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Abstract

In this paper a Developer contracts with a Researcher for the production of a non-drastic innovation. Since effort is non-contractible, the Developer offers an incentive contract dependent on the observed magnitude of the innovation. It is shown that the distribution of intellectual property rights (IPR) ownership does not affect the level of effort exerted for innovations where the Developer would choose to license the innovation to its competitors. This is because the possibility of leakage of the innovation through licensing subsidies the Developer's payment when IPR is delegated to the Researcher, while at the same time eroding its profit.

Key words: Innovation, Intellectual Property Rights, Licensing

JEL Classification: D23, L24

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1 Introduction

Innovation and technology are matters of ongoing importance in developed countries. There has been a great deal of research on incentives to undertake research and development, protection of the resultant intellectual property rights (IPR) by patenting or trade secrets, and licensing or knowledge sharing of innovations.[1] However, there has recently been greater focus on the way that innovators are compensated, since there is an increasing reliance of R&D intensive industries on outside research.[2] Issues of bargaining strength, ownership of IPR and the propensity for innovators to leak knowledge to parties outside a contract are at the focus of recent work. This paper contributes by examining the impact of the ownership of the IPR to an innovation on the incentive contract between developers and researchers.

Innovation creates knowledge, which has the peculiar nature of being durable, non-rivalrous in consumption and partially excludable. Durability means that once a party obtains knowledge, it does not wear out or depreciate making it difficult to commit to not using wherever it has value. Non-rivalrous in consumption means that different parties may use the knowledge simultaneously. Partial excludability implies that appropriation of the benefits of an innovation is problematic since the strength of property rights may vary considerably. These properties ensure that IPR plays a central role in the contracts written between a developer and researcher, since innovation knowledge can be leaked to parties outside of the contract.

An innovation contract in this paper involves a compensation wage, and an assignment of ownership of the IPR that results. Despite the capital intensity of most research programs, wages paid to researchers represent the largest component of R&D expenditures, averaging around 50% of total R&D expenditures in OECD countries (Public Support for Science and Innovation, PC Research Report 2007, pg. 588). Moreover, there is ample evidence of incentive contracting between large research intensive firms and innovators.[3] However, there

[1]See for example, Scotchmer (2004), Anton and Yao (2002, 2004), Gallini and Wright (1990), Kamien and Tauman (1986) and Wang (1998).

[2]See for example Lai, Riezman and Wang (2009), Veraevel and Vencatachellum (2009) and Martimort, Poudou and Sand-Zantman (2010).

[3]Lerner and Wulf (2006) empirically investigate the link between compensation of research personnel to the objectives of large US corporations.

is little theoretical attention on the wage contracting arrangements in innovation markets. The second part of an innovation contract, ownership, is crucial because it bestows the right to license new technologies, an important source of revenue for the holders of the IPR. One estimate of the market for innovation licensing in the software industry puts the figure at $US100 billion in 2003 (see Bhattacharya et al (2006)).

For a developer, the process of obtaining innovation knowledge is plagued by at least two agency problems. The first is a moral hazard problem of unobservable and non-verifiable effort. The second is a *leakage* problem that results because innovation knowledge is durable, partially excludable and non-rivalrous. In this paper, the first agency problem is tackled with the usual incentive contract approach. The second agency problem is avoided by assuming perfectly enforceable property rights, and that ownership rights can be assigned in a contract before the innovation is created.[4]

The model consists of a Development Unit (DU, for example, a pharmaceutical company, or a Silicon Valley firm) who enters into a contract with a Research Unit (RU, for example, a biotechnology laboratory, or a software designer) for the creation of an innovation. The DU is assumed not to have expertise in the RU's field, or the ongoing need for its skills to justify integration as an ownership configuration. Alternatively, the RU owns a bundle of complementary skills or assets that warrant a vertically separated structure.[5]

While each party may hold IPR for existing innovations, at the time of contracting the exact specification of the innovation to be created in the contract is unknown. As such, the RU has no bargaining power, since there are many RUs that could perform the research task. Moreover, the DU provides the framework for the innovation to be generated in: without this framework, the RU could not independently create the innovation. The question of this paper is then: under what conditions would the DU prefer to retain control over the IPR and residual control rights to licensing?

One reason for asking this question is concerned with the power of the incentive contract that the DU can offer. Since it retains all the bargaining power, any trade gains can be

[4]The alternative would be to model the imperfect protection that patents infer as in Lemley and Shapiro (2005), who examine the implication of uncertain property rights under patenting, or "probabilistic patents".

[5]See the incomplete contracting literature: Grossman and Hart (1986), Hart and Moore (1988).

transferred to it through ex post lump sums. However, more total producer surplus could be generated if the RU is given high powered incentives to work. Such incentives could come through entitlement to the stream of revenue from licensing the innovation to other DUs in the industry.

It is the uncertain nature of R&D and the inability of the DU to observe and verify the RU's action, or research effort, that necessitates the use of incentive contracting. In this respect, the model is not different from many other Principal-Agent relationships. Usually the interaction between the principal and the agent results in surplus that can be divided in some way between the two, according to a predetermined rule or contract. For example, in Holmstrom's (1979) example of a machine repairman whose unobservable action influences the expected time before the machine breaks down, the surplus generated is the expected net value of the production when the machine is put in use. The demand for the repairman's services is a derived demand extending from the principal alone. Unlike Holmstrom's example however, the agent's effort in this model confers two benefits: an internal and an external demand for the RU's services. The internal demand stems from a direct payoff to the Principal from utilising the resulting innovation. This is analogous to the result of the efforts of the repairman. Note that the incentives for the repairman depend only on the *explicit* incentives he faces as controlled by the Principal. Where the present model departs from the standard framework is in the incorporation of a second source of benefit from the RU's services: an external demand for the RU's innovation efforts from the DU's competitors. This provides an *implicit* incentive that is out of the control of the DU. Now the RU's efforts produce a new technology that has value not just to the DU, but also other actors in the DU's output market. So to completely describe the contracting environment, the assignment of the residual control rights, or the ownership of the IPR, will need to be considered. If the DU delegates IPR to the RU, then the RU faces both an *explicit* incentive through the incentive contract from the DU, and an *implicit* incentive through the private return it can receive through licensing of the new technology to consumers other than the DU.

Hence, for the DU, retaining control of the IPR may be inefficient in terms of eliciting effort from the RU. On the other hand, turning control of the IPR over to the RU results in innovations that could be licensed to its own competitor's, thus reducing its profitability in the output market. The results of this paper show that firstly, whenever an innovation would be profitable for the DU itself to license, ownership of the IPR is irrelevant. The reduction in the DU's expected profit from assigning IPR to the RU is offset by an exact reduction in its expected payment to the RU. Second, whenever the marginal licensing revenue of the innovation is greater than the reduction in the value of the innovation to the DU from allocating IPR to the RU, the DU prefers to retain the IPR for the innovation; in which case it will choose not to license.

The next section of the paper briefly reviews the related literature. Section 3 sets up the incentive contracting model and derives the optimal wage contract. Section 4 presents the main ownership equivalence result when the DU would leak the innovation through licensing itself, and section 5 demonstrates the conditions under which ownership matters. Section 6 provides an example of the results in the context of a product differentiation model, and the last section concludes.

2 Relation to the Literature

Much of the vast literature on innovation contracting and management is dedicated to assessing the impact of the legal strength and ownership of IPR on incentives under different informational environments. Broadly speaking, the innovation literature that deals with incentive theoretic issues can be divided into two streams: one where the informed party takes the initiative, and one where the uninformed party takes the initiative.[6]

The informed party takes the initiative in the signalling models of Bhattacharya and Ritter (1983), Gallini and Wright (1990), Anton and Yao (2002, 2004) and its extension Bhattacharya and Guriev (2006). The form that the signal can take differs among these papers. For example, the innovator's decision to publicly disclose knowledge through patenting in Bhattacharya and Ritter signals the economic value of the innovation to an external financier, while at the same time eroding its advantage over its competitors through leakage and imitation. In fact, the decision to disclose knowledge through a formal patent system or rely on common law and trade secrets depends on the legal IPR strength that patenting

[6] Such a distinction is used by Salanie (2005) to classify families of contract theory models (pg. 4).

confers to the innovator. This was studied in Anton and Yao (2002, 2004) and Bhattacharya and Guriev (2006). In Gallini and Wright, the structure of the licensing contract under asymmetric information serves as a signal of the licensor's pre-contractual information about the value of the innovation, a feature that is also examined in Martimort, Poudou and Sand-Zantman (2010). It is the possibility of imitation, or the strength of IPR that generate the results in all these papers.

