested with further empirical research. To the extent that more experience in technology transfer leads TTOs to be less asymmetrically informed about the market

Table 2 **Summary of Results**

	Adverse selection (§§4 and 5)	Adverse selection and moral hazard (§6)
Role of royalty	Extract value and distort production	Extract value and distort production and effort
Role of equity	Extract value (without any distortions)	Extract value and distort effort
Role of fixed-fee	Extract value (without any distortions)	Extract value (without any distortions)
Optimal contract	Equity–royalty (fixed fee optional)	Fixed-fee–equity–royalty
Trade-offs	Royalties distort production, which acts as a screening device. Compared to fixed-fee–royalty contracts, equity–royalty contracts allow for screening (i) with lower royalty leading to a lower level of distortion and (ii) over a wider range of parameters. For some model parameters, some amount of equity can be substituted with a fixed fee.	Royalties and equity cause distortions and either could be used as a screening device. As a result of the tension between the desire to use fixed fee to address the moral hazard problem and equity to address the adverse selection problem, the optimal contract includes all three terms.

potential of new technologies, our model predicts that more experienced TTOs will require lower levels of royalties and retain higher levels of equity when licensing technology to their spin-offs.[7] Future empirical work could investigate these hypotheses.

Last but not least, we believe that recognizing and mitigating problems of asymmetric information in university and corporate technology transfer can be an important driver in accelerating technology commercialization. Our work suggests that creating new spin-off companies to commercialize new technology is more efficient than licensing to incumbents because the licensor can take an equity stake with a value closely linked to the value of the new company, which, in conjunction with royalties, is shown to be a more efficient way of transferring technology than fixed fees. Thus, creating spin-offs, coupled with carefully designed contracts, may enhance the ability of institutions that produce IP through basic research to retain a larger share of the value they generate, which, in turn, will ensure that they have the resources and incentives, both financial and organizational, to further fund research and better facilitate technology transfer. This will encourage spin-off creation with knock-on effects on the economic performance and job creation capacity of both local and national economies.

Acknowledgments

The authors are grateful to David Hsu (department editor), the anonymous associate editor, and three anonymous referees for comments that have greatly improved the paper.

[7] A slightly different hypothesis, on the proportion of deals that include some element of equity in the portfolio of a TTO as a function of the TTO's experience, was investigated by Feldman et al. (2002) and Lockett et al. (2003). Feldman et al. (2002) find that the TTOs with the highest proportion of equity deals are more likely to be based in more experienced universities. Lockett et al. (2003) find that TTOs that have been more successful in spin-off creation are more likely to both employ experienced specialists who are dedicated to the establishment of technology-based spin-offs and include equity positions alongside royalties (and fixed fees) in their licenses to these spin-offs.

Appendix. Proofs of Propositions

Proof of Proposition 2. Since the feasible region is compact and all payoffs are continuous, an appeal to the Weierstrass Theorem proves the existence of a maximum for this problem. The constraints $e_M \geq 0$ and $e_N \geq 0$ are redundant, because they are implied by constraints (IRM) and (IRN). The payoff $U(e_M, e_N, r_M, r_N)$ is decreasing in both e_N and e_M. Therefore, at least one of the individual rationality constraints should be binding. If it were not, the TTO could decrease both e_N and e_M by the same fraction, which would leave the incentive compatibility constraints unaffected but increase the payoff. We check two cases: in the first case IRN binds and in the second case IRM binds.

Case 1. IRN is binding, which implies that $e_N = C/\pi_N(r_N)$. ICM becomes $e_M\pi_M(r_M) \geq e_N\pi_M(r_N) = (C/\pi_N(r_N))\pi_M(r_N)$. Then, at least one of (a) ICM or (b) IRM needs to be binding. This follows from the fact that, once we substitute the above expression for e_N into the relevant constraints, reducing e_M by some fraction increases the objective and does not affect ICN. Therefore, we can keep reducing e_M until at least one of IRM or ICM binds.

Case 1a. IRN and ICM are binding. The two binding constraints $e_N\pi_N(r_N) = C$ and $e_M\pi_M(r_M) = e_N\pi_M(r_N)$ allow us to eliminate e_N and e_M from the problem. Using this, IRM can now be written as $\pi_M(r_N) \geq \pi_N(r_N)$ and the constraint $e_N \leq 1$ can be written as $\pi_N(r_N) \geq C$.

