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Little patents and big secrets: managing intellectual property

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Exploitation of an innovation commonly requires some disclosure of enabling knowledge (e.g., to obtain a patent or induce complementary investment). When property rights offer only limited protection, the value of the disclosure is offset by the increased threat of imitation. Our model incorporates three features critical to this setting: innovation creates asymmetric information, innovation often has only limited legal protection, and disclosure facilitates imitation. Imitation depends on inferences the imitator makes about the innovator's advance. We find an equilibrium in which small inventions are not imitated, medium inventions involve a form of "implicit licensing," and large inventions are protected primarily through secrecy when property rights are weak.

1. Introduction

■ How should an innovator manage its intellectual property (IP) when confronted with limited intellectual property rights and possible imitation? Exploitation of an innovation commonly requires some disclosure of enabling knowledge to selected firms or to the public (e.g., to obtain a patent, obtain an alliance partner, or to induce investment in complementary assets). When property rights offer only limited protection, however, the value of the disclosure is offset by the increased threat of imitation. We focus on the decision of a firm about how much of an innovation should be disclosed (with and without legal protection) and how much should be kept secret. A major business concern is that disclosure through patenting or voluntary disclosure will provide competitors with usable information. Surveys of U.S. firms found that a substantial fraction of patentable inventions were not patented (Mansfield, 1986) and that secrecy was viewed as more important than patenting for appropriability (Cohen, Nelson, and Walsh, 2000).[1] Along these lines,

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[1] Many firms (e.g., 3M, Kodak, Dow) involve their business managers in the decision of what parts of the underlying technology to patent and what parts to keep secret. Jolly (1997, p. 83) argues that an important aspect of a business strategy for mobilizing interest in a technology is "formulating a communication strategy that balances interest creation with secrecy."

we explore, for example, why firms are likely to employ secrecy more heavily as the significance of the invention increases.

Three features of the economic environment of innovation are critical for understanding the management of IP. First, incomplete information about the extent of innovation is often fundamental. Second, it is common for inventions to have available only limited intellectual property protection. Third, enabling knowledge revealed through disclosures makes imitation easier.

Asymmetric information gains force when property rights are limited. For a fully protected innovation, full disclosure entails no risk of unauthorized imitation while offering potential signalling benefits. With limited protection, however, disclosure risks imitation and incomplete information remains a primary concern.

Imitation depends on each of these factors. Disclosure determines what imitation is possible, and limited property-right protection frequently makes unauthorized imitation economically attractive despite the possibility of legal damages.[2] Asymmetric information also figures prominently in the imitation decision. For instance, if an innovation were known *a priori* to be minor, a competitor might prefer to remain with existing technology rather than imitate and risk legal damages. If an innovation were known to be major, a competitor might imitate because its status quo technology would be noncompetitive. Under incomplete information, an imitation decision must necessarily be based on an inference about the extent of innovation and an assessment of the downstream competitive position relative to the innovator. The extent of disclosure and protection chosen by the innovator provides an important clue, and signalling concerns are important for managing IP vis-à-vis competitors. For example, Ford Motor Company's disclosure of substantial amounts of unprotected technical knowledge about its revolutionary moving assembly line system (Nevins and Hill, 1954) may have been partly motivated by its value as a signal to competitors of its dominant low-cost manufacturing position. Inferences are also pivotal when the innovator discloses enabling knowledge to obtain sales or secure third-party complementary investments or financing, or in strategic alliance negotiations, because the decisions of these third parties depend ultimately on an assessment of the innovator's relative advantages over its competition.[3] Our basic model provides a foundation for understanding such interactions.

Thus, the amount of the innovator's disclosure is critical to the imitation decision. In economic terms, one can view the innovator's disclosure choice as a decision about how to "manage" market competition between direct competitors when imitation is a central concern. The relative positions of the competitors are managed by moderating the amount of disclosed knowledge, and competition occurs in the shadow of an ongoing legal dispute over IP rights (e.g., Polaroid and Kodak in instant photography).

The strength of intellectual property rights is critical to our story and merits further comment. If patent, copyright, and trade secret law could fully protect all economically important inventions, circumvention and possible infringement would be of secondary importance to the management of IP. But clearly this is not the case. Surveys suggest that firms in a majority of industries do not see patents as providing strong appropriability (Levin et al., 1987; Cohen, Nelson, and Walsh, 2000). Some reasons for these results include the ease with which some patents can be circumvented, the possibility that a patent will be invalidated if challenged, and the sometimes modest damages awarded in successful infringement suits. Especially for process innovations, lack of appropriability may also simply result from the difficulty of detecting infringement.

We model these tradeoffs in a duopoly competition setting where an innovating firm (the "innovator") has private information about an invention, giving it weakly lower costs of production

[2] Mansfield, Schwartz, and Wagner (1981) found, for example, imitation within four years of 60% of the patented successful innovations in their sample of 48 innovations. Walsh, Arora, and Cohen (2002) report that their interviews with firms in the drug discovery industry suggest a pervasive infringement of research tool patents.

[3] A common form of voluntary disclosure is a conference presentation or publication made before the patent becomes public. For example, "Fina filed the patent application . . . and shortly afterword Dr. Ewen gave a speech about it at a symposium organized by Exxon [Fina's competitor]." "Battle over Patents Pits Two Oil Concerns Against One Scientist," *Wall Street Journal*, March 1, 1996, p. 1.

than the other firm (the "follower"). The degree of innovation ranges continuously from no advance to a major innovation. The innovator chooses whether to patent and how much knowledge to disclose. Then, after assessing the inventor's total knowledge, the follower decides whether to use the disclosed knowledge and risk infringement or to stay with the old technology. Thus, our analysis conforms best to a process-innovation setting. The ensuing market competition is modelled as Cournot, which captures the basic tension between the cost of enabling knowledge transfer and the benefits of signalling toughness to a competitor. Market competition takes place, followed by a transfer of legal damages, if any, from the follower to the innovator.[4]

Our analysis leads to four main results. For small innovations we find a no-imitation effect under which small innovations are patented and fully disclosed and no imitation occurs. The second result involves a licensing effect where larger innovations are protected both through patents and secrecy, and imitation occurs, leading to an implicit licensing relationship between competitors mediated by expected damage payments. Third, we find a waiver effect in which, for sufficiently weak property rights, very large innovations are protected not via patent but instead through a strong reliance on secrecy. Finally, we have a no-exit result under which innovations that would be drastic (force exit) if the follower knew the innovator's cost become incremental when the follower does not know the innovator's cost (i.e., under incomplete information). The recurring theme in these results is that weak property rights imply disclosure incentives that are relatively stronger for smaller innovations, and as a result, larger innovations are protected more through secrecy as a response to the problem of imitation.

Because IP protection is modelled as an *ex post* expected transfer of some damage payment back to the innovator—a general feature of property rights—the model allows an exploration of a variety of IP settings beyond that of patenting. These include, e.g., negotiations held under a confidentiality agreement between an innovator-seller and a buyer, departure of employees who had access to trade secrets, IP rights established via private contracts, and potential copyright violations by software developers. Further, the approach is helpful for developing intuition relevant to more complex IP settings such as (potentially) licensing an invention to a firm that does not know the value of the IP.

□ **Literature review.** The decision of whether to patent has been explored directly in Horstmann, MacDonald, and Slivinski (1985) and is an integral part of the analysis in the models of Scotchmer and Green (1990) and Gallini (1992). We examine two components that have not been fully explored in this previous work. First, what is patented (and/or publicly disclosed) is a decision on the amount of enabling knowledge to transmit to one's competitor, and second, the amount that is disclosed is a signal of the total knowledge the innovator possesses.[5] Both elements are important for understanding imitation.

Horstmann, MacDonald, and Slivinski (1985) (hereafter HMS) model an information signalling problem but not the strategic choice in the amount of knowledge transfer.[6] The innovator has private information about the follower's payoffs that is signalled through the innovator's patent decision to the follower, who can either stay out, imitate (without infringing), or directly duplicate (only possible if there is no patent). The optimal innovator strategy involves mixing between patenting and not patenting; the follower stays out of the market when the innovator patents and imitates when the innovator does not. In contrast, we find infringement-risking imitation in the face of a patent. Imitation in our model is more attractive, as the patent decision and disclosure

[4] Litigation involving infringement frequently lasts for many years and sometimes is resolved only after the effective economic life of the invention has ended. A common remedy is to assess damages on the infringer and to enjoin use into the future. In recent years, U.S. courts have been willing to grant preliminary injunctions when a difficult burden of proof is met. The economic implications of disclosure under a preliminary injunction are analyzed in Anton and Yao (2003).

[5] The signalling and disclosure elements in our article explore issues related to those examined in Bhattacharya and Ritter (1983), Milgrom and Roberts (1986), Okuno-Fujiwara, Postlewaite, and Suzumura (1990), and Anton and Yao (1994).

[6] HMS employ a leader-follower equilibrium concept that involves differences in observability and commitment relative to the equilibrium concept we use.

transmit enabling knowledge as well as information about the innovator's costs. HMS also do not examine cases where safe imitation or staying in the market will always be profitable, e.g., when innovation provides small cost reductions from current technology, and no duplication is permitted against a patent. We, therefore, interpret HMS to be most appropriate for cases where property rights are strong.

Scotchmer and Green (1990) and Gallini (1992) focus on the impact of patent policy on the incentives to innovate. The decision to patent or suppress the innovation is important to their models, but it is handled as a binary choice in which patents disclose fully and there are no incomplete information problems regarding whether innovation has occurred. These properties make our concern with the interaction between enabling knowledge transmission and information (cost) signalling essentially moot, as the knowledge transmission and information signal are inseparable.

We begin with a discussion of the model. Sections 3 through 5 provide the core analysis leading to our main propositions that characterize the patenting, disclosure, and infringement-risking imitation decisions under incomplete information. Some extensions and limitations to our model are discussed in Section 6. Section 7 concludes.

2. The model

■ We examine the choices to protect intellectual property and disclose information and the resulting market interactions in a model with two firms: an innovating firm (innovator) and a competing firm (imitator or follower). Each firm is risk-neutral and seeks to maximize expected profits. The model has three stages. First, in the protection and disclosure stage, the innovator realizes an R&D outcome and decides whether to protect via patent and how much of the invention ("enabling knowledge") to disclose. Next, after observing these choices, the follower decides whether to use the disclosed knowledge or to stay with the prior status-quo technology. For simplicity we assume that the follower has not engaged in R&D. (Follower innovation and patenting are discussed in Section 6.) Finally, there is a competition stage in which market outcomes are determined and, following the market outcomes, a third party (court) determines whether the follower is liable for use of knowledge disclosed by the innovator. We specify each stage in turn and then define equilibrium.

□ **Protection and disclosure stage.** The innovator, i, privately observes the realized outcome of i's prior R&D investment. This outcome involves the discovery of a process innovation that entails an associated marginal cost of producing (fixed costs are set to zero). The innovation is fully summarized by this marginal cost, c, and we assume that c is drawn from a c.d.f. F with support $[0, \bar{c}]$. The upper bound, $\bar{c}$, is the cost of the prior technology (an R&D failure is an atom in F at $\bar{c}$); we set the lower bound at zero as we seek to examine a wide range of potential cost innovations (results with a positive lower bound are a minor extension).

The innovator chooses whether to protect its innovation with a patent. We use $\{\mathcal{P}, \mathcal{S}\}$ to denote the choice of patent, $\mathcal{P}$, and secrecy (no patent), $\mathcal{S}$. Firm i also chooses how much enabling knowledge s to disclose. Disclosure may occur with either $\mathcal{P}$ or $\mathcal{S}$, though with $\mathcal{S}$ the disclosure is not protected.