The uninformed party takes the initiative through use of incentive contracts in the models of Bhattacharya, Glazer and Sappington (1992), Veraevel and Vencatachellum (2009), Lai, Riezman and Wang (2009) and Martimort, Poudou and Sand-Zantman (2010). The latter of these papers is a model of double sided asymmetric information. On one side, the innovator has private knowledge of the value of its innovation which it attempts to signal through contract form to a developer who must be incentivised to exert efficient effort by the same contract.[7] The optimal mode of licensing is studied in Bhattacharya, Glazer and Sappington, where entry fees into a research joint venture with simultaneous innovators can influence the degree of information sharing and effort levels. In their model, the innovators first produce an innovation, then compete with each other in a final output market. This is similar to Veraevel and Ventachellum's model where duopolists competing in an output market simultaneously innovate, however in their model the innovation is outsourced to a common R&D laboratory, which is compared to the benchmark of in-house innovation. In both cases, the degree to which the informed party can benefit from spill-overs determines to some extent the organisational form of the industry. In contrast, this paper starts out assuming that innovation is delegated to a researcher, and evaluates how assignment of IPR is relevant to the contract. The study that bears the most similarity to this endeavour is that of Lai, Riezman and Wang's (2009) model of innovation outsourcing.

At the heart of Lai et al (2009) lies the agency problem of leakage, where the researcher cannot commit (in general) to not exploit their knowledge. However, leakage does not emerge as an agency problem in this paper. Rather, the problem is analysed here as the external source of benefit in the contracting environment, and access to this external demand is

[7] Hence, Martimort, Poudou and Sand-Zantman (2010) really have both informed and uniformed parties taking initiative.

through leaking the innovation through the legitimate means of licensing. Like Lai et al (2009), this paper uses an incentive theory approach where the developer has all the bargaining power. They ask whether a developer wishing to develop a cost-reducing innovation should organise their innovation activities using an in-house research team, or outsource to an independent research team. So the ownership of the IPR is implicitly a choice variable in their problem. In essence, they investigate a make-or-buy decision for R&D contracts. In contrast, the present analysis takes as given a vertical industry structure - there is no question of innovating in-house.

Unverifiable leakage of knowledge leads to Lai et al (2009)'s central trade-off: the cost of outsourcing R&D, or the erosion of the developer's profit through leakage of the innovation knowledge, is weighed against the increase in efficiency of innovation from employing a specialist researcher. As a result, Lai et al (2009) find that the optimal incentives take the form of a revenue sharing contract. This arises because it is a mechanism that aligns the researcher's incentives with the developer's: the researcher is less likely to leak the innovation knowledge if it has a claim to a share of the developer's profit if leakage is harmful to the developer. If the balance of the effects falls in favour of the efficiency of the researcher, then outsourcing is the equilibrium outcome. Otherwise, the researcher prefers an in-house arrangement.

Unlike Lai et al (2009), this paper begins by assuming that the developer is in the business of licensing its new technology to competitors. Hence, the literature exemplified by Wang (1998) on insider patentees comes to bear on the investigation. Whenever it is optimal to license the innovation, the developer would choose to do it. IPRs are therefore formalised in this paper and play a fundamental role in determining who benefits directly from licensing, and the magnitude and determinants of the optimal incentive contract. Both the results of this paper and Lai et al (2009) imply a dependency of the optimal marginal incentive coefficient on the total revenue generated by the innovation. Hence, the incentives theory framework of both papers shed light on the determinants of the optimal incentive contract and the most efficient IPR ownership arrangement. The papers are however limited in situations where the researcher has some bargaining power and there is contractual incompleteness. Aghion and Tirole (1994) employ an incomplete contracting approach to deal with that case.

In this paper, the impact of IPR ownership with leakage is investigated in a model with linear incentive contracts. Specifically, the Linear-Exponential-Normal framework of Holmstrom and Milgrom (1987), (1991), as augmented by Laffont and Martimort (2002), is used here to outline a Principal-Agent problem. Their models feature a linear compensation wage that the Principal (developer) offers to the Agent (researcher). Moreover, the functional form of the researcher's utility is assumed to exhibit Constant Absolute Risk Aversion (C.A.R.A), with r defined to be the Arrow-Pratt absolute measure of risk aversion. Finally, the developer receives a noisy signal about the researcher's effort level, e, rendering effort a non-contractible variable. The noise is additive and assumed normally distributed. This framework requires a linearisation of the researcher's payoff in order to obtain explicit solutions for the contract.

3 Analytical Framework

This section employs a Principal-Agent model to establish a framework for analysing the delegation of the IPR. The framework allows for a comparison of the structure of the incentive contract that the DU offers the RU under the different ownership arrangements. First, the model is set up carefully to include the internal and external benefits from the creation of an innovation. Then individual rational and incentive compatible constraints are formalised taking into account the two sources of benefit. Finally, the optimal incentive contract is derived, and its properties evaluated in the conclusion to the section.

The risk neutral principal, or Development Unit (DU) and risk averse agent, or Research Unit (RU) enter a contractual arrangement to produce an innovation of magnitude indexed by $\theta \in \mathbb{R}$. The units of the measure of the index depend on the context of the innovation. For instance, for technological innovations, θ may measure the reduction in marginal cost when using the innovation. For product quality-improving innovations, θ may be a parameter in the consumers' utility function.

The innovation may be valuable to both DU and its competitors, the latter to whom it can be sold, or patented and licensed by the holder of the Intellectual Property Rights (IPR) of the innovation. The parameter τ, $0 \leq \tau \leq 1$ reflects the degree to which the innovation can be passed on to the DU's competitors. Equivalently, τ is a measure of the specificity of the innovation to the DU. If the nature of the innovation that is contracted for is firm-specific, then $\tau = 0$, and clearly none of the DU's competitors would purchase a license to use it. On the other hand, if the innovation is of a very general nature or common to the technology that each of DU's competitors have installed, then $\tau = 1$ and the innovation is valuable to the DU's competitors. For all other values of τ, only part of the full innovation that the DU can use can be implemented by its competitors.[8]

Innovation IPR is a valuable by-product of the RU-DU relationship. The IPR can be used to generate revenue in two ways: directly as a result of the DU's increased competitiveness in the output market, and indirectly through extracting rents created from competing firms using the innovation to produce in the output market. IPR, being a knowledge good, is durable. Hence, the RU team members who create the innovation retain the knowledge of the process of inventing the innovation. Hence, while the product of the knowledge can be legally defined as a property right, it is possible that the information from the IPR can be transferred both formally and informally through the RU's other activities.

To be explicit, even in the case that the RU does not retain the IPR from its relationship with the DU, it may use its experience to develop an innovation for one of the DU's downstream competitors at a small cost. Alternatively, the RU may overtly re-sell the innovation to the DU's competitors, whether it infringes on a patent, or imitates the technology in a way that does not infringe on IPR. In light of this, it is reasonably assumed that the only way the DU can protect its IPR, or appropriate the rents from its licensing, is if it incurs a cost of identifying infringements and enforcing the IPR. Moreover, the RU's expertise allows it to engage in the same activities for a negligible cost. Because of this, the RU can never credibly commit to not *leaking* the IPR to the downstream competitors, unless the DU patents and enforces the IPR of the innovation.

Hence the IPR can be patented at some cost and licensed, or kept as a trade secret

[8]A justification for use of this device can be found in Lai et al (2009). Their paper identifies *adaptability* of the outsourced innovation to the production firms' environment as a feature of R&D activity. Although in the context of their paper, adaptability refers to the relative ease with which an informed in-house team can adapt an innovation compared to an outsourced R&D team. The parameter τ can be thought of as a measure of relationship-specific investment, although it is taken to be exogenous in the model.

and leaked through the channels mentioned above. In either case, the revenue from the transactions over the new technology will be referred to as licensing. License revenue is denoted $l(\theta, \tau)$. In order to compute an explicit solution to the incentive problem, it is necessary to use a first order approximation to the license revenue:

$$l(\theta, \tau) \approx \kappa(\tau)\theta, \qquad \kappa(\tau) \geq 0 \tag{3.1}$$

where $\kappa(\tau)$ is a measure of the aggregate incremental value of a unit of innovation to the DU's competitors: the marginal licensing revenue. The marginal license revenue is non-decreasing in the degree of firm specificity of the innovation, $\kappa'(\tau) > 0$.

The RU can only produce *non-drastic* innovations. A drastic innovation is defined as one where, in maximising its profit, the innovator can drive the other firms out of the market with its new technology. It follows that a non-drastic innovation does not result in all firms being driven from the market. While it is not essential to the results presented here, it will be assumed that no firm is driven from the market as a result of adoption by one or many competitors of an innovation technology.