Next, we relax the problem by ignoring the ICN constraint, which holds at first best and $e_M \leq 1$. We will check whether these constraints are satisfied at optimum. The relaxed program becomes

$$\underset{r_M, r_N \geq 0}{\text{maximize}}\, U(r_M, r_N) = (1-\beta)U_M(r_M, r_N) + \beta U_N(r_N),$$

subject to $\pi_M(r_N) \geq \pi_N(r_N)$ and $\pi_N(r_N) \geq C$, which are equivalent to IRM and $e_N \leq 1$, respectively. Note that r_M does not appear in the constraints except $r_M \geq 0$ and that

$$\frac{\partial U}{\partial r_M} = \begin{cases} -(1-\beta)\dfrac{r_M}{4}\left[\dfrac{(1-\theta_M)}{\delta_h} + \dfrac{\theta_M}{\delta_l}\right] & \text{if } r_M < m+\delta_l - c, \\[2ex] -(1-\beta)\dfrac{r_M}{4}\dfrac{(1-\theta_M)}{\delta_h} & \text{if } m+\delta_l - c \leq r_M < m+\delta_h - c, \end{cases}$$

which is negative for all $r_M > 0$ and zero for $r_M = 0$; therefore, at the optimal contract $r_M = 0$. We are left with a single-variable optimization problem. The first constraint implies $r_N \leq \underline{r} = m - c - \sqrt{\delta_h\delta_l}$. Note that $\underline{r} > 0$ as $m - c > \delta_h > \delta_l$. The second constraint implies $r_N \leq \bar{r}$, where $\bar{r}$ is the positive root of the quadratic equation $\pi_N(r)=C$, which can be written as $\bar{r}=m-c-u$, where

$$u=\frac{-\delta_h\delta_l+\sqrt{\delta_h\delta_l(8C((1-\theta_N)\delta_l+\delta_h\theta_N)-(\delta_h-\delta_l)^2(1-\theta_N)\theta_N)}}{\delta_l(1-\theta_N)+\delta_h\theta_N}.$$

That $\bar{r}>0$ exists and is unique is a consequence of the fact that $\pi_N(0)>C$, $\lim_{x\to\infty}\pi_N(x)=0$ and $\pi_N(r)$ is continuous decreasing in r. The derivative of the objective function with respect to r_N, when $r_N\le \underline{r}$, is given by

$$\frac{\partial U}{\partial r_N}=-\beta\frac{r_N}{4}\left[\frac{(1-\theta_N)}{\delta_h}+\frac{\theta_N}{\delta_l}\right]+(1-\beta)\frac{C}{\pi_N(r_N)^2}(\delta_h-\delta_l)Q_l(r_N)Q_h(r_N)(\theta_M-\theta_N). \quad (4)$$

Since $\delta_h>\delta_l$ and $\theta_M>\theta_N$ there exists a positive r^* in $(0,m+\delta_l-c)$ such that $\partial U/\partial r_N(r^*)=0$. That such an r exists is a consequence of $\partial U/\partial r_N(0,0)>0$,

$$\lim_{r\to m+\delta_l-c}\frac{\partial U}{\partial r_N}(0,r)<0,$$

and $\partial U/\partial r_N(0,r)$ is continuous in $(0,m+\delta_l-c)$. Therefore, the optimal royalty will be $\min\{r^*,\bar{r},\underline{r}\}$.

We will now check if ICN and $e_M\le 1$ are satisfied at optimum. At optimum, $r_M\le r_N$. Since $\pi_i(r)$ is decreasing in r, $\pi_M(r_N)/\pi_M(r_M)\le 1$, and since $e_M=e_N(\pi_M(r_N)/\pi_M(r_M))\le e_N\le 1$, ICN can be written as $\pi_N(r_M)\pi_M(r_N)-\pi_N(r_N)\pi_M(r_M)\le 0$. The left-hand side (LHS) can be expressed as

$$\begin{aligned}&\pi_N(r_M)\pi_M(r_N)-\pi_N(r_N)\pi_M(r_M)\\&=\frac{(\theta_M-\theta_N)(\delta_h-\delta_l)(r_N-r_M)}{32\delta_l\delta_h}\big((m+\delta_l-c-\tfrac{1}{2}(r_N+r_M))\delta_h\\&\quad+\big(m-c-\tfrac{1}{2}(r_N+r_M)\big)\delta_l+(m-c-r_M)(m-c-r_N)\big).\end{aligned}$$

At the optimal contract $m-c\ge r_N\ge r_M=0$, therefore ICN is satisfied.

The remaining cases do not yield any new separating equilibria. □

Proof of Proposition 3. The royalty rate is given by $r_N=\min\{\underline{r},r^*,\bar{r}\}$. Note that $\underline{r}$ and $\bar{r}$ are independent of $\theta_M=\theta_N+\gamma$ and are therefore not affected by the degree of asymmetric information γ. We investigate r^* below. Starting from its definition and differentiating with respect to γ we get

$$\frac{\partial r^*}{\partial\gamma}\frac{v\pi_N(r^*)}{Q_l(r^*)Q_h(r^*)}\cdot\left[\pi_N(r^*)+r^*\left(2\pi_N'(r^*)-\pi_N(r^*)\left(\frac{Q_l'}{Q_l(r^*)}+\frac{Q_h'}{Q_h(r^*)}\right)\right)\right]=1,$$

