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Managing innovation: Optimal incentive contracts for delegated R&D with double moral hazard

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ABSTRACT

Managing innovation involves double moral hazard because the principal delegates R&D to a specialized agent and then makes decisions to apply the resulting invention. Double moral hazard is significant because innovation by the principal implies that the optimal incentive contract satisfies monotonicity conditions. The analysis shows that the optimal incentive contract for delegated R&D is an option. Delegated R&D with simultaneous sampling results in shirking but delegated R&D with sequential sampling attains the efficient outcome. The analysis considers a combined problem with simultaneous and sequential search and gives sufficient conditions under which delegated R&D attains the first best. The discussion also considers delegated R&D with stochastic innovation and with stochastic quality of inventions.

1. Introduction

The increased significance of invention and innovation help explain the rapidly growing use of stock options in compensation of research and development (R&D) managers.[1] Invention and innovation also help explain the use of stock options for non-executive employees (Core and Guay, 2001).[2] For example, software companies use stock options to provide incentives to engineers and programmers engaged in R&D (Andersson et al., 2009). To better understand these events, we model the management of invention and innovation. The key practical result of our analysis is that option contracts are optimal for delegated R&D when managing the combination of invention and innovation. We also show that although there are agency costs of R&D with simultaneous search, option contracts with sequential search generate full-information efficient R&D. We

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[1] See Mehran (1995), Bryan et al. (2000), Ryan and Wiggins (2001), and Lerner and Wulf (2007). (Lerner and Wulf, 2007, p.634) find that "the compensation of corporate R&D heads changed dramatically over the course of the 1990s, with much greater use of long-term incentives (such as restricted stock and stock options). The ratio of the value of long-term incentives to total compensation for corporate R&D heads has increased by more than 50% over the period from 1988 to 1998 with the value of long-term incentives (in 1996 dollars) almost tripling."

[2] Core and Guay (2001, p. 272), observe that "Firms with greater monitoring costs and greater growth options (proxied by firm size, the book-to-market ratio, and R&D expense) provide greater option incentives to non-executive employees."

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further show that shocks in implementing innovations have useful implications for the management of corporate intellectual property (IP).

Firms face major challenges in organizing and coordinating invention and innovation. Companies engage in extensive R&D activities and manage the application and commercialization of technological capital generated by R&D discoveries. Companies such as Apple, Boeing, Cisco Systems, General Motors, IBM, Intel, Johnson & Johnson, Merck, Microsoft, and Pfizer invest extensively in both invention and innovation.[3] Many leading companies say that "coming up with new ideas is not as big a problem as selecting and converting them to development projects" (Jaruzelski et al., 2012). For example, Andersson et al. (2009, p. F132), find that in software "there are two key groups of employees, each of which makes decisions about undertaking risky software projects. On the one hand, programmers and engineers must begin working on a new software project without knowing whether they will develop a great product. On the other hand, managers must allocate funds to research projects without knowing whether the resulting products will succeed in the market. Any theory of project selection, therefore, should pertain to both software engineers and managers."

The first challenge for firms is to provide incentives for specialized personnel to conduct R&D efficiently. This question is important because R&D is a critical driver of the growth of firms and the growth of the economy.[4] R&D expenditures are substantial; total US private, nonprofit and government investment in R&D exceeds $400 billion per year with private R&D constituting over 10% of private fixed investment.[5] Firms must design and apply incentive contracts for specialized economic agents who conduct R&D because most R&D is a *delegated* activity. The skills, knowledge and personnel necessary for the invention often differ from those needed for other production and operating activities and generally require independent business units.[6] Companies and government agencies conduct R&D in-house by employing specialized experts such as scientists, engineers, and statisticians. Companies and government agencies also outsource R&D by contracting with research laboratories, specialized firms, universities, and independent researchers. Firms contract with "star scientists" to increase organizational capabilities in scientific research (Lacetera et al., 2004) and to apply their discoveries (Zucker et al., 2002). Corporations and venture capitalists also engage in delegation of R&D through financing, monitoring, and directing entrepreneurial technology startups, specialized research firms, and independent researchers.

The second challenge for firms is that, after researchers create inventions, firms must organize innovation to implement inventions by own-use of discoveries within the company and commercializing IP. The firm's costs of innovation are distinct from R&D costs and involve expenditures devoted to managing and applying new technologies. After observing the outcomes of R&D, firms must decide whether or not to introduce inventions to the market and how much to invest in implementing inventions. Firms compare the returns and investment costs that are associated with alternative applications of inventions and different market channels for distributing disembodied IP (licensing, cross-licensing, IP sales) and embodied IP (products, services, production processes, transaction methods, spin-offs). Managerial innovation decisions affect the payoffs of R&D contracts to researchers and thus innovation decisions play a critical role in delegated R&D. The analysis helps understand the linkages between contracts for delegated invention and innovation decisions.

To address these management challenges, we present a comprehensive framework that shows the interaction between invention and innovation, and the resulting implications for managerial compensation and investment in innovation. We model *invention* as an R&D process of generating ideas or products that could potentially be applied and commercialized. We model *innovation* as management actions that take these ideas or products to the market. This study integrates the management of invention – before R&D takes place – and management of innovation – after R&D takes place. The analysis shows the critical interaction between the *ex ante* design of contracts to manage invention and *ex post* innovative actions that apply inventions. We do not require firms to commit to innovations that apply inventions so that managers have the flexibility to make innovation decisions after observing inventions. Also, we allow the manager and the researcher to renegotiate their contract after the agent reveals the invention but before the manager makes innovation decisions.

The integrated framework for studying invention and innovation generates a number of important results. First, Proposition 1, introduces what we refer to as the "actualization principle." This result shows that the principal's *ex post* decisions allow us to avoid making a standard assumption on the form of the payment contract between the principal and the agent. In equilibrium, the principal makes an optimal innovation choice on the basis of the realization of the invention, so that restrictions on the slope of the contract arise naturally from the principal's innovative decisions. The actualization principle is a general technical contribution that applies to double moral hazard models containing incentives for effort for both the principal and the agent.

We obtain our main results without assuming that there is an *upper bound* on the slope of the payment to the agent. Based on the actualization principle, we show that the innovative outcome is increasing in the quality of the invention be-

[3] The largest 1,000 global innovators spent over $600 billion on R&D in 2011 (Jaruzelski et al., 2012).

[4] See Lee and Schmidt (2010) on the contribution of R&D to economic growth.

[5] See Lee and Schmidt (2010). The National Income and product accounts have switched from treating public and private R&D as current expenditures to treating them as capital investments (Bureau of Economic Analysis, 2013; United Nations Statistical Commission, 2009).

[6] Because R&D is delegated, managers cannot assume that researchers will pursue efficient decisions without additional incentives for performance. Companies and sponsors of R&D must delegate decision-making authority to specialized researchers because it is costly for managers to monitor researchers' efforts and activities. Due to the specialized nature of R&D, managers generally lack the expertise to understand the design of experiments or scientific and technical efforts. R&D inputs may not be observable or verifiable by third parties so that it may not be possible or desirable to contract on investment in R&D activities.