It is conceivable that large innovations should emerge in different industry structures than the one considered here. For example, RUs can be contracted by a DU after already developing an innovation, or having some R&D at interim stages of development. In those situations, typically a bargaining framework is used, and the mechanics of incomplete contract theory are relied on to determine optimal ownership arrangements. While ruling out drastic-innovations may reduce the scope of this analysis, it is in accord with the other assumptions of the model. In particular, the modeling framework requires a degree of linearity that is best implemented by considering only small deviations from the initial optimum.

The RU has a linear innovation technology, where every unit of effort that it exerts, e, translates into a unit of innovation, up to the realisation of a random outcome:

$$\theta = e + \varepsilon \tag{3.2}$$

where ε is a random variable normally distributed with mean zero, $\varepsilon \sim N(0, \sigma^2)$. As a result of the random variable in the innovation technology, the realised size of the innovation is only a noisy signal of the agent's effort level. Hence, effort is unobservable and non-verifiable by a third party so that no contracts can be written directly on the RU's effort. However, since effort controls the mean of the innovation technology, contracts can be written on the innovation signal θ, which is positively correlated with effort.

The terms of the contract specify a money payment to the RU contingent on the size of the innovation. The compensation is linear in the innovation: $w(\theta) = \alpha\theta + \beta$, where α is the strength of the marginal effort incentives provided by the DU, and β is a fixed income to insure the RU against the uncertainty in the innovation technology. The strength of the α coefficient, which is the DU's control variable, determines the power of the incentive provided for the RU's task. The total money cost of producing an innovation is $C(e)$, which is assumed strictly increasing and convex in effort level. It is also assumed that $C(0) = 0$, $C'(0) = 0$ and $\lim_{e\to\infty} C(e) = +\infty$.[9] The expected value of the RU's payoff is then $w(\tilde{\theta}) + \lambda l(\tilde{\theta}, \tau) - C(e)$, with the expectation taken over ε. The binary variable λ indicates ownership of the IPR of the innovation. If the RU owns the IPR then $\lambda = 1$, otherwise the DU owns the IPR and $\lambda = 0$.

The DU's ex post payoff from R&D is denoted as $V(\theta, \tau)$. The benefit to the DU consists of the incremental direct profit, $\Delta\hat{\pi}(\theta, \tau)$, that it makes from selling in the output market with its new innovation-augmented technology, and the license revenue if it is the owner of the IPR. Regardless of who licenses the innovation, if the innovation is of value to the DU's competitors then it is assumed to erode the direct profit of the DU. Later on, to obtain an explicit solution for the incentive coefficients, the first order approximation for the DU's ex post benefit from producing with the innovation is employed: $\Delta\hat{\pi}(\theta, \tau) = \Delta\pi(\tau)\theta$ for any $\tau \in [0, 1]$. The risk neutral DU's expected profit becomes:

$$\mathbb{E}_{\tilde{\varepsilon}} V(\theta, \tau) = \int_{-\infty}^{+\infty} (\Delta\hat{\pi}(e + \varepsilon, \tau) + (1 - \lambda) l(e + \varepsilon, \tau) - w(e + \varepsilon)) dF(\varepsilon) \tag{3.3}$$

The timing of the model is illustrated in Figure (1) and summarised as follows: at date 0, the DU offers the RU a linear compensation wage, $w(\theta)$ and specifies the ownership mode of any IPR that is created; at date 1, the RU accepts or rejects the offer; at date 2, the RU exerts an effort e to produce an innovation according to its innovation technology; at date 3 the innovation outcome θ is realised; at date 4 the owner of the IPR chooses whether to

[9]These conditions ensure a positive finite amount of effort is exerted at the optimum.

license the innovation; at date 5 all output market transfers and production decisions are made, and the contract is executed. To operationalise the model, some specific functional

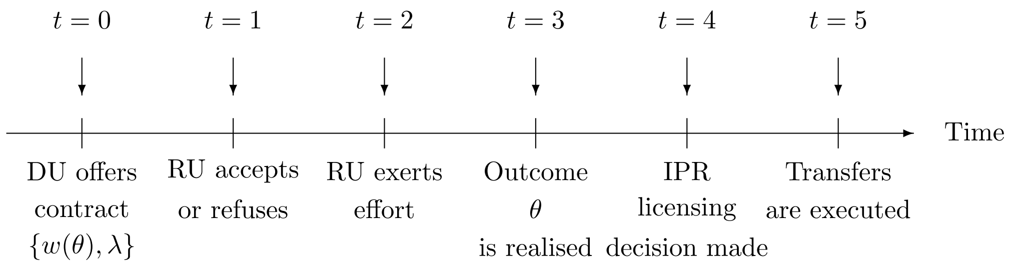

Figure 1: Timing

forms are introduced. First, a quadratic form is used for the RU's effort cost: $C(e) = \frac{1}{2}e^2$. Note that $C(e)$ satisfies all the restrictions mentioned above. The RU's attitude to risk is characterised by C.A.R.A. When it accepts the DU's incentive contract, it is exposed to uncertain variation in its wage due to the innovation shock. Hence, it is possible to define the certain amount of wealth, w_{CE}, that makes the RU indifferent to taking, or accepting the gamble of the DU's incentive contract; ie. its certainty equivalent:

$$u(w_{CE}) = \mathbb{E}_{\tilde{\varepsilon}} u(w(\theta) - C(e) + \lambda l(\theta, \tau)) \tag{3.4}$$

where the agent's utility function $u(.)$ defined over wealth, w, is C.A.R.A, with $u(w) = -e^{-rw}$, where r is the Arrow-Pratt measure of absolute risk aversion. Note that the agent's effort cost is defined in money terms, and so this is a case of non-separable utility (see Laffont and Martimort (2002), Ch. 5.2.3).

In order to induce the RU to accept the contract, the DU must offer it a level of expected utility equivalent to its reservation utility, or its opportunity cost. This is equivalent to guaranteeing the corresponding certainty-equivalent.

Lemma 1 *(Individual Rationality) Given the RU's utility function is C.A.R.A and defined over wealth, w, the RU's certainty equivalent defined in units of wealth is:*

$$w_{CE} = \beta + (\alpha + \lambda\kappa(\tau))e - \tfrac{1}{2}e^2 - \tfrac{r}{2}(\alpha + \lambda\kappa(\tau))^2\sigma^2 \tag{3.5}$$

Individual rationality requires $w_{CE} \geq \bar{w}$, where $\bar{w}$ is the RU's outside opportunity.

The individual rationality constraint alone does not provide incentives for the RU to exert effort. Since effort is unobservable to the DU and costly for the RU, the RU selects it in a way that optimises its utility from the R&D activity. This involves a balancing of the sources of revenue from the innovation and the personal effort cost incurred by the RU, while mitigating the risk inherent in the innovation technology. To this end, the RU will select a level of effort on its task to maximise the certainty equivalent payoff in equation (3.5). The RU's problem is:

$$e(\lambda) \in \arg\max_{e^* \geq 0} \left\{ \beta + (\alpha + \lambda\kappa(\tau))e^* - \tfrac{1}{2}e^{2*} - \tfrac{r}{2}(\alpha + \lambda\kappa(\tau))^2\sigma^2 \right\} \tag{3.6}$$

The solution to the RU's problem gives the incentive compatibility constraint for the DU. The DU anticipates the behaviour of the RU in choosing its level of effort, and should select the power of its incentive payment accordingly. Recognition of this leads to the following Lemma.

Lemma 2 *(Incentive Compatibility) In implementing the incentive feasible linear wage schedule, the DU is bound by the following constraint:* $\alpha(\lambda) + \lambda\kappa(\tau) = e(\lambda)$, $\lambda = 1, 0$.

The intuition for the incentive constraint is straightforward: the RU selects a level of effort where its marginal benefit in units of wealth is equal to the marginal cost of exerting effort, e, measured in units of wealth. When the RU retains the IPR of the innovation, it is rewarded at the margin for the last unit of effort exerted partly through the reward scheme, α, and partly through its private return from license revenues, $\kappa(\tau)$.