where v is a positive constant (i.e., independent of r and γ). Therefore, $\partial r/\partial\gamma>0$ is equivalent to $\pi_N(r^*)+r^*(2\pi_N'(r^*)-\pi_N(r^*)(Q_l'/Q_l+Q_h'/Q_h))>0$. The LHS, after some algebra, can be written as $\theta_N(x_l/\delta_l)[x_l(2+r^*/x_h)-3r^*]+(1-\theta_N)(x_h/\delta_h)[x_h(2+r^*/x_l)-3r^*]$, where $x_i=(m+\delta_i-c-r^*)/4>0$. We note that $\delta_h>\delta_l$ implies $x_h>x_l$. Clearly this expression is positive when $x_l\ge(3r^*)/2$. This is equivalent to $r^*\le(m+\delta_l-c)/7$. Furthermore, since $r^*\le m-c-\sqrt{\delta_l\delta_h}$, then $r^*\le(m+\delta_l-c)/7$ is always satisfied when $m-c-\sqrt{\delta_l\delta_h}\le(m+\delta_l-c)/7$ or equivalently $\delta_h\ge(6(m-c)-\delta_l)^2/(7^2\delta_l)$. To prove the second part, note that e_N depends on γ only when $r=r^*$, in which case $\partial e_N/\partial\gamma=(C/\pi_N(r^*))(\theta_N Q_l(r^*)+(1-\theta_N)Q_h(r^*))(\partial r^*/\partial\gamma)$; therefore $\partial e_N/\partial\gamma$ has the same sign as $\partial r^*/\partial\gamma$. Similarly, note that when $r=\underline{r}$ then $e_N=C/\pi_N(\underline{r})$, which is (linear) increasing in C; when $r=\bar{r}$ then $e_N=1$, which is independent of C; and when $r=r^*$ then $\partial e_N/\partial C=1/\pi_N(r^*)+(C/\pi_N(r^*))(\theta_N Q_l(r^*)+(1-\theta_N)Q_h(r^*))(\partial r^*/\partial C)$. Note that r^* is homomorphic in C and γ, therefore $\partial r^*/\partial C$ has the same sign as $\partial r^*/\partial\gamma$, which concludes the proof. □

Proof of Proposition 4. Since the feasible region is compact and all payoffs are continuous, an appeal to the Weierstrass Theorem proves the existence of a maximum for this problem. The objective $U(F_M,F_N,r_M,r_N)$ is increasing in both F_N and F_M. Therefore, at least one of the individual rationality constraints should be binding. If it were not, the TTO could increase both F_N and F_M by the same increment, which would leave the incentive compatibility constraints unaffected but increase the payoff. We check two cases: in the first case IRN binds and in the second case IRM binds.

Case 1. IRN is binding, which implies that $F_N=\pi_N(r_N)-C$. ICM becomes $\pi_M(r_M)-F_M\ge\pi_M(r_N)-F_N=\pi_M(r_N)-\pi_N(r_N)+C$. Then, at least one of (a) ICM or (b) IRM needs to be binding. This follows from the fact that, once we substitute the above expression for F_N into the relevant constraints, increasing F_M by some amount increases the objective value and does not affect ICN. Therefore, we can keep increasing F_M until at least one of IRM or ICM binds.

Case 1a. IRN and ICM are binding. The two binding constraints $\pi_N(r_N)-F_N=C$ and $\pi_M(r_M)-F_M=\pi_M(r_N)-F_N$ allow us to eliminate F_N and F_M from the problem. Using this, we can now write IRM as $\pi_M(r_N)\ge\pi_N(r_N)$ and the constraint $F_N\ge 0$ can as $\pi_N(r_N)\ge C$.

Next, we relax the problem by ignoring ICN, which holds at first best and $F_M\ge 0$. We will check whether these constraints are satisfied at optimum. The relaxed program becomes

$$\underset{r_M,\,r_N\ge 0}{\text{maximize}}\; U(r_M,r_N)=(1-\beta)U_M(r_M,r_N)+\beta U_N(r_N)$$

subject to $\pi_M(r_N)\ge\pi_N(r_N)$ and $\pi_N(r_N)\ge C$, which are equivalent to IRM and $F_N\ge 1$, respectively. Note that r_M does not appear in the constraints except $r_M\ge 0$ and that

$$\frac{\partial U}{\partial r_M}=\begin{cases}-(1-\beta)\dfrac{r_M}{4}\left[\dfrac{1-\theta_M}{\delta_h}+\dfrac{\theta_M}{\delta_l}\right] & \text{if } r_M<m+\delta_l-c,\\[2ex] -(1-\beta)\dfrac{r_M}{4}\dfrac{1-\theta_M}{\delta_h} & \text{if } m+\delta_l-c\le r_M<m+\delta_h-c,\end{cases}$$

which is negative for all $r_M>0$ and zero for $r_M=0$; therefore at optimum $r_M=0$. We are left with a single-variable optimization problem. The first constraint implies $r_N\le\underline{r}=m-c-\sqrt{\delta_h\delta_l}$. Note that $\underline{r}>0$ as $m-c>\delta_h>\delta_l$. The second constraint implies $r_N\le\bar{r}$.