A disclosure transfers technological information that makes it feasible for firm j to produce at cost s. We require that

$$s \geq c \tag{1}$$

so that the innovator cannot disclose more knowledge than is actually possessed, but can disclose less. We refer to $s > c$ as partial disclosure; j does not directly observe how much enabling knowledge remains confidential, since c is private information of i. In terms of patents and managing IP, we interpret disclosure in our model in two ways. First, the patent itself may be the primary vehicle for disclosure of the enabling knowledge.[7] A second ("blocking patent") interpretation is that disclosure is separate from the patent, though the patent is the means of overall protection against unauthorized use of the disclosed knowledge.[8]

□ **Infringement-risking imitation stage.** The follower observes whether the innovator patented and the disclosed knowledge. Given $(s, \mathcal{S})$, there is no patent and the follower may use disclosed knowledge without penalty and produce at cost s. Given $(s, \mathcal{P})$, the follower decides whether to use the disclosed knowledge of s or the prior technology. These choices are denoted by $\mathcal{I}$, infringement-risking imitation, and $\mathcal{N}$, no imitation. As we specify below, a choice to imitate is actually a choice to risk a legal finding of infringement. We assume that the innovator can observe whether the follower has chosen to imitate or not prior to the subsequent competition stage.[9]

□ **Competition stage.** This stage consists of a duopoly market competition that we model as quantity setting (Cournot) with linear market demand

$$p(Q) = \alpha - \beta Q, \tag{2}$$

where $Q \equiv q_i + q_j$ is the sum of outputs. Market competition takes place under one of three possible regimes, depending on prior moves. At $(s, \mathcal{S})$ and $(s, \mathcal{P}, \mathcal{N})$ the market reduces to pure Cournot competition (in which j may remain uncertain about i's cost). At $(s, \mathcal{P}, \mathcal{I})$ the market competition occurs under the shadow of infringement. Firms first choose quantities, and this determines price, revenues, and production costs (with i at c and j at s). Infringement is modelled after the legal practice of awarding "reasonable royalties," which is the approach most appropriate to our setting. With probability γ, j is found to have infringed and is forced to pay damages to i. Infringement damages are assessed at a royalty rate of τ on the realized market price for each unit j produced. Thus, j is required to pay $\tau p q_j$ to i with probability γ and nothing with $1 - \gamma$. Because the expected penalty is what matters, we define $g \equiv \gamma\tau$, where $0 < g < 1$. To avoid nuisance division by zero, we treat full property rights ($g = 1$) and no property rights ($g = 0$) as limiting cases.

We assume that $\bar{c} < \alpha$ so that both firms would be active in the absence of innovation. Cases for α, $\bar{c}$, and g are introduced below.

□ **Equilibrium.** Strategic options are as follows. A protection and disclosure strategy for the innovator is a map from $[0, \bar{c}]$ into $\{\mathcal{P}, \mathcal{S}\} \times [0, \bar{c}]$. By feasibility, disclosures must satisfy (1). We use $\varphi_{\mathcal{P}}(c)$ to denote the disclosure of an innovator with cost draw c who decides to patent and $\varphi_{\mathcal{S}}(c)$ for the disclosure when no patent is chosen.

An imitation strategy for the follower is a choice from $\{\mathcal{I}, \mathcal{N}\}$ based on the observed protection and disclosure choice of the innovator, either $(s, \mathcal{P})$ or $(s, \mathcal{S})$. Quantity strategies for i and j at the competition stage are choices for output based on the observed prior disclosure, protection and imitation history, and, for i, the privately observed cost c. Finally, a belief of j regarding i's cost conditional on an observed protection and disclosure choice by i is a c.d.f. on $[0, s]$, since a disclosure s is feasible for i only if $c \leq s$.

We focus on separating perfect Bayesian equilibria (PBE), which we will refer to as "equilibria" in the remainder of this article. In such equilibria each observed disclosure and protection

[7] The disclosure choice can be viewed as a portfolio-of-technologies problem (which of a set of related technologies to patent) instead of a single-technology problem.

[8] It is feasible to patent any invention ($c < \bar{c}$), and the direct cost of obtaining a patent is assumed to be zero. Because the imitator can always use the prior technology without legal risk, there is no economic force to a disclosure of $s = \bar{c}$ or larger. Our model does not allow the innovator to license the follower. In our duopoly setting, antitrust considerations may preclude or severely restrict licensing.

[9] There are many settings in which the infringement-risking imitation choice is known either before or shortly after competition commences, e.g., Polaroid-Kodak and Intel-AMD. In other cases, the imitation choice may not be known to the innovator before production and competition. The effect of unobservability is that j will mix between $\mathcal{I}$ and $\mathcal{N}$ for a subset of the (c, s) points in Figure 1.

choice is made by a unique cost type of i, and all i and j strategies are optimal given the history and beliefs.

3. Market competition

■ At the point when the innovator i and the follower j choose quantities, the history of the game consists of a disclosure, s, and property-right choice $\{\mathcal{P}, \mathcal{S}\}$ by i and, given $\mathcal{P}$ by i, an infringement-risking imitation choice, $\{\mathcal{I}, \mathcal{N}\}$, by j. In a separating equilibrium, j infers i's cost c from the observed disclosure and property-right choices.

For any given c and s, one of three cases for competition arises: (i) if i chose $\mathcal{S}$, then we have (pure) Cournot competition between i with cost c and j with cost s; (ii) if i chose $\mathcal{P}$ and j chose $\mathcal{N}$, we have Cournot competition between i at cost c and j at cost $\overline{c}$; (iii) if i chose $\mathcal{P}$ and j chose $\mathcal{I}$, we have Cournot competition under the imitation regime with i at c and j at s. We focus on case (iii), since understanding the consequences of imitation is essential to the analysis.

The key aspect of market competition captured in our model is that there are profit benefits to (a) having a differential cost advantage over one's competitor and (b) making this fact known prior to some downstream competitive interaction. It pays to appear to be strong at the start of market competition. Many other competitive settings (e.g., a choice of capacity followed by market competition or a second-phase R&D competition in which lagging firms reposition their efforts) have this strategic substitutes feature and should create similar incentives for disclosure and imitation.

□ **Patent and infringement-risking imitation.** Consider the competition stage given that i chose to patent and disclose s and that j chose to imitate. Thus, the observed history is $(s, \mathcal{P}, \mathcal{I})$. In equilibrium, j infers that the innovator i has cost $c = \varphi_{\mathcal{P}}^{-1}(s)$.

Imitation allows j to produce at cost s, but it also exposes j to the risk of paying infringement damages. Given imitation, if i produces q_i and j produces q_j, then $\pi_j = (p - s)q_j - gpq_j$ and $\pi_i = (p - c)q_i + gpq_j$, where g is the expected infringement damages rate.[10] The best response for j to q_i is given by

$$q_j^{BR} = \frac{1}{2\beta}\left[\alpha - \frac{1}{1-g}s - \beta q_i\right]$$

when the interior term is positive (and zero if not). The damages payment leads j to be more timid and produce as if it had a higher marginal cost of $[1/(1-g)]s$ rather than s. Thus, as property rights weaken, j will produce more aggressively. The best response for i is given by

$$q_i^{BR} = \frac{1}{2\beta}\left[\alpha - c - \beta(1+g)q_j\right]$$

when the interior term is positive (and zero if not). The prospect of an infringement payment gives i an incentive to keep prices higher than otherwise, as the damage payment is a function of j's revenue.

The resulting competition stage outcome is given by the following:

Lemma 1. Consider an equilibrium and suppose $(s, \mathcal{P}, \mathcal{I})$ is observed at the competition stage. Let $c = \varphi_{\mathcal{P}}^{-1}(s)$. Then the unique outcome is given by

$$q_j(s, \mathcal{P}, \mathcal{I}) = \frac{1}{\beta(3-g)}\left[\alpha - \frac{2}{1-g}s + c\right]$$

[10] In this model g is not a function of the extent of use of the patented enabling knowledge, so it is optimal for imitation to involve the maximum use possible. Under the blocking-patent interpretation, when key disclosures are made outside of the patent, g is not likely to be a function of s.

$$q_i(c, s, \mathcal{P}, \mathcal{I}) = \frac{1}{\beta(3-g)}\left[\alpha(1-g) - 2c + \frac{1+g}{1-g}s\right]$$

if $s < [(1-g)/2](\alpha+c)$ and by monopoly for i at an output of $(\alpha-c)/2\beta$ if $s \geq [(1-g)/2](\alpha+c)$.

Note first that if i discloses more information (at a given inference of c), then an imitating follower has lower costs and j produces more while i produces less. A higher cost c for i, in equilibrium, also leads j to produce more and i to produce less (at a given s). Second, weaker property rights lead j to increase output while i reduces output.

In equilibrium, the competition-stage payoffs under imitation are

$$\pi_j(s, \mathcal{P}, \mathcal{I}) = \frac{1-g}{\beta(3-g)^2}\left[\alpha - \frac{2}{1-g}s + c\right]^2 \tag{3}$$

$$\pi_i(c, s, \mathcal{P}, \mathcal{I}) = \frac{1}{\beta(3-g)^2}\left[\alpha - (2-g)c + s\right]^2 + \frac{gc}{\beta(3-g)}\left[\alpha + c - \frac{2}{1-g}s\right]. \tag{4}$$

We see that i's profit increases when i is (correctly) inferred to have lower costs and that i's profit falls as more information is disclosed. These incentive properties form the basis for i to signal low costs through disclosure.

□ **Patent and no imitation.** Here j operates at cost $\bar{c}$ and infers that i has cost $c = \varphi_{\mathcal{P}}^{-1}(s)$. Equilibrium competition is analogous to a full-information Cournot setting with i at cost c and j at cost $\bar{c}$.

Lemma 2. Consider an equilibrium and suppose $(s, \mathcal{P}, \mathcal{N})$ is observed at the competition stage. Let $c = \varphi_{\mathcal{P}}^{-1}(s)$. Then the unique outcome is given by $q_j(s, \mathcal{P}, \mathcal{N}) = (1/3\beta)(\alpha - 2\bar{c} + c)$ and $q_i(c, s, \mathcal{P}, \mathcal{N}) = (1/3\beta)(\alpha - 2c + \bar{c})$ if $c > \max\{2\bar{c} - \alpha, 0\}$ and by monopoly for i with output of $(\alpha - c)/2\beta$ if $c \leq \max\{2\bar{c} - \alpha, 0\}$.

Payoffs are $\pi_i(c, s, \mathcal{P}, \mathcal{N}) = \beta q_i(c, s, \mathcal{P}, \mathcal{N})^2$ and $\pi_j(s, \mathcal{P}, \mathcal{N}) = \beta q_j(s, \mathcal{P}, \mathcal{N})^2$.

□ **No patent.** In this case j produces using s and faces no damages payment. In equilibrium, j infers that i has cost $c = \varphi_{\mathcal{S}}^{-1}(s)$. Equilibrium competition is analogous to full-information Cournot between i at cost c and j at cost s.

Lemma 3. Consider an equilibrium and suppose $(s, \mathcal{S})$ is observed at the competition stage. Let $c = \varphi_{\mathcal{S}}^{-1}(s)$. Then the unique outcome is given by $q_j(s, \mathcal{S}) = (1/3\beta)(\alpha - 2s + c)$ and $q_i(c, s, \mathcal{S}) = (1/3\beta)(\alpha - 2c + s)$ if $c > \max\{2s - \alpha, 0\}$ and by monopoly for i with output of $(\alpha - c)/2\beta$ if $c \leq \max\{2s - \alpha, 0\}$.

Payoffs are $\pi_i(c, s, \mathcal{S}) = \beta q_i(c, s, \mathcal{S})^2$ and $\pi_j(s, \mathcal{S}) = \beta q_j(s, \mathcal{S})^2$.

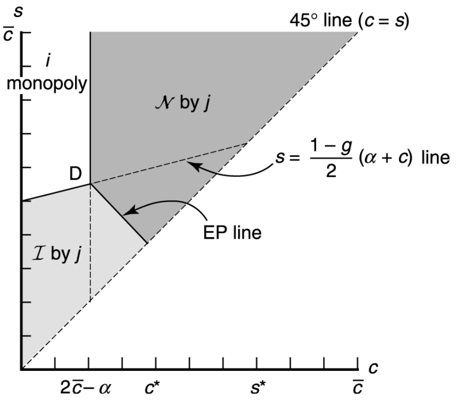
4. Infringement-risking imitation

■ Because j can always access disclosed knowledge, we must consider when j will find it profitable to imitate rather than stay with the noninfringing old technology. Suppose that i chose to patent, $\mathcal{P}$, and disclose s, and that j thereby infers i has cost $c = \varphi_{\mathcal{P}}^{-1}(s)$. By not imitating, $\mathcal{N}$, j faces a cost disadvantage of $\bar{c}$ versus c. By imitating, $\mathcal{I}$, j reduces the cost disadvantage to s versus c but risks infringement. To decide which is better, the anticipated payoffs from the competition stage at an observed history of $(s, \mathcal{P}, \mathcal{N})$ and at $(s, \mathcal{P}, \mathcal{I})$ must be compared. The results from Section 3 are used to compare the payoffs for j under $\mathcal{N}$ and $\mathcal{I}$. The choice depends on the relative cost positions of i and j and the strength of the property right. See Figure 1.[11]

[11] In Figure 1, we assume that $0 < 2\bar{c} - \alpha < s^* \equiv [(1-g)/(1+g)]\alpha < \bar{c}$. While useful for the graph, these conditions are much stronger than necessary.

FIGURE 1

IMITATION CHOICE



First, consider the vertical line at $2\bar{c} - \alpha$. Under $\mathcal{N}$, j is active in the competition stage and earns a positive profit provided that c is to the right of the line. Since j operates at $\bar{c}$ under $\mathcal{N}$, s matters only indirectly via the inference $c = \varphi_{\mathcal{P}}^{-1}(s)$. To the left, where $c < 2\bar{c} - \alpha$, j is inactive under $\mathcal{N}$ and earns zero, as i's large cost advantage forces j from the market.