The DU's problem can be written as:

$$\max_{\{\alpha,\beta,e\}} \left[\mathbb{E}_{\tilde{\varepsilon}}(\Delta\pi(\tau)\theta + (1-\lambda)l(\theta,\tau)) - w(\theta)\right], \quad \text{s.t Lemmata (1) and (2)} \tag{3.7}$$

In the Principal-Agent relationship, the DU has all the bargaining power which means the IR constraint will always bind. If the DU leaves the RU with any wealth over its certainty equivalent from entering the relationship, then the RU's expected utility is higher than the utility of its certainty equivalent. Then it would always be possible for the DU to reduce its payment to $w(\theta) - \epsilon$, for an $\epsilon > 0$ and still induce the RU to sign the contract. Using the fact that the IR and IC are binding at the optimum solution for effort profiles, the problem can be rewritten as a maximisation of the choice of incentive coefficient α only. First, using the IC condition in Lemma (2) to eliminate effort choices from the certainty-equivalent wage in Lemma (1) yields:

$$w_{CE} = \beta + \tfrac{1}{2}(\alpha + \lambda\kappa(\tau))^2(1 - r\sigma^2) \geq \bar{w}$$

Since this equation binds at the reservation certainty-equivalent level $\bar{w}$, an expression of the fixed income component of the linear compensation wage, β, can be recovered. Now replacing the new expression for the certainty equivalent wage in program (3.7) yields:

$$\max_{\{\alpha\}} \left[\mathbb{E}_{\tilde{\varepsilon}}(\Delta\pi(\tau)(\alpha + \lambda\kappa(\tau)) + (1-\lambda)l(\theta,\tau)) - \bar{w} + \tfrac{1}{2}(\alpha + \lambda\kappa(\tau))^2(1 - r\sigma^2) - \alpha(\alpha + \lambda\kappa(\tau))\right] \tag{3.8}$$

The DU's program in (3.8) is concave. The unique solution gives the optimal incentive coefficient $\alpha^*(\lambda)$, from which the general linear compensation wage can be constructed:

Proposition 1 *(Optimal Linear Compensation Wage) The unique solution to the DU's program in (3.8) yields a linear incentive compensation wage given by:* $\{\alpha^*(\lambda), \beta^*\}$, *where:*

$$\alpha^*(\lambda) := max \left\{ \frac{\Delta\pi(\tau) + (1-\lambda)\kappa(\tau) - \lambda\kappa(\tau) r\sigma^2}{1 + r\sigma^2}, 0 \right\} \quad \& \quad \beta^* := \bar{w} + \tfrac{(r\sigma^2 - 1)}{2} \left(\frac{\Delta\pi(\tau) + \kappa(\tau)}{1 + r\sigma^2} \right)^2$$

where $\lambda = 1$ *for RU IPR ownership, and* $\lambda = 0$ *for DU IPR ownership.*

The optimal incentive coefficient $\alpha^*(\lambda)$ depends on both the internal and external demands for the innovation, and the risk aversion parameters of the RU's utility. As usual, when the risk aversion parameter r and the variance of the innovation shock, σ^2 are large, the DU optimally shades the strength of the marginal incentive coefficient. This is to shield the risk averse RU from the full uncertainty in the innovation production, while still forcing the RU to bear some of the risk so as to align their incentives with those of the DU. The risk aversion parameters can be assumed to take values such that $r\sigma^2 > 1$, without impacting on the results. Then an increase in r or σ^2 also raises the fixed component of the wage, β. This is the standard insurance versus incentives trade-off in the moral hazard literature.

The magnitude of the marginal incentive coefficient, $\alpha^*(\lambda)$, reflects the value to the DU from the RU's effort. If the IPR is retained by the DU, then it appropriates the internal value $\Delta\pi(\tau)$ as well as the external value $\kappa(\tau)$ from leaking the IPR through licensing. As such, to optimally align the explicit incentives of the RU with the DU, α incorporates the full value of both these sources of benefit, $\Delta\pi(\tau) + \kappa(\tau)$, appropriately shaded for risk by $1 + r\sigma^2$: $\alpha^*(0) = \frac{\Delta\pi(\tau)+\kappa(\tau)}{1+r\sigma^2}$. In contrast, when the IPR of the innovation is delegated to the RU, the DU only appropriates the internal benefit from its direct profit $\Delta\pi(\tau)$. Hence, the DU only explicitly incentivises the RU's effort for that value, and not for the license revenue. Moreover, since the RU now faces an implicit incentive through leaking the innovation to the external market, the DU can lower the marginal incentive coefficient: $\alpha^*(1) = \frac{\Delta\pi(\tau)-r\sigma^2\kappa(\tau)}{1+r\sigma^2}$. So under IPR delegation, the RU bears the risk for the effort to satisfy the internal demand for its services, for which it is partially insured and rewarded explicitly by the DU. It is also bears some risk itself for the effort that it exerts to satisfy the external demand, for which it is not insured, but is rewarded implicitly through the marginal licensing revenue it receives.

Proposition (1) also reports that the optimal marginal incentive coefficient cannot be negative. A negative marginal incentive implies that the RU would have to provide payments to the DU for provision of its own efforts.[10] To this end, incentive contracting is defined as *feasible* only if $\alpha(\lambda) > 0$ under the relevant ownership mode. Later in this paper the key results are studied in a product differentiation model. In that setting, feasibility of incentive contracting yields an IPR ownership result where only innovations whose value to the DU's competitors are small enough will be delegated.

In summary, it can be seen that the IPR delegation decision will affect the optimal incentive contract that the DU can offer the RU. Leakage through licensing is explicitly rewarded if the IPR belongs to the DU. Under delegation, leakage through licensing is not explicitly rewarded, but rather subsidises the DU's marginal wage bill. The next section draws out the implications of this subsidy on the total effort level of the RU, the wage bill for the DU under both ownership arrangements, and the impact in the DU's expected profit.

4 Weak Equivalence of Ownership

This section presents the main result of the paper using the optimal incentive contract derived in Proposition (1) in the previous section. Whenever it would be profitable for the

[10] Note that payments from the RU to the DU are ruled out by assuming that the RU is cash-constrained.

DU to license an innovation to its own competitors, an incentive contract to obtain such an innovation results in an invariance of the DU's expected payoff to delegation of IPR. This result is underpinned by three key assumptions: first, that the RU has superior information regarding the innovation technology. Second, the DU has all the bargaining power in the contract. Third, the DU is neutral to the risk in the creation of the innovation, whereas the RU is risk averse. Under these conditions, an IPR ownership invariance results.

The first key assumption gives rise to the agency problem. If the DU has perfect and complete information, then it would have no problem in implementing the first-best level of effort from an in-house research team with a simple discrete contract. In practice, R&D divisions use a large number of performance measures to monitor their workers' efforts. The literature on performance measures and R&D projects, (for example, see Bergmann and Friedl (2008)), identifies a number of non-financial performance measures for R&D managers. These include functionality points (particularly relevant for software companies), achievement of milestones, and achievement of efficiency and quality standards. This non-exhaustive list includes measures that can be directed at individual, team or workplace levels. Moreover, there is empirical support for the link between the use of such measures and successful innovation as documented in Kressens-van Drongelen and Bilderbeek (1999). The use of these performance measures in innovative activities is evidence that an agency problem exists.

The strong bargaining power assumption can be qualified by focusing attention on small innovations, like process innovations to reduce the marginal cost of a developed product, or quality innovations that capture small increments in market share. In these cases it is reasonable to assume that there are many RUs that are equally capable of undertaking the R&D, and so competition prevents them from earning rents. Notwithstanding, the bargaining power assumption is pertinent to the results that follow. Allowing the RU to have the ability to bargain, or making bargaining power endogenous to the contract is left for future research.

The validity of the assumptions on attitudes to risk can be justified on grounds of scale: typically, DUs are much larger entities than RUs, and have a correspondingly larger and more diverse asset base. As the innovations provided for in the contract are small relative to the size of the DU, they comprise only a small part of the risk profile of the DU, whereas, the RU is considered as a specialist in the area it is contracted for and is therefore not diversified. Even if the RU firm itself is diversified in an array of other projects, the research manager is assumed to care about the success of the innovation, not just its expected value.

These three key assumptions permit a closer examination of the determinants of IPR ownership on R&D incentives. In agency problems with only an internal benefit of the type described above, the power of the incentive contract is determined by a balance of provision of incentive for exertion of effort on one hand, and the need to insure the agent against the risk inherent in the contracted activity on the other. The same is true in the set up here: as has been noted, the optimal incentive contract involves a marginal incentive coefficient $\alpha(\lambda)$ that rewards the RU's marginal effort, and a fixed payment β that the RU receives regardless of the outcome of their activities (from Proposition (1)). However, unlike standard agency problems, both of these coefficients depend upon the internal and external demand for the innovation.

The degree to which the internal and external demands affect the marginal incentive depend on the delegation of IPR decision. Consequently, the magnitude of the optimal incentive coefficient, and the elicitation of RU effort through Lemma (2) both depend upon the delegation decision. To see this more clearly, note that ex ante, the DU has two control variables: it can choose to delegate IPR to the RU, or retain it. Secondly, it selects a level for the marginal incentive coefficient, or *explicit* incentives, conditional on the assignment of IPR.