The derivative of the objective function with respect to r_N, when $r_N\le\underline{r}$, is given by

$$\frac{\partial U}{\partial r_N}=-\beta\frac{r_N}{4}\left[\frac{1-\theta_N}{\delta_h}+\frac{\theta_N}{\delta_l}\right]+(1-\beta)(Q_l(r_N)-Q_h(r_N))(\theta_M-\theta_N). \quad (5)$$

Solving $\partial U/\partial r_N(r^*) = 0$, we find

$$r^* = \frac{(1-\beta)(\theta_M-\theta_N)(\delta_h-\delta_l)(m-c)}{(1-\beta)(\theta_M-\theta_N)(\delta_h-\delta_l)+\beta(\theta_N\delta_h+(1-\theta_N)\delta_l)}.$$

Therefore, the optimal royalty will be $\min\{r^*, \bar{r}, \underline{r}\}$.

We will now check if ICN is satisfied at optimum. ICN can be written as $\pi_N(r_N)\pi_M(r_M) - \pi_N(r_M)\pi_M(r_N) \geq 0$. The LHS simplifies to $((\theta_M-\theta_N)(\delta_h-\delta_l)(m-c-\frac{1}{2}r_N)r_N)/(4\delta_l\delta_h)$, which is greater than zero since $\theta_M > \theta_N$, $\delta_h > \delta_l$, and $r_N \leq \underline{r} = m-c-\sqrt{\delta_h\delta_l} \leq m-c$. Last, we check if $F_M \geq 0$ is satisfied at optimum. Note that $r_N \geq r_M = 0$ at optimum. We have from ICN that $\pi_N(r_N) - F_N = C \geq \pi_N(r_M) - F_M$. Rearranged, this inequality gives $F_M \geq \pi_N(r_M) - C \geq \pi_N(r_N) - C \geq 0$. The two omitted constraints are therefore satisfied. The remaining cases do not yield any new separating equilibria. □

Proof of Proposition 5. Since the values of $\bar{r}$ and $\underline{r}$ given in Proposition 4 are equal to the corresponding royalties of Proposition 2, we will proceed by showing that r^* in Proposition 2 is less than that in Proposition 4. Denote the first by r_1 and the second by r_2. Then r_1 is given by setting the expression of (4) to zero, while r_2 is given by setting the expression of (5) to zero. Rearranging (4) and (5) gives $\lambda r_1 = f_1(r_1)$ and $\lambda r_2 = f_2(r_2)$, where $\lambda > 0$, $f_1(r) = \frac{1}{8}(C/\pi_N(r)^2)(m-c-r+\delta_l)(m-c-r+\delta_h)$ and $f_2(r) = m-c-r$. Note that f_2 is decreasing in r. Therefore, to show that $r_1 < r_2$, it will be sufficient to show that $f_2(r) - f_1(r) > 0$ for all $0 < r < \underline{r} = m-c-\sqrt{\delta_l\delta_h}$. Let $x(r) = m-c-r$. Also note that $C \leq \pi_N(r)$ and $\pi_N(r) = \theta_N((x+\delta_l)^2/(8\delta_l)) + (1-\theta_N)(x+\delta_h)^2/(8\delta_h) \geq (x+\delta_h)^2/(8\delta_h)$. Then

$$\begin{aligned} f_2(r) - f_1(r) &= x - \frac{1}{8}\frac{C}{\pi_N(r)^2}(x+\delta_l)(x+\delta_h) \\ &\geq x - \frac{1}{8}\frac{1}{\pi_N(r)}(x+\delta_l)(x+\delta_h) \\ &\geq x - \frac{1}{8}\frac{(x+\delta_l)(x+\delta_h)}{(x+\delta_h)^2/(8\delta_h)} = x - \frac{(x+\delta_l)\delta_h}{x+\delta_h} \\ &= \frac{x^2-\delta_h\delta_l}{x+\delta_h}. \end{aligned}$$

For $r < m-c-\sqrt{\delta_l\delta_h}$, which implies that $x > \sqrt{\delta_l\delta_h}$, the above expression is always positive. □

Proof of Proposition 6. Since the feasible region is compact and all payoffs are continuous, an appeal to the Weierstrass Theorem proves the existence of a maximum for this problem. The constraints $e_M, e_N \geq 0$ are redundant because they are implied by the individual rationality constraints. The objective $U(F_M, F_N, e_M, e_N, r_M, r_N)$ is increasing in both F_N and F_M. Therefore, at least one of the individual rationality constraints should be binding. If it were not, the TTO could increase both F_N and F_M by the same amount, which would leave the incentive compatibility constraints unaffected but increase the payoff. We check two cases: in the first case IRN binds and in the second case IRM binds.