Next, consider the upward-sloping line, given by $s = [(1-g)/2](\alpha + c)$, that crosses the 45° line at $s^* \equiv [(1-g)/(1+g)]\alpha$. Under $\mathcal{I}$, j is active and earns a positive profit provided that s and the inferred c lie below this line. Above the line, j is inactive under $\mathcal{I}$ and earns zero. In this case, the cost gap between s and c is large enough, relative to the damages payment implied by g, that j is forced from the market.

The $\mathcal{I}$ versus $\mathcal{N}$ choice has substance in the lower-right region (where $c > 2\bar{c} - \alpha$ and $s < [(1-g)/2](\alpha + c)$). Here j is active at each of $(s, \mathcal{P}, \mathcal{I})$ and $(s, \mathcal{P}, \mathcal{N})$ against an inferred cost of $c = \varphi_{\mathcal{P}}^{-1}(s)$ for the innovator, and we have

$$\pi_j^{\mathcal{I}} \gtrless \pi_j^{\mathcal{N}} \iff \left[\frac{1-g}{2}\right](\alpha + c) - \left[\frac{(3-g)\sqrt{1-g}}{6}\right](\alpha + c - 2\bar{c}) \gtrless s. \tag{5}$$

Equality in (5) defines a linear relationship between s and c, denoted by $s = e(c)$, along which j is indifferent between $\mathcal{N}$ and $\mathcal{I}$. This equal payoff (EP) line has a negative slope and always passes through the point $c = 2\bar{c} - \alpha$, $s = (1-g)\bar{c}$. In Figure 1 the EP line begins at point D, which is at the edge of the monopoly region for i, and falls as c rises, hitting the 45° line at the point above c^*. Above the EP line, j will choose $\mathcal{N}$, and below it, j will choose $\mathcal{I}$. Thus, the follower will imitate when the cost disadvantage for j at s with i at c is small enough, given the expected damages payment implied by g under imitation, relative to the larger cost disadvantage for j at $\bar{c}$ with i at c, under $\mathcal{N}$.

The final step is to characterize formally the infringement-risking imitation decision. Two properties are necessary for j to have a nontrivial imitation decision. First, j must be active in the competition stage under $\mathcal{N}$ and under $\mathcal{I}$ for a nonempty set of c and s values. Second, given that j is active under $\mathcal{N}$ and $\mathcal{I}$ at a set of c and s values, one of the choices must not strictly dominate the other across the set.

In terms of the graph, we see that $0 < c^* < \bar{c}$ is the necessary property with respect to a nontrivial imitation choice. If $c^* > \bar{c}$, then $\mathcal{N}$ is never chosen by j, and if $c^* < 0$, then $\mathcal{I}$ is never chosen. Solving for the intersection of EP with the 45° line, we find

$$c^*(g, \alpha, \bar{c}) = \frac{2\bar{c} + \alpha[(1-g)h(g) - 1]}{1 + (1+g)h(g)}, \tag{6}$$

where $h(g) \equiv 3/[(3-g)\sqrt{1-g}]$. For reference, define the set

$$B \equiv \left\{(c, s) \mid \max\{0, 2\bar{c} - \alpha\} < c \leq \min\{\bar{c}, s^*\} \quad \text{and} \quad c \leq s < \min\{\bar{c}, \frac{1-g}{2}(\alpha + c)\}\right\}.$$

B corresponds (in general) to the lower-right region in Figure 1 where j is active under $\mathcal{I}$ and $\mathcal{N}$. Analysis of the EP line and the $\mathcal{N}$ versus $\mathcal{I}$ choice yields the following:

Lemma 4. Suppose that $\bar{c} < \alpha/(1+g)$. Consider the infringement-risking imitation decision for j given that i patented and disclosed s. Then

(i) $B \neq \phi$, and for any $(c, s) \in B$, j actively produces at $(s, \mathcal{P}, \mathcal{N})$ and at $(s, \mathcal{P}, \mathcal{I})$;
(ii) for $(c, s) \in B$, $\mathcal{N}$ is optimal for j if $s \geq e(c)$ and $\mathcal{I}$ is optimal if $s \leq e(c)$;
(iii) $c^* < \bar{c}$;
(iv) $c^* > 0$ and c^* is strictly decreasing in g if and only if $\bar{c} > \alpha k(g) \equiv (\alpha/2)[1-(1-g)h(g)]$.

The condition $\bar{c} < \alpha/(1+g)$ necessarily holds as property rights become weak. This implies B is nonempty, the first necessary feature. When $\bar{c} > \alpha/(1+g)$, the active regions for j in Figure 1 do not intersect, as $2\bar{c} - \alpha > s^*$, and the choice of $\mathcal{I}$ versus $\mathcal{N}$ is trivial at any disclosure s and inferred cost c. The second essential feature is captured by $0 < c^* < \bar{c}$. This ensures that the EP line crosses the 45° line at a possible innovation cost draw and, hence, that j will be induced to choose $\mathcal{I}$ and $\mathcal{N}$ in response to the observed disclosure and inferred cost type.

An important implication of Lemma 4 is that the innovator will not, in equilibrium, be able to force the follower to exit the market, no matter how large the innovation (when $\bar{c} < \alpha/(1+g)$). Refer to Figure 1 and note that i can induce j to exit the market (when $c < 2\bar{c} - \alpha$) only if a relatively small fraction of the innovation is disclosed. But if the equilibrium has j exiting, then the partial disclosure necessarily implies that innovators with a much smaller innovation will be able to mimic the disclosure, ensuring exit and a monopoly payoff for themselves. This cannot be an equilibrium outcome. Referring again to Figure 1, we see that the size of the disclosure required to induce j to exit also necessarily makes it feasible and desirable for types above c^* to mimic such a disclosure. However, j will not exit against types above c^*. Formally, we have the following:

Corollary 1 (no exit). Suppose $\bar{c} < \alpha/(1+g)$. Then, in equilibrium, the follower is active in the competition stage for all patent and disclosure choices of the innovator.

This no-exit result is a consequence of incomplete information regarding innovation. If partial disclosure could induce exit, then higher-cost types would have a strong incentive to mimic such a disclosure. In contrast, under complete information, if j had cost $\bar{c}$ and knew that i had cost c, firm j would exit whenever $c < 2\bar{c} - \alpha$. Thus, we find that there are no drastic innovations for $\bar{c} < \alpha/(1+g)$. When the range of potential innovation is large relative to the prior technology, a setting with complete information will lead the follower to exit the market when the innovator has a sufficiently large success. But this does not occur under incomplete information and weak property rights because persuading the imitator of the size of the innovation requires disclosing enabling knowledge that, in turn, reduces the innovator's advantage. Although other factors not considered here might moderate the no-exit result, the difference in conclusions under complete versus incomplete information highlights the value to studying IP transactions and decisions in an incomplete-information setting.

In summary, the imitation decision depends critically on the follower's assessment of the innovator's cost position. This dependence underscores this article's focus on the signalling aspect of the competitive interaction: an optimal imitation decision when there is the option of producing with noninfringing technology necessarily turns on how the follower assesses the innovator's advantage.

5. Equilibrium protection and disclosure

■ We now examine the incentives of the innovator in the protection and disclosure stage. The equilibrium involves three distinct regions: (i) high-cost types (with small innovations) that choose to patent and disclose fully, (ii) medium-cost types that also patent but disclose only partially, and (iii) low-cost (large innovation) types that eschew a patent entirely, disclose partially, and rely more extensively on secrecy. Proposition 1 establishes existence of this three-region equilibrium, and Proposition 2 considers uniqueness.

□ **Small innovation region (no-imitation effect).** Suppose $c \geq c^*$ so that the innovation is relatively small, and that i patents and discloses $s = \varphi_{\mathcal{P}}(c)$ in equilibrium. Then j will not imitate, since with $s \geq c \geq c^*$, the cost reduction benefit of s over $\bar{c}$ is insufficiently attractive to justify infringement-risking imitation. As a result, i would earn a payoff of $(1/9\beta)(\alpha - 2c + \bar{c})^2$. The important point is that this payoff does not depend directly on s; the disclosure only affects the inference of j regarding i's innovation, since j's cost remains at $\bar{c}$ absent imitation.

The innovator, therefore, has a strong incentive to disclose fully in the small innovation region. If some type c were to disclose partially, say at $s = \varphi_{\mathcal{P}}(c) > c$, then all higher-cost types $\hat{c}$ between c and s would find it feasible and profitable to disclose s in order to be perceived as the lower-cost type of c. Significantly, for types above c^*, even a very weak property right (small g) is sufficiently strong to deter imitation: in this region weak patents are economically equivalent to strong patents. Thus, i discloses fully under a patent and $\varphi_{\mathcal{P}}(c) = c$ for $c \geq c^*$. In Figure 2, $\varphi_{\mathcal{P}}$ coincides with the 45° line above c^*.[12]

This region characterizes equilibrium outcomes under strong property rights. As $g \to 1$, $c^* \to 0$. Infringement is always deterred and all types patent and disclose fully.

□ **Medium innovation region (licensing effect).** For $c < c^*$, we know that the follower will find infringement-risking imitation to be attractive provided s is not too far above the inferred cost of the innovator (s and c lie below the EP line). Because types above c^* disclose fully, a disclosure to signal cost below c^* must be less than c^*. Then, in equilibrium, j will choose to imitate.

The payoff for the innovator from patenting and disclosing $s = \varphi_{\mathcal{P}}(c)$ is given by equation (4). Consider the incentive of a different innovator type, say $\hat{c}$, who finds it feasible to disclose such an $s < c^*$ This would lead j to infer that the innovator is type $c = \varphi_{\mathcal{P}}^{-1}(s)$ and, hence, to imitate and produce $q_j(s, \mathcal{P}, \mathcal{I})$. By choosing a best response to this quantity, type $\hat{c}$ can obtain the deviation payoff

$$\frac{1}{\beta(3-g)^2}\left[\alpha - \frac{3-g}{2}\hat{c} - \frac{1-g}{2}c + s\right]^2 + \frac{g}{\beta(3-g)}\left[\alpha - \frac{2}{1-g}s + c\right]\hat{c}. \qquad (7)$$

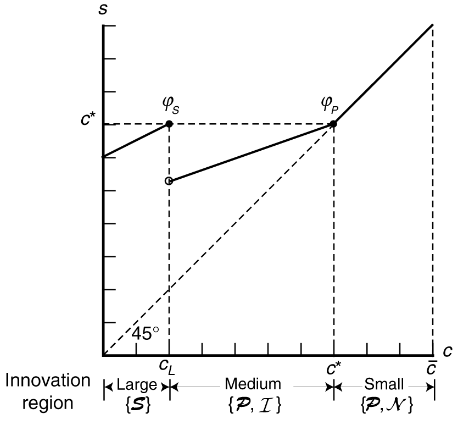
In equilibrium, since j imitates and operates at cost s, the innovator no longer has an incentive to disclose fully. Instead, as s varies, we find a tradeoff between signalling low costs plus gaining increased benefits of expected damage payments and transferring enabling knowledge to an imitating follower. A simple incentive-compatibility argument based on (7) then establishes that as c rises, $\varphi_{\mathcal{P}}(c)$ must rise at the rate of $(1 - g)/2$. A larger (smaller) slope for $\varphi_{\mathcal{P}}$ would imply that some type in this range has an incentive to mimic a higher (lower) type. As this rate is below one, we find partial disclosure of innovations when $c < c^*$. (See $\varphi_{\mathcal{P}}$ in Figure 2 in the medium innovation region.) In equilibrium, as the innovation becomes larger, the gap between disclosed and actual knowledge increases: partial disclosure and imitation go hand in hand.

The familiar single-crossing property for signalling models with a continuum of types (see,

[12] Our result that small innovations (in terms of variable cost reduction) are fully disclosed and not imitated in equilibrium is similar in spirit to a result in Gallini (1992) in which a short patent life in conjunction with a fixed cost of imitation implies no imitation.

FIGURE 2

EQUILIBRIUM PROTECTION AND DISCLOSURE



e.g., Mailath, 1987) can be applied here. Since the constraint $s \geq c$ is not binding in this region, $\varphi_{\mathcal{P}}$ satisfies the standard conditions for a signalling equilibrium for types in (c_L, c^*).[13]

Finally, consider for purposes of discussion what happens to market competition between the innovator and the follower at c^*, where j is exactly indifferent between $\mathcal{N}$ and $\mathcal{I}$, and examine the competition stage as j switches from $\mathcal{N}$ to $\mathcal{I}$. Imitating and producing at cost c^* leads j to increase output while i is led to reduce output relative to no imitation ($q_j^{\mathcal{I}} > q_j^{\mathcal{N}}$ and $q_i^{\mathcal{I}} < q_i^{\mathcal{N}}$). The net effect is that aggregate output falls, the market price rises, and total profits for i and j rise. Thus, imitation has the beneficial joint effect of creating a market relationship in which i is effectively "licensing" j and the relationship is governed by the property-rights regime. In this interpretation of imitation and infringement, the innovator chooses the technology transfer (via the disclosure) and the license fee is set exogenously by the court (via *ex post* expected per-unit damages). Imitation can then be viewed as an exercise of the implicit option to license.[14]

□ **Large innovation region (waiver effect).** For small and medium-sized innovations, the innovator has a strong incentive to patent. For large innovations, however, the economic tradeoff to signalling via partial disclosure and patenting becomes less attractive: high-cost types disclose fully, which pushes disclosure down to c^*, and then medium-cost types disclose partially, which forces still more disclosure on lower-cost innovator types. Will patenting remain optimal?