It follows that if the DU wishes to raise the effort level of the RU, it has two feasible options. The first is to raise the value of α. Through Lemma (2), the RU optimally raises its effort in response, since for every dollar that the innovation generates in total to the DU, the RU receives a greater proportion. The second option is to delegate IPR to the RU. In doing this, the DU exposes the RU to the implicit incentive channel through the possibility to license the IPR in the output market. Then the RU receives a share of the profit realised by the DU in its output market, and all of the licensing revenue it can generate in the output market. Since it is only capturing the rent from its own profit, the internal benefit, the DU lowers the level of the marginal incentive coefficient. Inspection of the incentive coefficient in

Proposition (1) confirms that delegation of IPR ownership results in a lowering of the power of incentives, since $\alpha(1) - \alpha(0) = -\kappa(\tau)$. This expression points toward the result on the impact on the overall incentives facing the RU.

IPR delegation results in two competing effects on the overall level of incentives facing the RU. There is a reduction in the explicit incentive from the marginal incentive coefficient offered by the DU, by the full amount of the marginal licensing revenue. Simultaneously, there is an increase in the implicit incentive offered through the private market for the innovation. What then, is the overall impact on the effort level of the agent? Proposition (2) provides the answer:

Proposition 2 *With a linear incentive compensation wage, the RU's effort level is identical regardless of who owns the IPR:* $e(\lambda = 1) = e(\lambda = 0) = e^*$.

This Proposition shows that optimal effort level e^* that the RU exerts is invariant to the IPR ownership mode. This occurs because the DU has all the bargaining power in the contract relationship. As a result, the DU can hold the RU to its reservation certainty-equivalent. Delegation transfers licensing revenue from the DU's competitors away from the DU to the RU, but in doing so, accomplishes two things: (i) delegation perfectly crowds out the explicit marginal effort incentive, and (ii) delegation lowers the DU's total wage bill since it is paying less per unit of effort exerted than when it retains the IPR, and the same amount of effort is exerted. This means that under delegation, the overall incentives facing the RU are still determined by the internal and external demands. The difference is that the implicit external demand effect, which is positive under delegation, is completely offset by the reduction in the DU's explicit incentives. This intuition for Proposition (2) is the critical result of the analysis. Using this invariance of effort to IPR ownership, it is straightforward to prove that the DU's wage bill is lower under RU IPR. This is demonstrated below in Lemma (3):

Lemma 3 *The total wage bill for the DU is larger if it retains the IPR ownership.*

The reduction in the total wage bill at first points to the conclusion that the DU prefers to delegate IPR ownership. However, while the license market subsidises the explicit provision of incentives to the RU, the DU still both loses the licensing revenue, and is exposed to the erosion of its profits through the licensing. This means that in deciding whether to delegate

IPR ownership, the DU must weigh up the reduction in the wage bill against the loss of total profit. The effort invariance result of Proposition (2) implies that the DU can impute that the expected size of the innovation is the same under either ownership mode. The implication of this is gathered in Proposition (3) below. In a situation where the DU would license if it owned the innovation, the following Proposition provides an equivalence of IPR ownership.

Proposition 3 *(Equivalence) Whenever the DU would license the innovation to its competitors, its expected profit is identical under either ownership mode.*

Proposition (3) can be understood by a marginal analysis of the explicit and implicit incentives in the problem. An increase in the marginal incentive coefficient by $d\alpha$ raises the RU's effort. This has three impacts: (i) the DU's direct profit increases by $\Delta\pi(\tau)d\alpha$, (ii) an increase in the licensing revenue by $\kappa(\tau)d\alpha$, and (iii) a reduction in the total wage bill by $\kappa(\tau)d\alpha$. Delegation of the IPR to the RU results in changes in the magnitudes and distribution of these marginal effects. To see this more clearly, first note that because the optimal effort level does not change, the DU's profit is reduced by exactly the amount of the licensing revenue under delegation. Since the DU does not accrue the revenue from licensing under delegation, it reduces the incentives to exert effort by just enough to still induce the RU to participate in the project. As a result, the total wage bill reduces under delegation by exactly the same amount as the loss of licensing revenue to the DU. Since the DU is risk neutral and the expected return under both ownership modes is the same, it is indifferent to both. The RU receives the reservation utility in both cases. Under DU IPR ownership the certainty-equivalent is made up by a compensation wage whose marginal incentive coefficient depends positively on the DU's direct profit and the licensing revenue. However, under the delegation, the marginal incentive coefficient depends on the DU's direct profit, but is reduced exactly by the marginal licensing revenue. The RU still exerts the same amount of effort because it has private incentives provided by the return from licensing the innovation in the output market.

This equivalence result suggests that when the DU wishes to be an insider patentee, leakage of the innovation is not the critical factor in determining ownership of IPR as in Lai et al (2009) and Bhattacharya et al (2006). However, by considering the costs and benefits of formalising innovation more carefully, a tie-breaking rule may be fruitful in predicting ownership assignment.

For example, suppose the RU by the nature of their expertise and experience in IP markets are able to enforce or detect infringement of their IPR at a low cost. Alternatively, suppose the DU has to incur a non-trivial cost to protect, enforce and detect an infringement on their IPR which is much greater relative to the RU, since they would have to hire a team of experts to verify infringement. Then on balance the DU may always prefer to delegate IPR. Hence, in this framework, it is factors like transaction costs of enforcement rather than the provision of incentives that would give rise to efficient ownership assignment of IPR. This is in contrast to the analysis of Lai et al (2009) and Bhattacharya et al (2006).

Issues of transaction costs aside, the hypothesis of Proposition (2) contains a restriction: for it to apply, the DU would have to want to leak the innovation through licensing on its own account. Essentially this implies that there is no agency problem with leakage. However, in the literature on patent licensing, there is usually a threshold innovation size beyond which the innovator prefers not to license.[11] The next section relaxes the requirement that the DU would wish to license the innovation to establish under what conditions ownership of the IPR matters to the DU.

5 When IPR Ownership Matters

In the previous section, the DU was indifferent to delegating IPR ownership to the RU and retaining it. This section discusses the circumstances under which the ownership of the IPR is going to matter to the DU. The hypothesis of Proposition (2) requires that the DU would license the innovation itself. In that case, the DU is indifferent to the mode of IPR ownership. At what point then does the DU prefer to retain IPR?

[11] See for example Wang (1998) and Hernandez-Murillo and Llobet (2006). Wang (1998) considers a cost-reducing innovation in a homogeneous output market. In his model, for innovations larger than some critical value θ^*, the innovator prefers not to license the innovation. For smaller innovations, the innovator licenses. Hernandez-Murillo and Llobet (2006) consider the case of patent licensing with heterogeneous firms in a product differentiated market.

To help answer this question, it is useful to decompose the DU's marginal profit from an innovation into the direct impact from operating in the final output market, $\Delta\pi(0)$, and the external marginal erosion from having its competitors use the innovation, $\delta(\tau)$: $\Delta\pi(\tau) := \Delta\pi(0) - \delta(\tau)$. Note that $\tau = 0$ in the direct marginal profit since this measures the marginal value of the innovation to the DU gross of the influence of its competitors. In contrast, the magnitude of the marginal erosion depends on how valuable the innovation is to the DU's competitors, parameterised by τ. Specifically, it is assumed that when the innovation only has value to the DU there is no erosion: $\delta(0) = 0$. Also, as the innovations parametrically become less specific to the DU – τ increases – the marginal erosion of the DU's profit increases: $\delta'(\tau) > 0$.

Using these definitions, Proposition (4) below characterises the condition for DU IPR ownership. Whenever the marginal erpsion of the DU's profit is greater than the marginal extraction of licensing revenue from its competitors, the DU prefers to retain ownership of the IPR. In this case, it would choose not to license. On the other hand, the RU would always choose to license: there is a conflict of interest. This conflict is similar in spirit to the incomplete contracting models, where the action of the agent who controls residual property rights leads to a reduction in the objective of the other agent.