Case 1. IRN is binding, which implies that $F_N = e_N\pi_N(r_N) - C$. ICM becomes $F_M \leq e_M\pi_M(r_M) - e_N(\pi_M(r_N) - \pi_N(r_N)) - C$. Then, at least one of (a) ICM or (b) IRM needs to be binding. This follows from the fact that, once we substitute the above expression for F_N into the relevant constraints, increasing F_M by some amount increases the objective value and does not affect ICN. Therefore, we can keep increasing F_M until at least one of IRM or ICM binds.

Case 1a. IRN and ICM are binding. The two binding constraints $F_N = e_N\pi_N(r_N) - C$ and $F_M = e_M\pi_M(r_M) - e_N(\pi_M(r_N) - \pi_N(r_N)) - C$ allow us to eliminate F_N and F_M from the problem. The value for the TTO that deals with a spin-off of type M becomes $U_M(e_N, r_M, r_N) = e_N(\pi_N(r_N) - \pi_M(r_N)) + \pi_M(r_M) + r_M\bar{Q}_M(r_M) - C$ and with a spin-off of type N becomes $U_N(r_N) = \pi_N(r_N) + r_N\bar{Q}_N(r_N) - C$, where $\bar{Q}_i(r) = \theta_i Q_l(r) + (1-\theta_i)Q_h(r)$. Similarly, the IRM constraint can be written as $r_N \leq \underline{r}$ and the constraint $F_N \geq 0$ can be written as $e_N\pi_N(r_N) \geq C$.

First, we note that the objective does not depend on e_M; therefore any $e_M \leq 1$ that satisfies ICM (i.e., $F_M = e_M\pi_M(r_M) - e_N(\pi_M(r_N) - \pi_N(r_N)) - C$) for $F_M \geq 0$ is optimal. Next, we relax the problem by ignoring the ICN constraint, which holds at first best. We will check whether this constraint is satisfied at optimum. The problem becomes

$$\begin{aligned} &\underset{e_N, r_M, r_N, \geq 0}{\text{maximize}}\ U(e_N, r_M, r_N) \\ &\quad = (1-\beta)U_M(e_N, r_M, r_N) + \beta U_N(r_N) \end{aligned} \tag{6}$$

subject to $e_N \leq 1$, $\pi_M(r_N) \geq \pi_N(r_N)$, and $e_N\pi_N(r_N) \geq C$. The last two constraints are equivalent to IRM and $F_N \geq 0$, respectively. Furthermore, the constraint $\pi_M(r_N) \geq \pi_N(r_N)$ can be written as $r \leq \underline{r}$. Note that r_M does not appear in the constraints except $r_M \geq 0$ and that

$$\frac{\partial U}{\partial r_M} = \begin{cases} -(1-\beta)\dfrac{r_M}{4}\left[\dfrac{(1-\theta_M)}{\delta_h} + \dfrac{\theta_M}{\delta_l}\right] & \text{if } r_M < m+\delta_l-c, \\ -(1-\beta)\dfrac{r_M}{4}\dfrac{(1-\theta_M)}{\delta_h} & \text{if } m+\delta_l-c \leq r_M < m+\delta_h-c, \end{cases}$$

which is negative for all $r_M > 0$ and zero for $r_M = 0$; therefore at optimum $r_M = 0$. The derivative of the utility function with respect to e_N is given by $\partial U/\partial e_N = -(\pi_M(r_N) - \pi_N(r_N))$. This is negative for $r_N < \underline{r}$ and zero for $r_N = \underline{r}$. Assuming that $r_N < \underline{r}$ then the optimal e_N is given by $e_N = C/\pi_N(r_N)$. The constraint $e_N \leq 1$ implies $r \leq \bar{r}$. The derivative of the objective with respect to r_N is given by

$$\begin{aligned} \frac{\partial U}{\partial r_N} &= -\beta\frac{r_N}{4}\left[\frac{(1-\theta_N)}{\delta_h} + \frac{\theta_N}{\delta_l}\right] + (1-\beta)\frac{C}{\pi_N(r_N)^2} \\ &\quad \cdot (\delta_h - \delta_l)Q_l(r_N)Q_h(r_N)(\theta_M - \theta_N), \end{aligned} \tag{7}$$

which is zero at r^*, which was shown to exist in the proof of Proposition 2. Therefore, the objective is maximized at $r_N = \min\{\bar{r}, r^*\}$ provided that $\underline{r} > \min\{\bar{r}, r^*\}$. If $\underline{r} \leq \min\{\bar{r}, r^*\}$ then the objective is maximized at $r_N = \underline{r}$ and the TTO is indifferent between any $F_N \geq 0$ and $e_N \geq 0$ such that $F_N = e_N\pi_N(\underline{r}) - C$.