We find that with relatively weak property-right protection, the innovator will sacrifice patent protection and the associated "licensing" revenues because the value of licensing falls as c and g fall. To see this, recall that the innovator has two sources of profit under imitation: "licensing" revenues of $gp^{\mathcal{I}}q_j^{\mathcal{I}}$, and operating profits of $(p^{\mathcal{I}} - c)q_i^{\mathcal{I}}$. In turn, the price and the quantities depend on the cost differential between i and j.

At $c = c^*$, where imitation commences, we have $\varphi_{\mathcal{P}}(c^*) = c^*$ and there is no cost differential in absolute terms. As c falls, i is led to disclose more knowledge, but a cost differential opens up because the gap $\varphi_{\mathcal{P}}(c) - c$ increases as c falls. Firm i increases output as c falls. The follower, however, does not change quantity: the rate at which equilibrium disclosure $\varphi_{\mathcal{P}}(c)$ falls exactly

[13] Let $V(\hat{c}, c, s)$ denote the payoff in (7); single crossing requires that $-V_2/V_3$, the slope of a (c, s) indifference curve for a type $\hat{c}$, is nonincreasing in $\hat{c}$ so that lower-cost types are "more willing" to disclose than higher-cost types. With the linear-quadratic payoff structure under Cournot competition in (7), we find $V_2/V_3 = -(1-g)/2$ and single-crossing holds weakly, as indifference curves are linear with a common slope.

[14] The implicit licensing effect may show up as actual licensing in which some portion of the innovation is withheld from the licensee. Foster (1986) indicates that such a two-step approach is not uncommon in the chemical industry, where an innovator will license an early-generation process while reserving a later-generation process for itself (e.g., BASF's process to produce phthalic anhydride).

balances the effect of lower costs for j against that of facing a lower-cost opponent. In sum, the effect of lower cost is to increase industry output and reduce price, with the cost advantage leading i to assume the more dominant role.

These effects shift the innovator's profit source from licensing revenue toward operating profit. With $p^{\mathcal{I}}$ falling and $q_j^{\mathcal{I}}$ steady, licensing revenue of $gp^{\mathcal{I}}q_j^{\mathcal{I}}$ falls. The price-cost margin for i, $p^{\mathcal{I}} - c$, rises as c falls because of the widening cost differential over j. Operating profit, $(p^{\mathcal{I}} - c)q_i^{\mathcal{I}}$, is then driven up by each of the margin and volume changes.

A large innovation leads i to rely more strongly on the cost advantage against j and less on expected infringement payments. When g is sufficiently small and $\bar{c}$ is sufficiently large, the cost-advantage effect becomes dominant. In equilibrium, giving up property rights (or patenting and licensing for a nominal sum) signals a large innovation and permits less disclosure of valuable enabling knowledge. See $\varphi_{\mathcal{S}}$ and the jump from $\varphi_{\mathcal{P}}$ at c_L in Figure 2. The follower operates at cost c^* without risking infringement, the cost disadvantage jumps to $c^* - c_L$ from $\varphi_{\mathcal{P}}(c_L) - c_L$, and so j becomes a weaker competitor.

Let c_L denote the upper boundary of the large innovation range. The formal parameter condition on $\bar{c}$, α, and g that ensures $c_L > 0$ is provided next.

Lemma 5. Suppose $\alpha k(g) < \bar{c} < \alpha/(1+g)$. Then there exists a unique c_L that satisfies

$$\pi_i(c_L, c^*, \mathcal{S}) = \pi_i\left(c_L, \frac{1+g}{2}c^* + \frac{1-g}{2}c_L, \mathcal{P}, \mathcal{I}\right),$$

provided that $g < 1/3$ and $\bar{c} > \alpha m(g)$ where $m(g) \equiv k(g) + g[1 + (1+g)h(g)]/(3-5g)$. Further, we have $c^* > c_L > \max\{0, 2c^* - \alpha\}$. Otherwise, when $g > 1/3$ or when $g < 1/3$ and $\bar{c} < \alpha m(g)$, we have $\pi_i(c, c^*, \mathcal{S}) < \pi_i(c, [(1+g)/2]c^* + [(1-g)/2]c, \mathcal{P}, \mathcal{I})$ for all $c \in [0, c^*]$.

The type c_L is indifferent in equilibrium between patenting at a high level of disclosure and secrecy with a lower level of disclosure. Regarding the parameter conditions, a small value for g is important. In particular, as $g \to 0$ both $m(g)$ and $k(g)$ approach zero and, consequently, the jump type exists for any value $\bar{c}$ of the older technology cost. When the existence conditions in Lemma 5 do not hold, we effectively have c_L at zero, and a special case of our analysis provides the corresponding equilibrium.

Finally, we need to explain why the jump is to c^* and not higher. Low-cost innovators prefer the jump to be as large as possible, since this would mean less "free" disclosure. What limits the size of the jump is the necessity of maintaining a consistent signal of low costs. A jump above c^* would make it feasible for innovator types in the no-imitate region ($c > c^*$) to mimic this signal. Moreover, these types would find it profitable to deviate if the jump point were above c^*. Thus, the jump is capped at c^*.

Although our discussion has focused on waiving the patent, the core economic signal is the sacrifice of expected damages. Eschewing the patent and then making unprotected disclosures is one implementation of the signal, though one with practical deficiencies because the choice to not patent is a nonaction and, even if noticed, might be attributed to a problem with the legal patentability of the invention. An alternative signal with the same expected damages feature is a patent coupled with a nominal lump-sum license, which arguably is better tailored in practice to creating a safe yet ineluctable signal. Actions consistent with such signals include public disclosures of enabling knowledge in conferences and papers and licenses of technology for (surprisingly) low fees.[15]

One prominent example that can be interpreted through the lens of disclosure to signal low costs involves the actions of the Ford Motor Company in 1913–1915 during its implementation of the arguably revolutionary moving assembly line process for mass production of automobiles. During this period Ford allowed a number of journalists to write extensively about its (unpatented)

[15] This approach also avoids in part the problem associated with having some other firm inventing and then patenting the technology that the innovator kept secret.

processes. Hounshell (1984), in a historical study of American manufacturing technologies, remarks that Ford "educated the American technical community in the ways of mass production" (p. 261). One series of articles in *Engineering Magazine* resulted in a 440-page book, published in 1915, on Ford's manufacturing methods. Although detailed, these publications were only a partial disclosure of the knowledge it took to make the system work. One reason Ford may have done this was to signal its competitors that it had extremely low costs and that a head-to-head competition with Ford would be unprofitable.[16]

□ **Existence and uniqueness of a three-region equilibrium.** Define the parameter set $A \equiv \{(g, \bar{c}, \alpha) \mid g \in (0, 1/3) \text{ and } \alpha m(g) < \bar{c} < \alpha/(1+g)\}$. We now show the equilibrium exists.

Proposition 1. Assume that $(g, \bar{c}, \alpha) \in A$. Then an equilibrium exists and is given by the following strategies:

(i) The innovator patents and discloses according to the

(a) no-imitation effect. In the small innovation range, $c \geq c^*$, i patents and fully discloses with $\varphi_{\mathcal{P}}(c) = c$;
(b) licensing effect. In the medium innovation range, $c^* > c > c_L$, i patents and partially discloses with $\varphi_{\mathcal{P}}(c) = [(1+g)/2]c^* + [(1-g)/2]c$;
(c) waiver effect. In the large innovation range, $c_L \geq c$, i eschews a patent and partially discloses with $\varphi_{\mathcal{S}}(c) = c^* - (c_L/2) + (1/2)c$;

(ii) The follower imitates under the risk of infringement according to

(a) j chooses not to imitate, $\mathcal{N}$, when $(s, \mathcal{P})$ is observed and $s > c^*$, and
(b) j chooses to imitate, $\mathcal{I}$, when $(s, \mathcal{P})$ is observed and $s \leq c^*$.

(iii) At each observed history on the equilibrium path, $(s, \mathcal{P}, \mathcal{N})$ for $s \geq c^*$, $(s, \mathcal{P}, \mathcal{I})$ for $s < c^*$, and $(s, \mathcal{S})$ for $s \leq c^*$, the innovator and follower produce in the competition stage according to the implied Cournot outputs.

(See the Appendix for off-equilibrium beliefs and actions.) The proof of Proposition 1 involves verifying that each of i and j finds it optimal to follow the specified strategies, and this entails a set of profit comparisons for deviations from the equilibrium strategies.

In Proposition 2 we characterize the set of equilibria (separating PBE). For reference, define

$$\underline{\sigma} = \frac{1}{2(3-g)}\left[2g\alpha + 3(1+g)c^*\right];$$

for $(g, \bar{c}, \alpha) \in A$, we have $\underline{\sigma} < c^*$. A generalization of Lemma 5 (see Lemma A6 in the Appendix) shows that for each disclosure $\sigma \in [\underline{\sigma}, c^*]$, there is a unique type c_σ at which $\pi_i(c_\sigma, \sigma, \mathcal{S}) = \pi_i(c_\sigma, [(1+g)/2]\sigma + [(1-g)/2]c_\sigma, \mathcal{P}, \mathcal{I})$. We then have the following:

Proposition 2. Assume $(g, \bar{c}, \alpha) \in A$. For each disclosure $\sigma \in [\underline{\sigma}, c^*]$ and associated crossing type c_σ, the strategies in Proposition 1 constitute an equilibrium when we replace c_L with c_σ and set $\varphi_{\mathcal{S}}(c) = \sigma - (c_\sigma/2) - c/2$. Every separating PBE is of this form, and for all types the equilibrium of Proposition 1 is maximal with respect to the innovator's payoff.

Thus, equilibrium choices and outcomes for all types above c_L are unique.[17] The switch from a patent to secrecy strategy can occur, in equilibrium, at any type below c_L. All innovator

[16] Further, efficiency depended in part on economies of scale available to Ford with its dominant sales position. Ford may also have signalled its low costs with aggressive pricing, its \$5/day wage (double the going rate), and its 1914 sales-volume-triggered rebate policy. See Nevins and Hill (1954) and Hounshell (1984).

[17] Consider the possibility of all types pooling at no disclosure ($s = \bar{c}$) so that the distinction between $\mathcal{P}$ and $\mathcal{S}$ is moot. Letting μ denote the mean of the prior F on innovation draws, the payoff to type c is given by $(1/9\beta)(\alpha - (3/2)c - (1/2)\mu + \bar{c})^2$. Suppose type c deviates to $(s, \mathcal{P})$ and that j forms the (most) pessimistic belief of $\hat{\mu} = s$. For a choice of $s > c^*$, j chooses $\mathcal{N}$ and the deviation payoff to i is given by $(1/9\beta)(\alpha - (3/2)c - (1/2)s + \bar{c})^2$. Then the deviation is profitable if $\mu > s$. Thus, pooling at $\bar{c}$ is not an equilibrium if $\mu > c^*$.

types in $[0, c_L]$, however, strictly prefer the equilibrium in which secrecy is used to the maximum extent possible.

6. Discussion

■ Our model allows for endogenous interactions involving secrecy and imitation but suppresses some features of the patenting environment. In this section we discuss our modelling choices and the robustness of our results to the addition of some of these features.

□ **Follower innovation and patenting.** The addition of follower innovation complicates the analysis by giving the follower protection and disclosure choices. One risk with partial patenting in the United States (though not typically in Europe, where the leader is given a right to use its unpatented, previously invented IP) is that the follower may obtain a patent over some or all of the withheld part of the leader's innovation (see, e.g., Friedman, Landes, and Posner, 1991; Denicolò and Franzoni, 2002). The formal analysis requires a model of two-sided incomplete information with sequential signalling that is beyond the scope of this article. Because our main interest here is why some IP is left *unpatented,* the addition of follower innovation and patenting would be a major concern if they overwhelmed the forces we model that push against full patenting. Here we argue that this does not occur—full patenting is not an equilibrium—and provide some evidence that our analysis of partial patenting is robust.