Proposition 4 *(Ownership) Provided the marginal revenue from licensing exceeds the marginal erosion of the DU's profit, the DU is indifferent to IPR ownership, otherwise the DU prefers to retain the IPR and not license the innovation.*

The proof of Proposition (4) is straightforward. It involves evaluating the difference in the expected profit to the DU from delegating IPR ownership to the RU in which case its direct profit is decreased, and retaining the IPR and not licensing. Substituting the optimised linear compensation wage into the DU's expected profit in the situation where it retains IPR ownership and chooses not to license yields the expression V_{NL}:

$$V_{NL} = \frac{\Delta\pi(0)^2}{2(1+r\sigma^2)}, \qquad V_{RU} = \frac{(\Delta\pi(\tau) + \kappa(\tau))^2}{2(1+r\sigma^2)}$$

Note that no licensing corresponds to the case where $\tau = 0$. The right hand expression V_{RU} is the DU's expected profit from delegating IPR whereupon the RU licenses the innovation.

The difference between these two expected profits yields:

$$V_{RU} - V_{NL} = \left(\frac{(\Delta\pi(\tau) + \kappa(\tau)) + \Delta\pi(0)}{2} \right) \left(\frac{\kappa(\tau) - \delta(\tau)}{2(1 + r\sigma^2)} \right) \tag{5.1}$$

Since the first factor in the difference in expected profits is the arithmetic average of the total surplus generated under the two arrangements (which is strictly positive), then the sign of the difference in expected profits is governed by the second factor, $\kappa(\tau) - \delta(\tau)$. Thus, whenever the marginal erosion of the DU's profit, $\delta(\tau)$, is larger than the marginal licensing revenue, $\kappa(\tau)$, the DU prefers to retain IPR ownership and not license the innovation. Otherwise the equivalence result holds: the DU is indifferent to the ownership arrangement.

The result contrasts somewhat to the Lai, Riezman and Wang (2009), to the extent that they can be compared. In their paper, a revenue-sharing contract emerges as the optimal form of contract more often when the RU's benefit from the external demand by leakage is a relatively small fraction of the erosion of the DU's profit from the leakage. So, in their model, the DU is more inclined to have a vertically separated structure, which effectively signs IPR over to the RU, only if it can implicitly control the RU's decision to leak with an incentive contract. In that situation, the DU trades off the probability of leakage occurring against the greater efficiency from the incentives offered to the RU. The opposite is true in Proposition (3). It is only when the erosion in the DU's profit from leakage through licensing dominates the benefit to the RU from leakage that the DU prefers to control the IPR, since in that case it would not wish to license. While it is difficult to make a clear comparison between the two outcomes, the difference in the results does appear to stem from the fact that Lai et al (2009) do not allow that the DU might license the innovation to the external market itself.

It can be seen directly from the condition in Proposition (3) that the degree of firm specificity of the innovation may impact the DU's decision to delegate IPR. The reason is intuitive: innovations which are specific to the DU have low value to the competing firms in the output market, and erode the DU's profit by a smaller amount than general innovations. By imposing some additional structure on $\kappa(\tau)$ and $\delta(\tau)$, it is possible to be more precise about the impact of firm specificity of the innovation. It is reasonable to assume that both the marginal licensing revenue and the erosion of the DU's profit are non-decreasing in innovation specificity. This gives rise to the possibility that on some intervals of the range of specificity the marginal licensing revenue exceeds the erosion of the DU's profit, and on other intervals the reverse is true. This idea is gathered in the Corollary below:

Corollary 1 *If* $\kappa(\tau)$ *and* $\delta(\tau)$ *are non-decreasing in* τ *on* $[0,1]$*, then:*
(i) if $\kappa(\tau) < \delta(\tau)\ \forall\ \tau$*, then the DU always prefers to retain IPR.*
(ii) if $\kappa(\tau) > \delta(\tau)\ \forall\ \tau$*, then the DU is always indifferent to ownership of IPR.*
(iii) on any interval $[\tau_0^*, \tau_1^*] \subseteq [0,1]$ *where* $\kappa(\tau^*) < \delta(\tau^*)\ \forall\ \tau^* \in [\tau_0^*, \tau_1^*] \subseteq [0,1]$*, the DU prefers to retain IPR, otherwise it is indifferent to ownership on that interval.*

Corollary 1 implies that the DU's ownership assignment depends on the firm-specificity of the innovation. This is because the relative magnitudes of the marginal licensing revenue and the rate of erosion of the DU's profit depend on the firm-specificity of the innovation, τ. However, these magnitudes are also industry specific: they will depend on the structural parameters of the industry under study. Different factors, such as the number of firms in the industry, or the nature of the strategic interaction between the firms will impact on the DU's decision to retain the IPR. Hence, the next section employs a specific output market structure to obtain the sensitivity of the DU's decision to various market parameters.

6 Innovation in a Differentiated Product Market

In this section, a specific market structure is used to explore the IPR ownership issue when the innovation is for cost reduction or quality improving. The exogenous quantity competition model of Vives (1985) provides a useful framework for analysing the optimal ownership arrangement, as it allows for an examination of goods that are gross substitute or complements. Suppose there are n firms, and there is no entry. Each firm produces a quantity of a single product, denoted x_k, $k = 1\dots,n$. Take firm i to be the DU. For the demand side, suppose that a representative consumer has quasi-linear utility:

$$u(y, x_1, \dots, x_n) = y + \sum_{j=1}^{n} a_j x_j - \tfrac{1}{2}\left(\sum_{j=1}^{n} x_j^2 + 2\gamma \sum_{j \neq i}^{n} x_i x_j\right)$$

where y is the numeraire good, and γ is the degree of substitutability of all the goods, with $-1 \leq \gamma \leq 1$. The goods are strategic complements if $\gamma < 0$, are independent if $\gamma = 0$, and are strategic substitutes if $\gamma > 0$. With this utility representation, the demand facing each firm is linear in quantities:

$$p_k = a_k - x_k - \gamma \sum_{j \neq k}^{n-1} x_j, \qquad k = 1, \ldots, n$$

where the prices p_k, $k = 1, \ldots, n$ are taken by the consumer to be fixed. The DU competes in the product market by selecting a quantity $x_i \geq 0$ to maximise its profits, conditional on the anticipated list of quantities selected by each of its rivals.

Then firm k's best-response to the other firm's quantities X_{-k} is given by:

$$x_k^*(X_{-k}) \in \arg\max_{x_k \geq 0} \left(a_k - x_k - \gamma \sum_{j \neq k}^{n-1} x_j - c_k \right) x_k, \qquad k = 1, \ldots, n \tag{6.1}$$

where $a_k - c_k$ is assumed large enough so that every firm chooses a non-negative quantity of the good. The Nash equilibrium quantity for each firm in the output market at an interior solution is given by:

$$x_k^* = \frac{(2 + (n-1)\gamma)(a_k - c_k) - \gamma \sum_k (a_k - c_k)}{(2 - \gamma)(2 + (n-1)\gamma)}, \qquad \forall k \tag{6.2}$$

Innovations can be either cost-reducing, or quality improving. In either case, it is assumed that innovations are non-drastic. They do not drive other firms from the market. In this linear demand system, cost reducing innovations have the same effect as quality-improving innovations. For a cost-reducing innovation, θ is the reduction in the DU's constant marginal cost c, so that its augmented cost per unit produced is: $c - \theta$. In a symmetric framework, each of the DU's rivals could have access to the innovation, although only τ may be installed. Restricting $a_k = a_j \; \forall \, k, j$, the profit for firm k is given by:

$$\pi_k = (a - x_k - \gamma \sum_{j \neq k}^{n-1} x_j - (c - \tau\theta))x_k = (a + \tau\theta - x_k - \gamma \sum_{j \neq k}^{n-1} x_j - c)x_k$$

A quality-improving innovation shifts out the demand curve for the innovating firm. To simplify the analysis, the marginal cost is assumed to be constant. That is, suppose $c_k = c$ for all k. An innovation of size θ results in a shift out in the demand by $\tau\theta$, so that $a_k = a + \tau\theta$, with $\tau = 1$ for $k = i$. Making these restrictions in (6.2) yields the same expression for profit as above. Hence, cost-reducing innovations will result in the same optimal output choice as quality-improving innovations in this model. Hence, the optimal output choices for each firm are given by:

$$x_i^* = \frac{(2-\gamma)(a-c)+(2-\gamma+(n-1)(1-\tau)\gamma)\theta}{(2-\gamma)(2+(n-1)\gamma)}, \qquad x_k^* = \frac{(2-\gamma)(a-c)+(2\tau-\gamma)\theta}{(2-\gamma)(2+(n-1)\gamma)}, \;\; \forall k \neq i \tag{6.3}$$

A first order approximation about a zero innovation for the profit of the DU and the license revenue, assuming a fixed fee license are:

$$\Delta\pi(\theta,\tau,\gamma) := \left(\frac{2(a-c)(2-\gamma+(n-1)(1-\tau)\gamma)}{(2-\gamma)(2+(n-1)\gamma)^2}\right), \quad \text{and} \quad \kappa(\theta,\tau,\gamma) := \left(\frac{4(n-1)(a-c)\tau}{(2-\gamma)(2+(n-1)\gamma)^2}\right) \tag{6.4}$$