We now check that the constraint ICN is satisfied at the solution identified above. By eliminating F_N and F_M, it can be written as $e_M(\pi_N(0) - \pi_M(0)) + e_N(\pi_M(r_N) - \pi_N(r_N)) \leq 0$. The first term is nonpositive, and when $r_N = \underline{r}$ the second term is zero; therefore ICN is satisfied. When $r_N < \underline{r}$ then $e_N = C/\pi_N(r_N)$ and without loss of generality we can choose $F_M = 0$ and $e_M\pi_M(r_M) - e_N(\pi_M(r_N) - \pi_N(r_N)) = C$. The proof then proceeds as in Proposition 2. □

Proof of Proposition 7. The problem of the TTO is given by $\max V^{\text{TTO}}(F, e, r)$ such that $V^S(F, e, r) \geq 0$, $0 \leq r \leq$

$m+\delta-c$, $8\kappa\delta/(m+\delta-c-r)^2 \le e \le 1$, where $V^S(F,e,r)$ and $U(F,e,r)$ are given by (2) and (3), respectively. Clearly, the first constraint will be binding at the solution; if it were not the TTO could increase the fixed fee F, which would increase the objective function. Therefore, we can use the binding constraint to eliminate F from the objective. The derivative of the objective with respect to (wrt) to r is given by $\partial V^{\text{TTO}}/\partial r = -(2\kappa/(e(m+\delta-c-r)))(1-e+r) - r/(4\delta)$, which is negative for any $r>0$; therefore at the solution $r=0$. Similarly, the derivative of the objective wrt to e at $r=0$ is given by $\partial V^{\text{TTO}}/\partial e = (\kappa/e^2)(1-e)$, which is positive for any $e<1$; therefore at the solution $e=1$, which proves that the value-maximizing contract for the TTO contains fixed fees only.

To compare equity to royalty, we fix $F=0$. First, assume that the constraint $V^S(0,e,r)\ge 0$ is not binding. Then the derivatives of the objective function wrt to e and r are given by

$$\frac{\partial V^{\text{TTO}}}{\partial e} = -\frac{(m+\delta-c-r)^2}{8\delta} + \frac{\kappa}{e^2}\frac{m+\delta-c+r}{m+\delta-c-r},$$
$$\frac{\partial V^{\text{TTO}}}{\partial r} = e\frac{m+\delta-c-r}{4\delta} - \frac{r}{4\delta} - \frac{2\kappa}{e}\frac{m+\delta-c}{(m+\delta-c-r)^2}.$$

The first-order conditions imply that the maximum occurs at $e^2 = 8\delta k((m+\delta-c+r)/(m+\delta-c-r)^3)$. At this point the second equation becomes $\partial V^{\text{TTO}}/\partial r = -(r/(4\delta))(1-(8\kappa\delta/e(m+\delta-c-r)^2))$. Since $e \ge 8\kappa\delta/(m+\delta-c-r)^2$, this last expression is always negative for $r>0$, suggesting that the payoff is maximized at $e=\sqrt{8\delta k}/(m+\delta-c-r)$ and $r=0$. Second, assume that the constraint $V^S(0,e,r)\ge 0$ is binding. This allows us to eliminate e from the objective and the derivative of the objective wrt to r is given by $dV^{\text{TTO}}/dr = -(r/(4\delta))(1-(8\kappa\delta/e(m+\delta-c-r)^2))$, which again is negative for all $r>0$, suggesting that the optimal occurs at $r=0$. The second-order conditions in all cases confirm that the stationary point is indeed a maximum. □

Proof of Proposition 8. Since the feasible region is compact and all payoffs are continuous, an appeal to the Weierstrass Theorem proves the existence of a maximum for this problem. Since $\pi_i(r)=0$ for $r \ge m+\delta_h-c$, we can conclude that the optimal royalties will have to satisfy $r_N, r_M \le m+\delta_h-c$. The constraints $e_M, e_N \ge 0$ are redundant because they are implied by the individual rationality constraints. The payoff $U(F_M,F_N,e_M,e_N,r_M,r_N)$ is increasing in both F_N and F_M. Therefore, at least one of the individual rationality constraints should be binding. If it were not, the TTO could increase both F_N and F_M by the same amount, which would leave the incentive compatibility constraints unaffected but increase the payoff. As with the proof of the previous proposition, at optimum the IRN and ICM constraints are binding. These imply

$$F_N = e_N\pi_N(r_N) - \kappa\left(1+\log\frac{e_N\pi_N(r_N)}{\kappa}\right) - C,$$
$$F_M = e_M\pi_M(r_M) - e_N(\pi_M(r_N)-\pi_N(r_N)) - \kappa\left(1+\log\frac{e_M\pi_M(r_M)\pi_N(r_N)}{\kappa\pi_M(r_N)}\right) - C,$$