A follower confronts problems similar to those faced by the leader in deciding on protection and disclosure. Suppose the follower privately draws an innovation $c_j \in [0, \overline{c}]$ after observing the leader's choices and can only patent an "improvement," which is feasible whenever $c_j < s_i$. Also suppose, for reference, that equilibrium behavior involves full patenting by both parties. This behavior necessarily leads to situations in which the follower provides the leader with an attractive option for infringing on the follower's technology (e.g., i has a draw near $\overline{c}$ while j is near zero) and where i and j infringe. Full patenting by the follower is dominated, therefore, by a deviation to partial disclosure. A similar argument also reveals that full patenting is not an equilibrium outcome for the leader. Such a choice is dominated by a partial disclosure deviation: choosing the disclosure of a higher-cost type and then producing at that cost level when necessary to avoid infringement on any follower improvement patent, the innovator necessarily earns a strictly greater payoff.[18]

We can also isolate a pure effect of follower innovation from effects due to follower patenting and disclosure. As $g \to 0$ and property rights vanish, the protection choice is moot and imitation incentives are dominant. In equilibrium, the leader employs secrecy and discloses partially when the innovation is significant (Anton and Yao, 2003).

More broadly, weak property rights make imitation and infringement a primary concern, and, as in our basic analysis, we expect to find the tradeoff between signalling cost capability (and damage payments) and transferring enabling knowledge. These initial steps provide a measure of assurance on robustness, but further work is needed on follower innovation to identify the interaction of protection and disclosure incentives.

□ **Damage function.** In practice, damages to past infringement fall into two categories: reasonable royalties and lost profits (see, e.g., Blair and Cotter, 2001; Schankerman and Scotchmer, 2001). A reasonable royalty has been interpreted by the U.S. courts as a royalty based on a hypothetical negotiation between a "willing" licensor and licensee. Infringement damages in our model—an exogenous (percentage) rate times infringing sales—roughly correspond to the common practice of basing reasonable royalties on sales. Lost profit is defined as a payment that would make the patentholder "whole" from infringement. In the United States, reasonable royalties

[18] Suppose that the follower is expected to patent to the full extent feasible. Consider $c_i = 0$ and suppose i patents fully at $s_i = 0$. This action effectively makes the follower's innovation draw and patent options irrelevant, but it comes at the cost of transferring the full innovation to all follower types and triggers a strong infringement response.

are the default if the patentee cannot establish the extent of lost profits. To determine whether lost profits should be awarded, courts commonly use the *Panduit* test: the patentholder must establish (1) demand, (2) absence of acceptable noninfringing substitutes, (3) manufacturing/capability, and (4) amount of profit that would have been made. Applied to our model, a literal interpretation of *Panduit* element (2) makes a lost-profits award unlikely (noninfringing production at $\bar{c}$). In such a case, reasonable royalties would typically be used.[19]

Interpret the lost profits measure as follows. Assuming the court makes an accurate assessment and defining g (as before) to be the expected damage rate, lost profits are the (absolute value) of the difference between $\pi_i\,(c, \overline{c}, \mathcal{P}, \mathcal{N})$ from Lemma 2 and the realized profit $\pi_i\,(c, s, \mathcal{P}, \mathcal{I})$ from market competition for the analog of Lemma 1, with objective functions corresponding to the lost-profit measure. It is easy to show that the follower will always infringe.[20] We find a dividing line for (c, s) pairs, much like Figure 1, above which the follower infringes in a timid fashion by producing the reference Cournot output and realized lost profit is zero. Below the dividing line, there is aggressive infringement and realized lost profits are positive. The incentives of the innovator for partial disclosure are then similar to those in our base model (full disclosure above the dividing line and partial below). More significantly, differences between the outcomes given each of the damage functions become increasingly less important as property-right protection becomes weaker because profits obtained through market competition increasingly dominate the profits obtained through damages.

One limitation of our model is that we treat the effective expected penalty rate g as exogenous.[21] Relaxing this assumption could prove interesting. For example, one could model $g'(s) < 0$, which would cover the possibilities that greater disclosure would increase the likelihood that a court will find infringement or award greater per-unit damages based on the extent of infringement. If $g'(s) < 0$, then it remains optimal for the follower to make full use of s. Partial use only increases production costs without changing expected damage payments. Making g an endogenous function of s creates an additional benefit to disclosure, thereby pushing the signalling tradeoff toward greater disclosure in equilibrium. The leader payoff in (7) determines the slope of the signalling function via the benefit-to-cost ratio implied by the partial with respect to c divided by the partial with respect to s. With an endogenous $g(s)$, the numerator is unchanged but the denominator falls, implying a steeper tradeoff. Alternatively, the follower could reduce the probability of infringement by using less than s.[22] Under nonextreme versions of $g(s)$, these cases will most likely lead to increased disclosure at the margin, though the signalling analysis will probably be considerably more complex.

7. Conclusion

■ Our model focuses on three features of innovation and the patent system: innovation implies incomplete information, property rights often provide only limited protection from imitation, and disclosures make imitation feasible. In settings where imitation is a real possibility, the interplay between property rights, disclosure, and the imitation decision is key to managing IP. In this section we discuss some empirical implications of our theory and then modelling extensions.

[19] Further, the courts often find it difficult to assess the counterfactuals needed to assess lost profits, as might be expected under incomplete information. This frequently results in lost profits that bear strong similarities to reasonable royalties: the patentholder's unit margin (at the actual price) times either lost sales or sometimes even the defendant's actual sales (Blair and Cotter, 2001).

[20] The leader follows the standard Cournot best response, since a lost-profit objective is effectively a rescaling of realized market profit. The follower becomes less aggressive, since the objective includes a potentially positive weight on the leader's market profit. The competition-stage equilibrium under infringement then takes one of the two forms described above.

[21] Damages in our model do, however, increase as the extent of infringement increases.

[22] In this case, let t be the cost chosen by the follower and assume $g = \Gamma(s, t)$, where the partials Γ_1 and Γ_2 are negative. When full use is optimal by the follower, the leader is effectively choosing the infringement probability and the analysis is similar to the first case but with $\Gamma(s, s)$ substituting for $g(s)$. Partial use by the follower involves a more complex analysis. We conjecture that the more muted follower action leads to more leader disclosure.

Our cost-oriented model offers some predictions relating innovation size, market structure, imitation, and disclosure. To the extent that firms have been treating IP in a business-sophisticated way, the model predicts that (abstracting from litigation fixed-cost effects) small process innovations will not be imitated, in contrast to medium and large process innovations that will be imitated, where imitation will be associated with an infringement lawsuit or perhaps licensing.[23] The size of the innovation may be estimated by examining the change between pre- and post-innovation market share. Large cost differentials—larger innovations—will lead to a larger relative market share for the innovator. In industries where property rights are generally considered weak, we further predict that very large cost differentials will not be associated with infringement suits, though some (low-royalty) licensing may occur. In such cases, for example, our model suggests that an exogenous increase in the strength of property rights might lead a firm that had previously relied on nominal license fees and (more) secrecy to try to collect substantial license fees (through the threat of enforcement of the patent) and to increase the fee revenue by disclosing additional enabling knowledge, which in turn encourages greater output by the competition. The change in the strength of patent protection after the advent of the Federal Circuit provides a natural experiment with which to look for such changes.

Two standard concerns of the R&D literature involve investment incentives and licensing. With respect to investment incentives, our model could be used to connect issues of appropriability under conditions of incomplete information, limited property rights, and imitation to incentives to innovate.[24] For example, it might be interesting to see if weaker property rights create a bias toward investment in smaller over larger innovations because small innovations have effectively better IP protection.

Licensing is a more complex variant of the basic problem we analyze and would be quite valuable to develop in the context of our framework. The basic inference and imitation issues remain critical: the potential licensee needs to know the value of the license before it can strike a deal, and as the value is difficult to establish absent disclosure, some amount of partial, but enabling, disclosure will typically be necessary. The analysis in our "implicit licensing" case provides a preliminary result in this direction—the fallback or threat points for each party to the license negotiation—that is helpful for the analysis of fully strategic licensing in the joint presence of incomplete information and limited property rights.[25]

Finally, a natural extension of our model is to settings in which innovators disclose enabling knowledge to third parties to induce market demand, e.g., indirectly through the development of complementary products or facilitating financial backing (Bhattacharya and Ritter, 1983), or directly to obtain buyers (Anton and Yao, 2002). Such disclosures run the risk that some of the enabling knowledge will flow to competitors. The interest of noncompetitors will turn on their assessment of the relative advantage of the new technology over the old. That assessment requires noncompetitors to make inferences based on disclosed knowledge, just as the competitors do in our basic model. Further, even though the targets of the signal may be noncompetitors, the signal is likely to reach competitors as well. Thus, information-flow strategies directed to noncompetitors should not be divorced from issues affecting direct competitors such as we have analyzed in this article.

Appendix

■ Proofs of Lemmas 4 and 5, Corollary 1, and Propositions 1 and 2 follow. We discuss technical issues but omit several proofs (available from authors).

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[23] It is only in the last decade or so that firms have begun serious efforts to manage IP from a business point of view (Grindley and Teece, 1997). Firms signal credibility via publications (Hicks, 1995) and through patents (Cohen, Nelson, and Walsh, 2000). Rivette and Kline (2000) note how firms have begun to use patents to assess a competitor's relative technology position.

[24] See Katz and Shapiro (1987) for a model involving innovation incentives and imitation.

[25] Under the assumptions adopted in our model, antitrust laws will sometimes present an impediment to the use of licensing, as both players compete in the market even when the follower is using the old technology. The form of licensing (e.g., per-unit fees) is also likely to be constrained in close-call situations.

□ **Lemmas 1, 2, and 3 and related results.**

Lemma A1. Let $t \in [0, \bar{c}]$ and $g \in [0, 1)$. Suppose firm j has cost $c_j \in [t, \bar{c}]$. Suppose firm i 's cost type is private information and takes values in $[0, t]$ with c.d.f. G, and let $\mu \equiv \int_0^t c_i dG(c_i)$ be the mean cost type of i. Strategies are nonnegative quantity choices of q_j for j and $q_i(c_i)$ for each $c_i \in [0, t]$. Payoffs are $\pi_j = (p - c_j)q_j - gpq_j$ and $\pi_i = (p - c_i)q_i + gpq_j$. Then a unique Bayesian equilibrium exists. When $(1 - g)(\alpha + \mu) > 2c_j$, we have

$$q_j^* = \frac{1}{\beta(3-g)}\left[\alpha - \frac{2}{1-g}c_j + \mu\right],$$

$$q_i^*(c_i) = \frac{1}{\beta(3-g)}\left[\alpha(1-g) - \frac{3-g}{2}c_i - \frac{1+g}{2}\mu + \frac{1+g}{1-g}c_j\right];$$

when $(1 - g)(\alpha + \mu) \leq 2c_j$, we have $q_j^* = 0$ and $q_i^*(c_i) = (\alpha - c_i)/2\beta$ (monopoly for i).

For Lemma 1 set $t = c_j = s$ and let G be degenerate at $c_i = \varphi_{\mathcal{P}}^{-1}(s)$, so that $\mu = c_i$. For Lemma 2 set $t = s$, $c_j = \bar{c}$, let G be degenerate at $c_i = \varphi_{\mathcal{P}}^{-1}(s)$, and set $g \equiv 0$. Finally, for Lemma 3 set $t = c_j = s$, let G be degenerate at $c_i = \varphi_{\mathcal{S}}^{-1}(s)$, and set $g \equiv 0$. Now, let $\pi_i^*(c_i)$ be the payoff to i in Lemma A1. We record for reference:

Lemma A2. $\pi_i^*(c_i)$ is strictly decreasing in μ if j is active and constant in μ if j is inactive.

□ **Proofs of Lemma 4, Corollary 1, and related results.**

Proof of Lemma 4. The proof is straightforward. We develop Table A1 to summarize optimal $\{\mathcal{I}, \mathcal{N}\}$ choices for j, employing Lemma A1 for off-equilibrium cases. Thus, suppose j observes $(t, \mathcal{P})$ by i, where $t \in [0, \bar{c}]$, and holds (mean) belief $\mu \in [0, t]$. In Figure 1, consider a horizontal line at vertical height t with μ ranging from zero to t. We can divide $[0, t]$ into at most three subintervals, say K_M, $K_{\mathcal{I}}$, and $K_{\mathcal{N}}$. For $\mu \in [0, t]$, j chooses to be inactive when $\mu \in K_M$, $\mathcal{I}$ when $\mu \in K_{\mathcal{I}}$, and $\mathcal{N}$ when $\mu \in K_{\mathcal{N}}$. When t lies on the boundary between cases, one of these intervals typically collapses to a single point; we omit these details from the table. Recall that $t = e(\mu)$ is the EP line and e^{-1} denotes the inverse; the domain for the EP line is $\mu \in [2\bar{c} - \alpha, c^*]$ when $2\bar{c} - \alpha > 0$ and $[0, c^*]$ when $2\bar{c} - \alpha \leq 0$. In the table, $M \equiv \max\{[(1 - g)/2]\alpha, c^*\}$, and $m \equiv \min\{[(1 - g)/2]\alpha, c^*\}$.