Given this specification, the optimal incentive coefficient and fixed insurance payments are:

$$\begin{aligned} \alpha(\lambda) &= \left(\frac{2(a-c)(2-\gamma+(n-1)(\gamma+(2-\gamma)\tau))}{(2-\gamma)(2+(n-1)\gamma)^2(1+r\sigma^2)}\right) - \lambda\left(\frac{4(n-1)(a-c)\tau}{(2-\gamma)(2+(n-1)\gamma)^2}\right) \\ \beta &= \bar{w} + \frac{(r\sigma^2-1)}{2}\left(\frac{2(a-c)(2-\gamma+(n-1)(\gamma+(2-\gamma)\tau))}{(2-\gamma)(2+(n-1)\gamma)^2}\right)^2 \end{aligned}$$

These expressions can be used to establish necessary conditions on the pairs of values that the innovation specificity and substitutability parameters can take. This is done in Lemma (4):

Lemma 4 *The following restrictions are required on the substitution parameter γ and the degree of innovation specificity τ for an innovation incentive contract to exist:*
(A) $\tau < min\left\{\frac{n-2}{n-1}, \frac{1+r\sigma^2}{1+2r\sigma^2}\right\} \equiv \hat{\tau}$, (B) $\gamma \in I$, where $I := \left\{\gamma | \gamma \in [0,1] \; or \; -\gamma \leq \frac{2}{(n-1)(1-\tau)-1}\right\}$.

This product differentiation specification can be used to explore the impact of innovation specificity, product substitutability, and the number of firms competing in the same output market as the DU on the IPR ownership decision. In addition, the bearing of the degree of risk aversion and the variance of the innovation technology on incentives can be determined more precisely than in the general case.

It was established after Proposition (1) that $\alpha(0) > \alpha(1)$, and for an incentive contract to be *feasible*, $\alpha(1) > 0$. That is, the incentive contract must have some "power", otherwise the wage payment is simply a fixed fee. Cases where $\alpha(\lambda) < 0$ would mean that the RU must make transfers back to the DU - effectively paying the DU for provision of its own effort. It is not untenable that this could happen. After all, the RU needs the DU in order to create the innovation in the first place that gives rise to the to the external demand. However, negative marginal incentive coefficients will be ruled out on the grounds that the RU is cash constrained and is unable to obtain external financing (see Aghion and Tirole (1994) for the case where a cash-constrained RU may obtain external finance).

Proposition (5) below establishes that feasibility of RU IPR incentive contracts are bound above by a critical level of innovation specificity. The reason is not because of an agency leakage problem as in Lai et al (2009), but rather that the implicit licensing market subsidisation of the explicit incentive provided by the DU to the RU would require a negative marginal incentive coefficient. For innovation specificity above the critical threshold, DU IPR is always chosen in the production differentiation model. This is because the marginal incentive coefficient $\alpha(0)$ is always strictly positive, whenever the conditions set out in Lemma (4) hold.

Proposition 5 *There exists a* $\tau^* \in [0, 1]$ *such that for all* $\tau \in [0, \tau^*)$*, RU IPR incentive contracting is feasible, otherwise the DU prefers to retain ownership of the IPR.*

An implication of Proposition (5) is that delegation of IPR would only be observed when the innovation contracted for has little external value. It is more likely that the DU is indifferent to IPR ownership when the consequences for erosion of its profit by licensing is small. Again, other papers have arrived at a similar conclusion, but that is because their analysis trades off an erosion in profit against the efficiency effect of hiring a specialist. Here, the upper bound on innovation specificity arises due to a cash-constrained RU.

Given that there is an innovation specificity upper bound on the feasibility of RU IPR incentive contracting, it is possible to analyse some comparative static effects on the upper bound. In particular, it is possible to examine how the degree of product differentiation, γ, and the number of firms in the DU's output market influence the critical innovation specificity, τ^*.

Intuitively, an increase in γ increases the substitutability of the competing firm's outputs in the eyes of consumers. This lowers the market power that each firm has for its particular good, hence lowering the external demand effect. Thus, the proportion of licensing revenues in total producer surplus becomes smaller, and so the implicit incentive effect from licensing is smaller, permitting a greater critical pass through of the innovation to the competing firms before a full crowding out of explicit DU incentives occurs.

On the other hand, an increase in the number of firms competing in the output market raises the external demand effect. Therefore, the proportion of licensing revenues in total surplus becomes larger, and the implicit effect becomes larger. The result is the opposite from an increase in product substitutability: the marginal incentive coefficient with RU IPR becomes smaller more rapidly as more firms demand the innovation license, so the critical pass through of the innovation is smaller when full crowding out of explicit DU incentives occurs. Proposition (6) formalises these comparative static effects:

Proposition 6 *In the product differentiation model, an increase in n, a decrease in γ and an increase in r or σ^2 lower the critical innovation specificity, τ^*:*

$$\frac{d\tau^*}{dn} < 0, \qquad \frac{d\tau^*}{d\gamma} > 0, \qquad \frac{d\tau^*}{dr\sigma^2} > 0$$

The positive relationship between the critical innovation specificity and the size r and σ^2 arises because the more risk averse the RU is, or the more risky their task is, the lower effort they exert. So on average, the innovation is smaller. Hence, more of the innovation can be passed through to the DU's competitors before the erosion of the DU's profit becomes dominant.

7 Conclusion

The purpose of this paper was to investigate the conditions under which a DU would prefer to retain control over the IPR and residual control rights to licensing when contracting for an innovation. The results showed that whenever it would be in the interest of the DU to license an innovation to its competitors, the DU is actually indifferent to delegating IPR ownership to the RU or keeping it. The reason was that the RU still exerts the same amount of effort under both ownership arrangements because its total incentives remain the same: the total marginal incentive under DU IPR is equal to the sum of the lower explicit incentive and the new implicit incentive from the external source of demand under RU IPR. In addition, the conditions for which the DU would choose to retain the IPR were derived: whenever the rate of erosion of the DU's profit from the leakage of the innovation knowledge to its competitors was greater than the marginal licensing revenue.

In the context of a product differentiation model, it was established that feasible incentive contracting gives rise to a new ownership result: provided that the innovation specificity, τ^* is below a given critical threshold, RU IPR is feasible, otherwise the DU prefers to retain IPR ownership. The critical threshold τ^* was shown to be sensitive to the degree of product substitutability, the number of firms that the DU competes with, and the risk aversion parameters of the RU.

The results of this model were generated by imposing some strict linearity conditions to get a closed form solution for the incentive coefficients in the linear compensation wage. The next step is to determine whether the equivalence of IPR ownership result holds more generally. If the result is more general, then the interesting question becomes how the equivalence of IPR ownership can be broken. This line of research is currently under study.

8 Appendix

8.1 Proof of Lemma (1)

Expanding the expression for the certainty equivalence of RU, $u(w_{CE}) = \mathbb{E}_{\tilde{\varepsilon}} u(w(\theta) - C(e) + \lambda l(\theta, \tau))$, yields:

$$\begin{aligned}
-e^{-rw_{CE}} &= -\int_{-\infty}^{+\infty} e^{-r(\beta+\alpha e+\alpha\varepsilon-\frac{1}{2}e^2+\lambda\kappa(\tau)e+\lambda\kappa(\tau)\varepsilon)} \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(\theta-e)^2}{2\sigma^2}} d\varepsilon \\
&= -e^{-r(\beta+\alpha e+\lambda\kappa e-\frac{1}{2}e^2)} \int_{-\infty}^{+\infty} e^{-r(\alpha+\lambda\kappa(\tau))\varepsilon} \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(\theta-e)^2}{2\sigma^2}} d\varepsilon \\
&= -e^{-r(\beta+(\alpha+\lambda\kappa(\tau))e-\frac{1}{2}e^2)} e^{-r(\frac{r}{2}(\alpha+\lambda\kappa(\tau))^2\sigma^2)} \\
\Longleftrightarrow w_{CE} &= \beta + (\alpha + \lambda\kappa(\tau))e - \tfrac{1}{2}e^2 - \tfrac{r}{2}(\alpha + \lambda\kappa(\tau))^2\sigma^2
\end{aligned}$$

where the third equality follows using the moment generating function:

$$\int_{-\infty}^{+\infty} e^{-r(\alpha+\lambda\kappa(\tau))\varepsilon} \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(\theta-e)^2}{2\sigma^2}} d\varepsilon = e^{-\frac{1}{2}r^2(\alpha+\lambda\kappa(\tau))^2\sigma^2}$$