respectively. The value for the TTO that deals with an M-type or N-type spin-off can be written as

$$U_M(e_M,e_N,r_M,r_N) = e_N(\pi_N(r_N)-\pi_M(r_N)) + \pi_M(r_M) + \left(1-\frac{\kappa}{e_M\pi_M(r_M)}\right)r_M\bar{Q}_M \cdot (r_M) + \kappa\left(1-\frac{1}{e_M}\right) - \kappa\left(1+\log\frac{e_M\pi_M(r_M)\pi_N(r_N)}{\kappa\pi_M(r_N)}\right) - C,$$
$$U_N(e_N,r_N) = \pi_N(r_N) + \left(1-\frac{\kappa}{e_N\pi_N(r_N)}\right)r_N\bar{Q}_N(r_N) + \kappa\left(1-\frac{1}{e_N}\right) - \kappa\left(1+\log\frac{e_N\pi_N(r_N)}{\kappa}\right) - C,$$

respectively, where $\bar{Q}_i(r) = \theta_i Q_l(r) + (1-\theta_i)Q_h(r)$. Similarly, the IRM constraint can be written as $\kappa\log(\pi_N(r_N)/\pi_M(r_N)) + e_N(\pi_M(r_N)-\pi_N(r_N)) \ge 0$, and the constraint $F_N \ge 0$ can be written as $e_N\pi_N(r_N) - \kappa\log(e_N\pi_N(r_N)/\kappa) \ge C+\kappa$. We ignore the ICN constraint (which holds at first best) and the constraint $F_M \ge 0$ for now. We will check that they are satisfied at the end. The problem becomes

$$\begin{aligned}\underset{e_M,e_N,r_M,r_N}{\text{maximize}}\quad & U(e_M,e_N,r_M,r_N) = (1-\beta)U_M(e_M,e_N,r_M,r_N) + \beta U_N(e_N,r_N)\\ \text{s.t.}\quad & \kappa\log\frac{\pi_N(r_N)}{\pi_M(r_N)} + e_N(\pi_M(r_N)-\pi_N(r_N)) \ge 0,\\ & e_N\pi_N(r_N) - \kappa\log\frac{e_N\pi_N(r_N)}{\kappa} \ge C+\kappa,\\ & e_N - 1 \le 1,\ r_M \ge 0,\ r_N \ge 0.\end{aligned}$$

Note that e_M only appears in the constraint $e_M \le 1$ and $\partial U/\partial e_M = (\kappa/e_M^2)(1-e_M) + r_M(\bar{Q}_M(r_M)/\pi_M(r_M))$, which is positive for any $e_M<1$. Therefore, the objective is maximized at $e_M=1$. Similarly, r_M only appears in the constraint $r_M \ge 0$. At $e_M=1$, $\partial U/\partial r_M = -(\kappa/\pi_M(r_M))(\bar{Q}_M(r_M))^2 + (1-\kappa/\pi_N(r_M))r_M\bar{Q}'_M(r_M)$ is negative for any $r_M>0$. Therefore, the objective is maximized at $r_M=0$.

We are left with the following constrained optimization problem:

$$\begin{aligned}\underset{e_N,r_N}{\text{maximize}}\quad & U(e_N,r_N) = (1-\beta)U_M(e_N,r_N) + \beta U_N(e_N,r_N)\\ \text{s.t.}\quad & h_1(e_N,r_N) = \kappa\log\left(\frac{\pi_N(r_N)}{\pi_M(r_N)}\right) + e_N(\pi_M(r_N)-\pi_N(r_N)) \ge 0,\\ & h_2(e_N,r_N) = e_N\pi_N(r_N) - \kappa\log\left(\frac{e_N\pi_N(r_N)}{\kappa}\right) - (C+\kappa) \ge 0,\\ & h_3(e_N,r_N) = 1-e_N \ge 0,\\ & h_4(e_N,r_N) = r_N \ge 0.\end{aligned}\tag{8}$$