While j is indifferent between $\mathcal{I}$ and $\mathcal{N}$ when $t = e(\mu)$, firm i strictly prefers an $\mathcal{I}$ choice by j. Let $\pi_i^{\mathcal{I}}(c)$ be the payoff to type i in Lemma A1 when $c_j = t$ (i.e., j chose $\mathcal{I}$) and let $\pi_i^{\mathcal{N}}(c)$ be the corresponding payoff when $c_j = \bar{c}$ and $g \equiv 0$ (i.e., j chose $\mathcal{N}$). We have

Lemma A3. Suppose $\alpha k(g) < \bar{c} < \alpha/(1 + g)$, so that $c^* \in (0, \bar{c})$. For the Bayesian game of Lemma A1, suppose (μ, t) lies on the EP line. Then $\pi_i^{\mathcal{I}}(c) > \pi_i^{\mathcal{N}}(c)$ for all $c \in [0, t]$.

Proof of Corollary 1. We must show $q_j > 0$ holds for any of the possible equilibrium paths, namely, $(s, \mathcal{P}, \mathcal{I})$, $(s, \mathcal{P}, \mathcal{N})$, or $(s, \mathcal{S})$. The case of $2\bar{c} - \alpha \leq 0$ follows directly from Lemma A1, as does the case of $2\bar{c} - \alpha > 0$ for types $c \in (2\bar{c} - \alpha, \bar{c}]$.

TABLE A1 **Follower $\mathcal{I}$ Versus $\mathcal{N}$ Choice Range for Mean Belief μ**

Disclosure t	K_M	$K_{\mathcal{I}}$	$K_{\mathcal{N}}$
Case: $2\bar{c} - \alpha > 0$			
$t > (1 - g)\bar{c}$	$[0, 2\bar{c} - \alpha]$	ϕ	$(2\bar{c} - \alpha, t]$
$(1 - g)\bar{c} > t > M$	$\left[0, \frac{2}{1-g}t - \alpha\right]$	$\left(\frac{2}{1-g}t - \alpha, e^{-1}(t)\right]$	$\left[e^{-1}(t), t\right]$
Case: $M > t > c^*$	ϕ	$\left[0, e^{-1}(t)\right]$	$\left[e^{-1}(t), t\right]$
Case: $M > t > \frac{1-g}{2}\alpha$	$\left[0, \frac{2}{1-g}t - \alpha\right]$	$\left(\frac{2}{1-g}t - \alpha, t\right]$	ϕ
$m > t$	ϕ	$[0, t]$	ϕ
Case $2\bar{c} - \alpha < 0$			
$t \geq e^{-1}(0)$	ϕ	ϕ	$[0, t]$
$e^{-1}(0) > t > c^*$	ϕ	$\left[0, e^{-1}(t)\right]$	$\left[e^{-1}(t), t\right]$
$c^* > t$	ϕ	$[0, t]$	ϕ

Consider $c \in [0, 2\bar{c} - \alpha]$. It is straightforward to show that if j is inactive in equilibrium, then type c necessarily discloses $s \geq [(1-g)/2](\alpha + c)$. Next, suppose that, in equilibrium, j is inactive following the disclosure and patent choice of some type $c_0 \in [0, 2\bar{c} - \alpha]$. Then c_0 discloses $s_0 \geq [(1-g)/2](\alpha + c_0)$ and earns the monopoly payoff (of type c_0). Let $c_1 \equiv [(1-g)/2]\alpha$. Since $c_1 \leq s_0$, the disclosure s_0 is feasible for any $c \in [0, c_1]$. Further, with j inactive, a deviation by c to type c_0's equilibrium choice yields the monopoly payoff (for c). Hence, in equilibrium, each $c \in [0, c_1]$ earns the monopoly payoff and j is inactive.

With j inactive, we know from above that c_1 discloses $s_1 \geq [(1-g)/2](\alpha + c_1) \equiv c_2$. Then all $c \in [c_1, c_2]$ must earn a monopoly payoff and j must be inactive, in equilibrium, as the disclosure s_1 is feasible. Iterating, we construct a sequence via $c_n = [(1-g)/2](\alpha + c_{n-1})$. By induction, $c_n = \rho\alpha \sum_{k=1}^{n-1} \rho^k$, where $\rho \equiv [(1-g)/2] \in (0, 1)$. Hence, $c_n \to [\alpha\rho/(1-\rho)] = s^*$. However, $2\bar{c} - \alpha < s^*$ by $\bar{c} < [\alpha/(1+g)]$. Then j is active for sufficiently large n, since, eventually, $c_n > 2\bar{c} - \alpha$. Thus, there is no type $c_0 \leq 2\bar{c} - \alpha$ for which j is inactive in equilibrium *Q.E.D.*

□ **Lemma 5 and related results.** We generalize Lemma 5 (to Lemma A6). Consider the payoff $\pi_i(c, \sigma, \mathcal{S})$ for type $c \in [0, \sigma]$ at a disclosure $\sigma \in [0, c^*]$; consider $\pi_i(c, r(c), \mathcal{P}, \mathcal{I})$ for $c \in [0, c^*]$ at a disclosure $r(c) \equiv [(1+g)/2]c^* + [(1-g)/2]c$. Lemma A6 establishes when there exists a type-disclosure pair (c_σ, σ) such that these payoff functions cross at c_σ. These payoff functions are as follows. At $(r(c), \mathcal{P})$ by type c, we have $r(c) < [(1-g)/2](\alpha + c) \Leftrightarrow c^* < s^*$. By Lemma 1, j is active, and by Lemma 4 and Table A1, j chooses $\mathcal{I}$. Then, with $s = r(c)$ in (4),

$$v(c) \equiv \pi_i(c, s, \mathcal{P}, \mathcal{I}) = \frac{1}{\beta(3-g)^2}\left[\alpha - \frac{3-g}{2}c + \frac{1+g}{2}c^*\right]^2 + \frac{gc}{\beta(3-g)}\left[\alpha - \frac{1+g}{1-g}c^*\right],$$

for any $c \in [0, c^*]$. Next, at $(\sigma, \mathcal{S})$ by a type c, where $c \in [0, \sigma]$ and $\sigma \in [0, c^*]$, we apply Lemma 3 to find j is active $\Leftrightarrow c > 2\sigma - \alpha$. Substituting into the payoff for i, we have

$$w(c, \sigma) \equiv \pi_i(c, \sigma, \mathcal{S}) = \begin{cases} \dfrac{1}{9\beta}(\alpha - 2c + \sigma)^2 & \text{for } c > M \equiv \max\{2\sigma - \alpha, 0\}, \\ \dfrac{1}{4\beta}(\alpha - c)^2 & \text{for } c \leq 2\sigma - \alpha, \end{cases}$$

(the lower branch is vacuous if $2\sigma - \alpha \leq 0$); w is defined for $c \in [0, \sigma]$ and $\sigma \in [0, c^*]$. The interval $[M, \sigma]$ is nonempty, as $M < \sigma$ always holds; the cases of $2\sigma - \alpha \gtreqless 0$ both arise, as $2c^* - \alpha \gtreqless 0$ occurs across $(g, \bar{c}, \alpha)$ values.

Define $\Delta(c, \sigma) = w(c, \sigma) - v(c)$ for $c \in [0, \sigma]$, $\sigma \in [0, c^*]$. The following properties are valid. First, Δ is strictly convex for $c \in [M, \sigma]$. Next, if $2\sigma - \alpha > 0$, then (i) Δ is linear in c over $[0, 2\sigma - \alpha]$, (ii) Δ is continuous at $c = 2\sigma - \alpha$, and (iii) Δ has a kink at $c = 2\sigma - \alpha$ and the partial derivative of w satisfies $0 > w_c^- > w_c^+$ at $(2\sigma - \alpha, \sigma)$. Finally, $\Delta(\sigma, \sigma) < 0$. Next, for the $(g, \bar{c}, \alpha)$ parameter cases that lead to $2c^* - \alpha \gtreqless 0$, we have

Lemma A4. If $g < 1/3$ and $\bar{c} > \alpha r(g) \equiv (\alpha/4)[3 - (1-3g)h(g)]$, then $2c^* - \alpha > 0$. If $g < 1/3$ and $\bar{c} < \alpha r(g)$ or if $g > 1/3$, then $2c^* - \alpha < 0$.

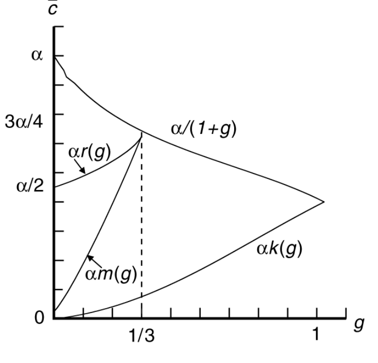
Lemma A5. If $g < 1/3$ and $\bar{c} > \alpha m(g)$, then we have $(3 - 5g)c^* > 2g\alpha$. If $g < 1/3$ and $\bar{c} < \alpha m(g)$ or if $g > 1/3$, then we have $(3 - 5g)c^* < 2g\alpha$.

As g varies, $m(g)$ rises from $m(0) = 0$ to $m(1/3) = 3/4$, and $r(g)$ rises from $r(0) = 1/2$ to $r(1/3) = 3/4$. Also, $m(g) < r(g)$ for $g < 1/3$. See Figure A1. We now have

Lemma A6. Assume $\alpha k(g) < \bar{c} < \alpha/(1+g)$. Suppose $(g, \bar{c}, \alpha)$ satisfy $g < 1/3$ and $\bar{c} > \alpha m(g)$. Then, for each

FIGURE A1

PARAMETER CASES



$\sigma \in [\underline{\sigma}, c^*]$ there exists a unique c_σ such that $\Delta(c_\sigma, \sigma) = 0$. Further, (i) $\Delta(c, \sigma) \gtreqless 0$ as $c \lesseqgtr c_\sigma$, (ii) c_σ increases with σ, and (iii) c_σ is between $\max\{2\sigma - \alpha, 0\}$ and σ, with $c_\sigma = 0$ for $\sigma = \underline{\sigma}$. Suppose, instead, that $g \geq 1/3$ or that $g < 1/3$ and $\bar{c} < \alpha m(g)$. Then $\Delta(c, \sigma) < 0$ for all $c \in [0, \sigma]$ and any $\sigma \in [0, c^*]$.

Lemma 5 follows from Lemma A6 with $\sigma = c^*$ and c_L for the crossing value c_σ.

Proof of Proposition 1. We verify that the equilibrium payoff $U(c)$ to i for each $c \in [0, \bar{c}]$ at the candidate disclosure and patenting choice exceeds the payoff for any feasible deviation, that j is choosing optimally from $\{\mathcal{I}, \mathcal{N}\}$, and that quantities are optimal. Supporting beliefs are specified later. By $(g, \bar{c}, \alpha) \in A$, the three ranges are well defined as $0 < c_L < c^* < \bar{c}$.

For $c \geq c^*$, we have $\varphi_\mathcal{P}(c) = c$. $\mathcal{N}$ is optimal for j, as $(c, \varphi_\mathcal{P}(c))$ lies above EP for $c \geq c^*$ (Table A1). By Lemma 2, j is active at $(\varphi_\mathcal{P}(c), \mathcal{P}, \mathcal{N})$, since $c \geq c^* > 2\bar{c} - \alpha$. Then, $U(c) = (1/9\beta)(\alpha - 2c + \bar{c})^2$. For $c^* > c > c_L$, with $(c, \varphi_\mathcal{P}(c))$ below EP, j chooses $\mathcal{I}$ (Table A1) and is active at $(\varphi_\mathcal{P}(c), \mathcal{P}, \mathcal{I})$ by Lemma 1. By (4),

$$U(c) = \pi_i(c, \varphi_\mathcal{P}(c), \mathcal{P}, \mathcal{I}) = \frac{1}{\beta(3-g)^2}\left[\alpha - \frac{3-g}{2}c + \frac{1+g}{2}c^*\right]^2 + \frac{g}{\beta(3-g)}\left[\alpha - \frac{1+g}{1-g}c^*\right]c.$$

For $c_L \geq c$, j is active at $(\varphi_\mathcal{S}(c), \mathcal{S})$, by Lemmas 3 and 5, and $U(c) = \pi_i(c, \varphi_\mathcal{S}(c), \mathcal{S}) = (1/9\beta)[\alpha - (3/2)c + c^* - (c_L/2)]^2$. For reference, $U(c)$ is strictly decreasing and convex in each of the three regions; U is continuous at $c = c_L$, by Lemma 5; at $c = c^*$, however, there is a downward jump in U, as j is indifferent between $\mathcal{I}$ and $\mathcal{N}$ for $(c^*, \varphi_\mathcal{P}(c^*))$ on the EP line. The equilibrium specifies $\mathcal{I}$ by j and, by Lemma A3, $U(c^*) > \lim_{c \downarrow c^*} U(c)$. With j indifferent, we could also specify $\mathcal{N}$ by j; then type c_L chooses $(\varphi_P(c_L), \mathcal{P})$ rather than $(c^*, \mathcal{S})$. Either specification works equally well and has no other impact.