Rewriting the last line yields the result. ■

8.2 Proof of Proposition (1)

Taking the derivative with respect to α of the maximand of the DU's program and using (3.8) yields:

$$\Delta\pi(\tau) + (1-\lambda)\kappa(\tau) + (\alpha + \lambda\kappa(\tau))(1 - r\sigma^2) - (2\alpha + \lambda\kappa(\tau)) = 0 \tag{8.1}$$

Solving this equation for α yields the result. The second order condition is satisfied: $-(1+r\sigma^2) < 0$. ■

8.3 Proof of Proposition (2)

The result follows directly from computing the equilibrium effort level from the RU's incentive compatibility constraint (2):

$$e(\lambda) = \left(\frac{\Delta\pi(\tau) + (1-\lambda)\kappa(\tau) - \lambda\kappa(\tau)r\sigma^2 + \lambda\kappa(\tau)(1+r\sigma^2)}{1+r\sigma^2}\right) = \frac{\Delta\pi(\tau) + \kappa(\tau)}{1+r\sigma^2} = e^*$$

since the second equality shows no λ dependence. ■

8.4 Proof of Lemma (3)

Starting with: $w(\theta) = \beta + \alpha(\lambda)e(\lambda)$, where $\alpha(\lambda)$ is from Proposition (1) and $e(\lambda)$ is the right hand side of the IC condition of Lemma (2). Writing in full,

$$w(\theta) = \beta + \left(\frac{\Delta\pi(\tau) + (1-\lambda)\kappa(\tau) - \lambda\kappa(\tau)r\sigma^2}{1+r\sigma^2}\right)\left(\frac{\Delta\pi(\tau) + \kappa(\tau)}{1+r\sigma^2}\right) \tag{8.2}$$

where it can be seen that β is independent of λ. Hence, the difference in the wage bill is due only to the difference in the expected marginal incentive bill:

$$\Delta w(\theta) = w(\theta)_{\lambda=1} - w(\theta)_{\lambda=0} = \alpha(1)e_1 - \alpha(0)e_0 = \frac{-\kappa(\tau)(\Delta\pi(\tau) + \kappa(\tau))}{1+r\sigma^2} < 0 \tag{8.3}$$

Hence, the total expected wage bill is smaller under RU IPR ownership. ■

8.5 Proof of Proposition (3)

The proof simply shows that if the DU would choose to license the innovation, then the reduction in its expected wage bill that would occur if it signed over the IPR to the RU is exactly offset by the loss of licensing revenue that it would incur. Define the change in the ex ante expected value to the DU as:

$$\Delta V(\theta,\tau) = \mathbb{E}_{\tilde{\varepsilon}}\left[\Delta\pi(\tau)(\alpha(1)+\kappa(\tau)) - (\Delta\pi(\tau)\alpha(0)+\kappa(\tau)\alpha(0)) - \Delta w(\tilde{\theta})\right]$$

From Lemma (2), the optimal amount of effort exerted is the same under either mode of ownership, hence the expected magnitudes of the gross profit effects are identical. Accounting for this and substituting for the linear approximation of the license revenue yields:

$$\Delta V(\theta,\tau) = \mathbb{E}_{\tilde{\varepsilon}}\left[-\kappa(\tau)\alpha(0) - \Delta w(\tilde{\theta})\right]$$

The result follows from Lemma (3) and the solution for the optimal incentive coefficient $\alpha(1)$ from Proposition (1). ■

8.6 Proof of Lemma (4)

For an incentive contract to exist, a necessary condition is for $\Delta\pi(\tau) \geq 0$. Since $a > c$ and $|\gamma| \leq 1$ by assumption, examination of the direct profit expressions show that it is always positive. In comparison, a quality-improving innovation requires condition (B). For condition (B) to hold, its denominator must be positive. This gives the first component of the minimum argument in condition (A) $\tau < \frac{n-2}{n-1}$. For an incentive contract to have *power*, it requires $\alpha > 0$. Moreover, discussion of the comparative statics for the optimal incentive coefficient of equation (1) indicate that $\alpha(1) < \alpha(0)$. So, for $\alpha(1) \geq 0$, then in general terms $\frac{\Delta\pi(\tau)}{\kappa(\tau)} \geq r\sigma^2$. In the parameters of the product differentiation model, $\tau \leq \frac{1+r\sigma^2}{1+2r\sigma^2}$, which accounts for the second component of condition (A). ■

8.7 Proof of Proposition (5)

Whenever $\alpha(1) < 0$, even though $\mathbb{E}\pi(1) = \mathbb{E}\pi(0)$, incentive contracting with IR IPR requires the RU to compensate the DU for its own effort, therefore RU IPR incentive contracts are not feasible. On the other hand $\alpha(0) > 0$, $\forall\tau$, which implies that DU IPR would be feasible. The proof of existence of a critical innovation specificity τ^* involves finding the value of τ^* where $\alpha(1,\tau^*) = 0$. It is straightforward to see that $\alpha(1) \geq 0 \Leftrightarrow \frac{1}{1+r\sigma^2} \geq \frac{\kappa(\tau)}{\Delta\pi(\tau)+\kappa(\tau)}$. Define

$f(\tau) := \frac{\kappa(\tau)}{\Delta\pi(\tau)+\kappa(\tau)} = \frac{2(n-1)\tau}{(2+\gamma+(n-1)(\gamma+(2-\gamma)\tau))}$. Then τ^* is implicitly defined by $f(\tau^*) \geq \frac{1}{1+r\sigma^2}$. Note that:

$$f'(\tau^*) = \frac{2(n-1)(2+n\gamma)}{(2+\gamma+(n-1)(\gamma+(2-\gamma)\tau))^2} > 0, \quad \forall n, \gamma \in I$$

Hence $f(\tau)$ is strictly increasing and continuous on $[0,1]$. Also, $f(0) = 0$ and $f(1) = \frac{2(n-1)}{(2+\gamma+2(n-1))} < 1$. There are two cases: (I) If $f(1) > \frac{1}{1+r\sigma^2}$ then RU IPR incentive contract is feasible for all τ. (II) If $f(1) < \frac{1}{1+r\sigma^2}$, then by the IVT, there exists a unique $\tau^* \in [0,1]$ such that $f(\tau^*) = \frac{1}{1+r\sigma^2}$. Then for $\tau \in [0,\tau^*) : f(\tau) < \frac{1}{1+r\sigma^2}$ which implies that RU IPR incentive contracting is feasible. For $\tau \in [\tau^*, 1] : f(\tau) \geq \frac{1}{1+r\sigma^2}$ which implies that RU IPR incentive contracting is not feasible. ■

8.8 Proof of Proposition (6)

The equation $f(\gamma, n, \tau^*(\gamma, n)) = \frac{\kappa(\tau^*)}{\Delta\pi(\tau^*)+\kappa(\tau^*)} = \frac{1}{1+r\sigma^2}$ implicitly defines τ^*. Totally differentiating this equation with respect to $i = \gamma, n$ yields:

$$\frac{\partial f}{\partial i} + \frac{\partial f}{\partial \tau}\frac{d\tau^*}{di} = 0, \quad i = \gamma, n, r\sigma^2$$

Solving for the comparative static yields: $\frac{d\tau^*}{di} = -\frac{\partial f/\partial i}{\partial f/\partial \tau}$ for $i = \gamma, n, r\sigma^2$. Then the signs of the comparative statics are:

$$\frac{d\tau^*}{d\gamma} = -sign\left(\frac{\partial f}{\partial \gamma}\right), \quad \& \quad \frac{d\tau^*}{dn} = -sign\left(\frac{\partial f}{\partial n}\right), \quad \& \quad \frac{d\tau^*}{dr\sigma^2} = -sign\left(\frac{\partial f}{\partial r\sigma^2}\right)$$

Using the definition of $f(\tau)$ from above, the signs of the derivatives of this function with respect to each of the variables are:

$$\frac{\partial f}{\partial \gamma} = -\frac{2(n-1)\tau(1+(n-1)(1-\tau))}{(2+\gamma+(n-1)(\gamma+(2-\gamma)\tau))^2} < 0, \quad \& \quad \frac{\partial f}{\partial n} = \frac{2\tau(2+\gamma)}{(2+\gamma+(n-1)(\gamma+(2-\gamma)\tau))^2} > 0, \quad \& \quad \frac{\partial f}{\partial r\sigma^2} = -\frac{1}{(1+r\sigma^2)^2} < 0$$

Using the signs of these derivatives gives the result. ■

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