We proceed to show that $r_N=0$ cannot be a solution, i.e., that the constraint $h_4 \ge 0$ cannot be binding. The Lagrangian of the problem is given by $L = U(e_N,r_N) + \lambda_1 h_1(e_N,r_N) + \lambda_2 h_2(e_N,r_N) + \lambda_3 h_3(e_N,r_N) + \lambda_4 h_4(e_N,r_N)$, and the Karush–Kuhn–Tucker (KKT) conditions of this problem at $r_N=0$ can be written as

$$(1-\beta-\lambda_1)(\pi_M(0)-\pi_N(0)) = \beta\kappa\frac{1-e_N}{e_N} + \lambda_2\left(\pi_N(0)-\frac{\kappa}{e_N}\right) - \lambda_3,$$

$$\beta\frac{\bar{Q}_N(0)\kappa}{e_N\pi_N(0)}(1-e_N) = (1-\beta-\lambda_1)\bigg[\bar{Q}_M(0)\bigg(e_N-\frac{\kappa}{\pi_M(0)}\bigg) - \bar{Q}_N(0)\bigg(e_N-\frac{\kappa}{\pi_N(0)}\bigg)\bigg] + \lambda_2\bar{Q}_N(0)\bigg(\frac{\kappa}{\pi_N(0)}-e_N\bigg)+\lambda_4,$$

with $\lambda_i \geq 0$, $h_i \geq 0$, and $\lambda_i h_i = 0$ for $i \in \{1,2,3,4\}$. Further to $r_N = 0$ at most one constraint can be binding. We check all four cases in turn. First, no other constraint is binding, therefore $\lambda_4 \geq 0$ and $\lambda_1 = \lambda_2 = \lambda_3 = 0$. The two equations above imply that

$$(1-\beta)\frac{e_N\pi_M(0)-\kappa}{\pi_N(0)\pi_M(0)}(\theta_M-\theta_N)Q_h(0)Q_l(0)(\delta_l-\delta_h)=\lambda_4.$$

Since the LHS is negative this condition cannot satisfy $\lambda_4 \geq 0$. Second, we assume that $h_1 = 0$, therefore $\lambda_1 \geq 0$ and $\lambda_2 = \lambda_3 = 0$. The KKT equations imply

$$(1-\beta-\lambda_1)(\pi_M(0)-\pi_N(0)) = \beta\kappa\frac{1-e_N}{e_N} \quad \text{and}$$

$$(1-\beta-\lambda_1)\frac{e_N\pi_M(0)-\kappa}{\pi_N(0)\pi_M(0)}(\theta_M-\theta_N)Q_h(0)Q_l(0)(\delta_l-\delta_h)=\lambda_4.$$

The first equation implies that $\lambda_1 < 1-\beta$, whereas the second equation implies $\lambda_1 > 1-\beta$, which is a contradiction. Third, we assume that $h_2 = 0$, therefore $\lambda_2 \geq 0$ and $\lambda_1 = \lambda_3 = 0$. The KKT conditions imply

$$(1-\beta)\frac{e_N\pi_M(0)-\kappa}{\pi_N(0)\pi_M(0)}(\theta_M-\theta_N)Q_h(0)Q_l(0)(\delta_l-\delta_h)=\lambda_4,$$

which violates $\lambda_4 \geq 0$. Finally, assume that $h_3 = e_N - 1 = 0$, therefore $\lambda_3 \geq 0$ and $\lambda_1 = \lambda_2 = 0$. The KKT conditions imply $(1-\beta)(\pi_M(0)-\pi_N(0)) = 0$ which violates the assumption that $\pi_M(0) > \pi_N(0)$. Therefore, any separating equilibrium cannot have $r_N = 0$.

Finally, we need to check that for $r_N > r_M = 0$ and $e_M = 1$ the two omitted constraints (ICN and $F_M \geq 0$) are also satisfied. Substituting for F_N and F_M, ICN can be written as $u(0) - u(r_N) \geq 0$ where $u(r) = (\pi_M(r)-\pi_N(r)) - \kappa\log(\pi_M(r)/\pi_N(r))$. Therefore, ICN is satisfied if $u(r)$ is a decreasing function of r for all $r \leq m+\delta_h - c$. Indeed this is the case since

$$\begin{aligned} u'(r) &= \bar{Q}_M(r)\bigg(\frac{\kappa}{\pi_M(r)}-1\bigg) - \bar{Q}_N(r)\bigg(\frac{\kappa}{\pi_N(r)}-1\bigg) \\ &\leq \bar{Q}_M(r)\bigg(\frac{\kappa}{\pi_N(r)}-1\bigg) - \bar{Q}_N(r)\bigg(\frac{\kappa}{\pi_N(r)}-1\bigg) \\ &= \frac{\bar{Q}_M(r)-\bar{Q}_N(r)}{\pi_N(r)}(\kappa-\pi_N(r_N)) < 0, \end{aligned}$$

where we have used the fact that for all $r \leq m+\delta_h - c$ the following inequalities hold: $\pi_M(r) \geq \pi_N(r)$, $\bar{Q}_M(r) \geq \bar{Q}_N(r)$, and $\kappa < \pi_N(r)$. To show that $F_M > 0$, we start from ICN and substitute for F_N to get $F_M \geq \pi_N(0) - \kappa[1+\log(\pi_N(0)/\kappa)] - C$. The right-hand side is the value of the N-type spin-off that retains 100% of the equity and does not pay any royalties or fixed fees and it is nonnegative by assumption. □

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