We need the following result to compare $U(c)$, for $c \leq c^*$, to deviation payoffs.

Lemma A7. Assume $(g, \bar{c}, \alpha) \in A$. Let c_0 and s_0 satisfy $0 < c_0 \leq c_L$ and $[(1+g)/2]c^* + [(1-g)/2]c_0 \leq s_0 < [(1-g)/2](\alpha + c_0)$. Suppose σ_0 satisfies $\pi_i(c_0, \sigma_0, \mathcal{S}) = \pi_i(c_0, s_0, \mathcal{P}, \mathcal{I})$. Then $\pi_i(c, \sigma_o - (1/2)(c_0 - c), \mathcal{S}) \gtreqless \pi_i(c, s_0 - [(1-g)/2](c_0 - c), \mathcal{P}, \mathcal{I})$ as $c \lesseqgtr c_0$, for any $c \in [0, c_0']$, where $c_0' > c_0$ is defined by $e(c_0') = s_0 - [(1-g)/2](c_0 - c_0')$.

We apply Lemma A7 with $c_0 = c_L$, $s_0 = \varphi_\mathcal{P}(c_L)$, and $\sigma_0 = c^*$. Consider deviations by i.

Case 1. $\bar{c} \geq c > c^*$. Feasible deviations for c are to patent and disclose $\hat{c} = \varphi_\mathcal{P}(\hat{c})$ for some $\hat{c} > c$. Upon inferring $\hat{c}$, j chooses $\mathcal{N}$ and then produces $\hat{q}_j = q_j(\hat{c}, \mathcal{P}, \mathcal{N})$, by Lemma 2. The best response for i is $q_i^{BR} = (1/2\beta)(\alpha - c - \beta\hat{q}_j)$. The deviation payoff of $u(\hat{c}, c) = (1/9\beta)(\alpha - (3/2)c - (1/2)\hat{c} + \bar{c})^2$ is strictly decreasing in $\hat{c}$. Hence, $U(c) > u(\hat{c}, c)$.

Case 2. $c^* \geq c > c_L$. There are three kinds of feasible deviations: (i) to the small innovation region at a $\hat{c}$ where $\hat{c} > c^*$, (ii) within the medium innovation region to a $\hat{c}$ where $c < \varphi_\mathcal{P}(\hat{c}) \leq c^*$, and (iii) to the large innovation region at $\hat{c}$ where $c \leq \varphi_\mathcal{S}(\hat{c}) \leq c^*$.

(i) $\hat{c} > c^*$: As in Case 1, $u(\hat{c}, c) = (1/9\beta)(\alpha - (3/2)c - (1/2)\hat{c} + \bar{c})^2$ is decreasing in $\hat{c}$. It is sufficient to show $U(c) \geq \lim_{\hat{c} \downarrow c^*} u(\hat{c}, c)$. As (c^*, c^*) lies on the EP line, set $t = \mu = c^*$ in Lemma A3 to see $U(c) = \pi_i^\mathcal{I}(c) > \pi_i^\mathcal{N}(c) = \lim_{\hat{c} \downarrow c^*} u(\hat{c}, c)$.

(ii) $c < \varphi_\mathcal{P}(\hat{c}) \leq c^*$. j infers $\hat{c}$ from $\varphi_\mathcal{P}(\hat{c})$, and chooses $\mathcal{I}$ and $\hat{q}_j = q_j(\varphi_\mathcal{P}(\hat{c}), \mathcal{P}, \mathcal{I})$, by Lemma 1. Then $q_i^{BR} = (1/2\beta)[\alpha - c - \beta(1+g)\hat{q}_j]$, and (7) implies $U(c) = u(\hat{c}, c)$; as we see later, $\varphi_\mathcal{P}(c)$ necessarily involves weak incentive compatibility in (c_L, c^*).

(iii) $c \leq \varphi_\mathcal{S}(\hat{c}) \leq c^*$. From $\varphi_\mathcal{S}(\hat{c})$, j infers $\hat{c}$ and $\hat{q}_j = q_j(\varphi_\mathcal{S}(\hat{c}), \mathcal{S})$, and i earns $u(\hat{c}, c) = (1/9\beta)(\alpha - (3/2)c + c^* - c_L/2)^2$, by Lemma 3. Thus, c is indifferent across feasible $\hat{c}$ deviations into the large innovation region. As $c > c_L$, $U(c) > u(\hat{c}, c)$ holds by Lemma A7.

Case 3. $c_L \geq c$.

(i) $\hat{c} > c^*$. As above, $u(\hat{c}, c) = (1/9\beta)(\alpha - (3/2)c - (1/2)\hat{c} + \bar{c})^2$ is decreasing in $\hat{c}$, so $U(c) \geq \lim_{\hat{c} \downarrow c^*} u(\hat{c}, c)$ is sufficient. From Case 2, $U(c') > \lim_{\hat{c} \downarrow c^*} u(\hat{c}, c')$ for $c' \in (c_L, c^*)$. Since U is continuous at c_L, we have $U(c_L) > \lim_{\hat{c} \downarrow c^*} u(\hat{c}, c_L)$, implying $3c^* \geq c_L + 2\bar{c}$ and, in turn, that $U(c) \geq \lim_{\hat{c} \downarrow c^*} u(\hat{c}, c)$ holds.

(ii) $c^* \geq \hat{c} > c_L$. Calculate $u(\hat{c}, c)$ as in Case 2(ii). For $c < c_L$, Lemma A7 implies $U(c) > u(\hat{c}, c)$. At $c = c_L$, we have equality and the type c_L is indifferent.

(iii) $c^* \geq \varphi_\mathcal{S}(\hat{c}) \geq c$. Calculate $u(\hat{c}, c)$ as in Case 2(iii). This yields $U(c) = u(\hat{c}, c)$; as we see later, $\varphi_\mathcal{S}(c)$ necessarily involves weak incentive compatibility in $[0, c_L]$.

Finally, for supporting beliefs at out-of-equilibrium $(s, \mathcal{P})$ and $(s, \mathcal{S})$ choices, the linear extension of $\varphi_\mathcal{P}(c)$ to $[0, c_L]$ and the mean belief $\mu = \varphi_\mathcal{P}^{-1}(s)$ for $s \in [\varphi_\mathcal{P}(0), \varphi_\mathcal{P}(c^*)]$, along with $\mu = \underline{c}$ for $s < \varphi_\mathcal{P}(0)$ is sufficient. A linear extension of $\varphi_\mathcal{S}$ to $(c_L, \bar{c}]$, however, will induce deviations (by types near c^*). It suffices to take beliefs at $(s, \mathcal{S})$ for $s > c^*$ to be $\mu = \bar{c}$ or $\mu = s$. Intermediate inferences also work. *Q.E.D.*

Proof of Proposition 2. The conditions are sufficient for a PBE: apply the proof of Proposition 1 with c_σ and $\varphi_\mathcal{S}(c_\sigma) = \sigma$

in place of c_L and $\varphi_{\mathcal{S}}(c_L) = c^*$ For payoff dominance, we compare the equilibrium in Proposition 1 to that with c_σ and σ for $\underline{\sigma} < \sigma < c^*$. As $c_\sigma < c_L$, all types above c_L earn the same payoff. By Lemma A7, $\pi_i(c, c^* - (1/2)(c_L - c), \mathcal{S}) > \pi_i(c, [(1+g)/2]c^* + [(1-g)/2]c, \mathcal{P}, \mathcal{I})$ for $c \leq c_L$, so all $c \in [c_\sigma, c_L]$ strictly prefer c_L and $\varphi_{\mathcal{S}}(c_L) = c^*$. For $c \in [0, c_\sigma]$, $\pi_i(c, c^* - (1/2)(c_L - c), \mathcal{S}) > \pi_i(c, \sigma - (1/2)(c_\sigma - c), \mathcal{S})$ reduces to $c^* - (1/2)c_L > \sigma - (1/2)c_\sigma$. By Lemma 5, c_σ and σ satisfy $\pi_i(c_\sigma, \sigma, \mathcal{S}) = \pi_i(c_\sigma, [(1+g)/2]c^* + [(1-g)/2]c_\sigma, \mathcal{P}, \mathcal{I})$. Using Lemma A7 at $c = c_\sigma$, we have $\pi_i(c_\sigma, c^* - (1/2)(c_L - c_\sigma), \mathcal{S}) > \pi_i(c_\sigma, \sigma, \mathcal{S})$, and this implies $c^* - (1/2)c_L > \sigma - (1/2)c_\sigma$.

Now consider necessary conditions. Reserve $\varphi_{\mathcal{P}}(c)$ and $\varphi_{\mathcal{S}}(c)$ for candidate equilibrium choices. First, we derive PBE continuation payoffs. Let j observe $(t, \mathcal{S})$ by i and hold mean belief $\mu \in [0, t]$. Then, q_j^* in Lemma A1 with $c_j = t$ and $g \equiv 0$ is optimal for j, and, similarly, $q_i^*(c)$ for i is a best response. The continuation payoff for i from $(t, \mathcal{S})$ is then $u_i(c, t, \mathcal{S}; \mu) = (1/9\beta)(\alpha - (3/2)c - (1/2)\mu + t)^2$ for $t < (\alpha + \mu)/2$, and $(1/4\beta)(\alpha - c)^2$ for $t \geq (\alpha + \mu)/2$. If $(t, \mathcal{S})$ occurs in equilibrium, then $\mu = \varphi_{\mathcal{S}}^{-1}(t)$. Off equilibrium, beliefs need only support equilibrium and satisfy Bayes' rule $(\mu \leq t)$; by Lemma A1, only the mean is payoff relevant.

Now, let j observe $(t, \mathcal{P})$ and hold $\mu \in [0, t]$. For each t and μ, PBE requires that we apply Table A1 for $\mathcal{I}$ or $\mathcal{N}$ by j and Lemma A1 for quantities. The continuation payoff is

$$u_i(c, t, \mathcal{P}; \mu) = \frac{1}{\beta(3-g)^2}\left[\alpha - \frac{3-g}{2}c - \frac{1-g}{2}\mu + t\right]^2 + \frac{gc}{\beta(3-g)}\left[\alpha - \frac{2}{1-g}t + \mu\right],$$

for $\mu \in K_{\mathcal{I}}$ at t, $(1/9\beta)[\alpha - (3/2)c - (1/2)\mu + \bar{c}]^2$ for $\mu \in K_{\mathcal{N}}$ at t, and $(\alpha - c)^2/4\beta$ for $\mu \in K_M$ at t. Note that u_i is single-valued unless μ and t are on the EP line: $t = e(\mu)$ and $\mu \in K_{\mathcal{I}} \cap K_{\mathcal{N}}$ imply $\mathcal{N}$ or $\mathcal{I}$ is optimal for j, and u_i has two possible values. We have

Lemma A8. u_i is nonincreasing in μ, and strictly decreasing in μ whenever j is active.

In a separating PBE, by feasibility, a disclosure of $\bar{c}$ leads j to infer i is type $\bar{c}$. As a convention, set $\varphi_{\mathcal{P}}(\bar{c}) = \bar{c}$. Now, suppose that $c \in (c^*, \bar{c})$ chooses $(s, \mathcal{S})$ for some $s \in [c, \bar{c}]$. Separation implies $s < \bar{c}$, and j infers c from $(s, \mathcal{S})$. By Lemma 3 , i earns $\pi_i(c, s, \mathcal{S}) = (1/9\beta)(\alpha - 2c + s)^2$. Let c deviate to $(t, \mathcal{P})$ for some $t \geq c$. By Lemma A8, c earns at least $u_i(c, t, \mathcal{P}; t)$, where $\mu = t$. By $c^* < c \leq t$, j chooses $\mathcal{N}$. Comparing, $u_i(c, t, \mathcal{P}; t) > \pi_i(c, s, \mathcal{S}) \Leftrightarrow \frac{1}{2}(c - t) + \bar{c} > s$, and the deviation is strictly profitable at $t = c$. Thus, all $c \in (c^*, \bar{c})$ use $\mathcal{P}$ in equilibrium. Next, suppose $c \in (c^*, \bar{c})$ chooses $(s, \mathcal{P})$ with $s > c$. Then $(s, \mathcal{P})$ is feasible for any $\hat{c} \in (c, s]$. Let $(\hat{s}, \mathcal{P})$ be the equilibrium choice of such a $\hat{c}$. As (c, s) and $(\hat{c}, \hat{s})$ each lie above the EP line, j must choose $\mathcal{N}$. Then, $\hat{c}$ prefers $(s, \mathcal{P})$ to $(\hat{s}, \mathcal{P}) \Leftrightarrow u_i(\hat{c}, s, \mathcal{P}; c) > \pi_i(\hat{c}, \hat{s}, \mathcal{P}, \mathcal{N}) \Leftrightarrow \hat{c} > c$. Hence, $\varphi_{\mathcal{P}}(c) = c$ for $c \in (c^*, \bar{c})$.

Now consider $c \leq c^*$. If some $c \leq c^*$ chooses $(s, \mathcal{S})$ with $s > c^*$ then, as $c \leq c^*$, it is feasible for c to deviate to $(\hat{c}, \mathcal{P})$ for any $\hat{c} > c^*$. Type c must prefer $(s, \mathcal{S})$ to $(\hat{c}, \mathcal{P})$ and $\pi_i(c, s, \mathcal{S}) \geq u_i(c, \hat{c}, \mathcal{P}; \hat{c}) \Leftrightarrow s \geq \bar{c} - (1/2)(\hat{c} - c)$. This must hold for any $\hat{c} > c^*$, so $s \geq \bar{c} - (1/2)(c^* - c)$. Consider $\hat{c} = \bar{c} - (1/2)(c^* - c)$: clearly, $c^* < \hat{c} \leq \bar{c}$, since $c \leq c^*$, and $(s, \mathcal{S})$ is feasible for type $\hat{c}$, since $s \geq \hat{c}$. Then, $\hat{c}$ strictly prefers $(s, \mathcal{S})$ to $(\hat{c}, \mathcal{P}) \Leftrightarrow u_i(\hat{c}, s, \mathcal{S}; c) > \pi_i(\hat{c}, \hat{c}, \mathcal{P}, \mathcal{N}) \Leftrightarrow s > \bar{c} - (1/2)(\hat{c} - c)$, which holds since $\hat{c} > c^*$. Thus, $s \leq c^*$ for any equilibrium choice of $(s, \mathcal{S})$. This implies c^* chooses $(c^*, \mathcal{P})$ in equilibrium, as the only possible $(s, \mathcal{S})$ equilibrium choice for c^* has $s = c^*$; this holds whether j (who is indifferent) chooses $\mathcal{I}$ or $\mathcal{N}$ upon observing $(c^*, \mathcal{P})$ and inferring type c^* for i.

Next, suppose some $c \in (c_L, c^*)$ chooses $(s, \mathcal{S})$. Then, $s \leq c^*$ holds and type c earns $\pi_i(c, s, \mathcal{S})$. Let c deviate to $(t, \mathcal{P})$ for some $t \in (c, c^*)$. By Lemma A8, this earns at least $u_i(c, t, \mathcal{P}; t)$, where $\mu = t$. Since $\mu = t < c^*$, Table A1 implies that j must choose $\mathcal{I}$, since $\mu = t \in K_{\mathcal{I}} = [0, t]$. Then, the deviation is strictly profitable for t sufficiently close to c^*. First, $\pi_i(c, s, \mathcal{S}) \leq \pi_i(c, c^*, \mathcal{S})$, by Lemma A2. Next (from the proof of Lemma 5), $0 > \Delta(c) \equiv \pi_i(c, c^*, \mathcal{S}) - \pi_i(c, r(c), \mathcal{P}, \mathcal{I})$ for $c \in (c_L, c^*)$. Also, $\lim_{t \uparrow c^*} u_i(c, t, \mathcal{P}; t) = \pi_i(c, r(c), \mathcal{P}, \mathcal{I})$. Combining, $\pi_i(c, s, \mathcal{S}) < u_i(c, t, \mathcal{P}; t)$ for $t < c^*$ and t sufficiently close to c^*. Thus, no $c \in (c_L, c^*)$ uses $\mathcal{S}$ in equilibrium.

Then, $c \in (c_L, c^*)$ earns $\pi_i(c, s, \mathcal{P}, \mathcal{I})$ in equilibrium. Let c deviate to $(\hat{s}, \mathcal{P})$, where $(\hat{s}, \mathcal{P})$ is the equilibrium choice of a $\hat{c} \in (c, c^*)$. In equilibrium, c must prefer $(s, \mathcal{P})$ to $(\hat{s}, \mathcal{P})$, so $\pi_i(c, s, \mathcal{P}, \mathcal{I}) \geq u_i(c, \hat{s}, \mathcal{P}; \hat{c})$. Define

$$n(c, x) = \frac{1}{\beta(3-g)^2}\left[\alpha - \frac{3-g}{2}c + x\right]^2 + \frac{gc}{\beta(3-g)}\left[\alpha - \frac{2}{1-g}x\right].$$

As in Lemma A2, $n(c, x)$ is strictly increasing in x. Further, $\pi_i(c, s, \mathcal{P}, \mathcal{I}) = n(c, s - [(1-g)/2]c)$ and $u_i(c, \hat{s}, \mathcal{P}; \hat{c}) = n(c, \hat{s} - [(1-g)/2]\hat{c})$. Hence, $s - [(1-g)/2]c \geq \hat{s} - [(1-g)/2]\hat{c}$ in equilibrium. This holds for $\hat{c}$ arbitrarily close to c^*, so $s - [(1-g)/2]c \geq c^* - [(1-g)/2]c^* = [(1+g)/2]c^*$, since $\hat{c} \leq \hat{s} < c^*$. Then, $s \geq [(1+g)/2]c^* + [(1-g)/2]c \equiv r(c) > c$, as $c < c^*$, and we have partial disclosure.

Partial disclosure implies $(s, \mathcal{P})$ is a feasible deviation for $\hat{c} \in (c, s]$. Since $\hat{c}$ must prefer $(\hat{s}, \mathcal{P})$ to $(s, \mathcal{P})$, the same argument implies $\hat{s} - [(1-g)/2]\hat{c} \geq s - [(1-g)/2]c$. Hence, $\hat{s} = s + [(1-g)/2](\hat{c} - c)$. It now follows that $\varphi_{\mathcal{P}}(c) = r(c)$ for $c \in (c_L, c^*)$: let some $c_0 \in (c_L, c^*)$ choose $(s_0, \mathcal{P})$ in equilibrium with $s_0 > r(c_0)$. Define $c_1 = s_0$ and, as above, $\varphi_{\mathcal{P}}(c_1) = s_1 = s_0 + [(1-g)/2](c_1 - c_0)$. Construct a sequence (c_n) via $c_n = c_{n-1} + [(1-g)/2](c_{n-1} - c_{n-2})$ for $n \geq 2$. Then $\lim_{n\to\infty} c_n = [2s_0 - (1-g)c_0]/(1+g) > c^*$, since $s_0 > r(c_0)$. But then $\varphi(c_n) > c_n > c^*$ holds for large n, which is not possible. Hence, $\varphi_{\mathcal{P}}(c) = r(c)$ for $c \in (c_L, c^*)$. Consider $c \in [0, c_L]$. Let Σ be the set of types who choose $\mathcal{S}$ in equilibrium. If $\Sigma = \phi$, then all types choose $\mathcal{P}$ and, from above, $\varphi_{\mathcal{P}}(c) = r(c)$. Thus, suppose $\Sigma \neq \phi$. In equilibrium, $(s, \mathcal{S})$ by $c \in \Sigma$ must satisfy (i) $s \leq c^*$; (ii) $c < \bar{c} - (1/2)(c^* - c) < s$; and (iii) if $\hat{c} \in \Sigma$ and $\hat{c} < c$, then $s > \hat{s} \geq s - \frac{1}{2}(\hat{c} - c)$, with equality if $c \leq \hat{s}$. Claim (i) is from above; (ii) is via a deviation by c to the range above c^*; and (iii) follows from a deviation by $\hat{c}$ to $(s, \mathcal{S})$ and, when feasible, vice versa. Define $c_\sigma \equiv \sup \Sigma$ and $\sigma \equiv \sup\{s \mid s = \varphi_{\mathcal{S}}(c)$ for some $c \in \Sigma\}$. From above, $c_\sigma \leq c_L$ and $\sigma \leq c^*$ must hold. Also, by claim (iii) for Σ, for any sequence of types in Σ converging to c_σ, $\varphi_{\mathcal{S}}(c)$ converges monotonically to σ. Finally, as above, all $c > c_\sigma$ choose $(r(c), \mathcal{P})$ in equilibrium. We claim $\pi_i(c_\sigma, \sigma, \mathcal{S}) = \pi_i(c_\sigma, r(c_\sigma), \mathcal{P}, \mathcal{I})$. To see this, take $c \in \Sigma$ such that $c_\sigma - \varepsilon < c \leq c_\sigma$ for $\varepsilon > 0$. By claim (ii) for Σ, $\varphi_{\mathcal{S}}(c) > c$. For small ε, $(\varphi_{\mathcal{S}}(c), \mathcal{S})$ is feasible for type $\hat{c} \in (c_\sigma, c_\sigma + \varepsilon)$. With $c < \hat{c}$, c can deviate to $(\varphi_{\mathcal{P}}(\hat{c}), \mathcal{P})$. The claim follows from incentive compatibility as $\varepsilon \to 0$. By Lemma A6, the resulting profit equality requires $\underline{\sigma} \leq \sigma$.

We now show that all $c < c_\sigma$ choose $\varphi_{\mathcal{S}}(c) = \sigma - (1/2)(c_\sigma - c)$ in equilibrium. Instead, suppose $c < c_\sigma$ chooses $(s, \mathcal{P})$. Since j is active, c earns $\pi_i(c, s, \mathcal{P}, \mathcal{I})$. By construction of c_σ, we can find $\hat{c} \in \Sigma$ such that $c < \hat{c} \leq c_\sigma$. Then $(\hat{s}, \mathcal{S})$, where $\hat{s} = \varphi_{\mathcal{S}}(\hat{c})$, is feasible for c and incentive compatibility implies $\pi_i(c, s, \mathcal{P}, \mathcal{I}) \geq u_i(c, \hat{s}, \mathcal{S}; \hat{c})$. As $\hat{c}$ approaches c_σ (or taking $\hat{c} = c_\sigma$ if $c_\sigma \in \Sigma$), $u_i(c, \hat{s}, \mathcal{S}; \hat{c})$ converges to $u_i(c, \sigma, \mathcal{S}; c_\sigma)$. Thus, $\pi_i(c, s, \mathcal{P}, \mathcal{I}) \geq u_i(c, \sigma, \mathcal{S}; c_\sigma)$. Type c can also feasibly deviate to $(r(\hat{c}), \mathcal{P})$, the equilibrium choice of $\hat{c} \in (c_\sigma, c^*)$. Incentive compatibility implies $s > r(c)$. To rule this out for c in a neighborhood of c_σ, suppose $r^{-1}(c_\sigma) < c < c_\sigma$ so that $(s, \mathcal{P})$ is feasible for $\hat{c} > c_\sigma$ and near c_σ. Incentive compatibility implies $s = r(c)$. With $s = r(c)$, however, apply Lemma A7 (set $c_0 = c_\sigma$, $s_0 = r(c_\sigma)$ and $\sigma_0 = \sigma$) to see that $u_i(c, \sigma, \mathcal{S}; c_\sigma) = \pi_i(c, \sigma - (1/2)(c_\sigma - c), \mathcal{S}) > \pi_i(c, r(c_\sigma) - [(1 - g)/2](c_\sigma - c), \mathcal{P}, \mathcal{I}) = \pi_i(c, r(c), \mathcal{P}, \mathcal{I})$, which violates incentive compatibility. Thus, $c \in \Sigma$ for all $c \in (r^{-1}(c_\sigma), c_\sigma)$.

Now, if $c_\sigma < r(0)$, then, from above, $c \in \Sigma$ and $\varphi_{\mathcal{S}}(c) = \sigma - (1/2)(c_\sigma - c)$ for all $c < c_\sigma$. If, instead, $c_\sigma \geq r(0)$, then define $\eta = \sup\{c \mid c < c_\sigma$ and $c \notin \Sigma\}$. We find that η and s_η satisfy $\pi_i(\eta, s_\eta, \mathcal{P}, \mathcal{I}) = \pi_i(\eta, \sigma - (1/2)(c_\sigma - \eta), \mathcal{S})$. But Lemma A7 implies that incentive compatibility will be violated and some type at or below η will strictly prefer a deviation to $(\varphi_{\mathcal{S}}(c), \mathcal{S})$ for $\eta < c < c_\sigma$. Thus, all types below c_σ choose $\mathcal{S}$ and disclose $\varphi_{\mathcal{S}}(c) = \sigma - (1/2)(c_\sigma - c)$.

Finally, type c_σ can choose $(\sigma, \mathcal{S})$ or $(\varphi_{\mathcal{P}}(c_\sigma), \mathcal{P})$ in equilibrium if $\sigma < c^*$. For $\sigma = c^*$, however, if j chooses $\mathcal{I}$ at $(c^*, \mathcal{P})$, then equilibrium requires that type c_L choose $(c^*, \mathcal{S})$; if j chooses $\mathcal{N}$, then c_L must choose $(\varphi_{\mathcal{P}}(c_L), \mathcal{P})$. Beyond this, equilibrium structure is not affected.

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