

Ownership, governance, and the brand-capital firm

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Abstract

We study the effect of ownership and governance on what is arguably a firm's most valuable asset: its reputation. We model a "brand-capital", a firm whose sole asset is its reputation with consumers. We show that, for such firms, professional non-owner-management can protect brand capital provided management compensation and retention policy are set by outsiders. Moreover, if compensation policy is transparent, professional management can sometimes protect brand capital better than owner-management. Separating ownership and management separates owners from incentives to opportunistically harvest reputation capital and provides them with incentives to counter managerial opportunism.

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1 Introduction

Corporate reputations are valuable. Nakamura (2009), for example, finds that the stock of corporate intangible assets is worth approximately three trillion dollars and has roughly the same value as the stock of tangible assets. Gaines-Ross (2008) estimates that reputation accounts for more than 60% of firm value.¹ Much of this value is brand capital, and brand capital depends on reputation with consumers. Thus, many firms, both large and small, can aptly be described as “brand-capital firms,” firms whose value is driven by brand reputation.

The reputation of a brand-capital firm adheres to the firm as a whole, not the specific agents who manage the firm (Barney, 1986). However, these fairly anonymous “reputationless” managers’ actions affect each firm’s reputation. For example, Lululemon Athletica’s reputation for product quality was damaged by mid-level factory managers who skimmed on material quality, and J.P. Morgan’s reputation for risk management was damaged by an anonymous trader’s (the “London Whale’s”) losses resulting from excessive risk taking. Hence, it is not surprising that brand-capital firms set up *control systems* to ensure reputable managerial behavior. Such systems impose external checks through monitoring, supervision, and cost accounting. The systems sometimes also impose internal checks by instilling a “corporate culture,” i.e., producing a managerial taste for reputation-preserving behavior. An example is Toyota’s program to instill the “Toyota Way” culture (Liker, 2004).

In this paper, we explore the optimal corporate governance of brand-capital firms. We do this by modeling a firm whose only source of value is its reputation for product quality. If management is delegated to a professional manager, the owner decides when to operate the firm and also fixes the manager’s compensation, which can vary with the observable past performance of the firm. Quality is important to the firm because, not only is high-quality production first best, but the price for goods known to be low quality is lower than their cost of production. In each period, the firm’s manager can undertake one of two actions: (1) an opportunistic action which raises current profit but risks harming the firm’s reputation by stochastically lowering the quality of its output, or (2) a reputable action, which entails lower current profit but protects the firm’s reputation by ensuring high-quality output. Outsiders, including the firm’s owner when its man-

¹Corporate reputations are valuable because reputable firms better motivate and retain employees (Edmans, 2011), are better able to maintain customers (Armour et al., 2010), can charge higher prices for their products (Milgrom and Roberts, 1982, 1986; Allen, 1984), maintain higher profitability (Roberts and Dowling, 2002), and obtain financing on favorable terms (Srivastava et al., 1997; Billet et al., 2014).

agement is delegated to a professional, cannot observe the action choice. The firm is endowed with a control system which can limit the manager's actions. If the control system is "secure," the manager must undertake the reputable action. If the control system is "insecure," the manager is free to choose between the opportunistic and reputable actions. Only the manager knows whether the control system is secure or insecure. Other agents, including the firm's owner if management is delegated, update their prior assessments of the security of the control system based on the observed quality of the firm's output. The firm's reputation is based on these outsider assessments about its control system.

In this framework we ask two questions: (a) Is it optimal for the owner to manage the firm or should management be delegated to a professional, and (b) if management is delegated, how should the manager be compensated? Since Jensen and Meckling (1976), the consensus answer to (a) in the contracting literature is that separation of ownership from management generates agency costs and thus, *ceteris paribus*, owner-management is optimal. Moreover, much of the contracting literature's answer to (b) is that, if ownership and management must be separated, optimal compensation contracts should aim to replicate the incentive effects of ownership through "high-powered" compensation schemes (Murphy, 1999). We show that, for brand-capital firms, these answers are generally not valid. We derive conditions under which delegated management supports firm reputation better than owner-management, and show that the optimal compensation for professional managers is "bureaucratic," featuring simple fixed payment contracts.

The superiority of delegated management arises because of the manner in which separating ownership and management changes the locus of the agency problem in a reputation setting. The source of the gain from delegated management is the "commitment effect." When the control system is insecure, under owner-management, the owner can capture opportunism gains by unobservably switching from the reputable to the opportunistic action. Since the owner-manager's opportunism is private and unobservable, if the owner-manager decides to deviate from the reputable strategy, consumer beliefs about the quality of the firm's goods, and hence the goods' prices, only change with a lag and even then only when opportunism actually lowers quality. In contrast, under delegated management, while the manager can act opportunistically, the owner no longer makes operating decisions and thus cannot capture opportunism gains. Instead, the non-managing owner is confined to deciding whether to pay the manager opportunism-detering compensation, *i.e.*, compensation sufficient to deter managerial opportunism. The compensation contracts, by their very nature must be observable and verifiable if they are to be enforced. Thus, by choosing to pay opportunism-

detering compensation, the non-managing owner publicly commits the manager to reputable actions. Consequently, if the owner deviates from paying reputation-ensuring compensation to a professional manager, this deviation will immediately be impounded into consumers' assessment of product quality and the price of the firm's goods. The immediacy of the updating of consumer beliefs favors the optimality of delegated management because it raises the owner's cost of deviating from reputation-assuring policies.

A second effect, which we term the "ignorance effect," militates against the optimality of delegated management. When the control system is insecure, the payment of opportunism-detering compensation alters the manager's behavior and thus the firm's reputation risk. When the control system is secure and effectively controls opportunism, the compensation simply enriches the manager at the owner's expense without benefiting the firm. The non-managing owner, who is an informational outsider, must decide on the value of opportunism-detering compensation without knowing the security of the firm's control system. Like consumers, the non-managing owner must use Bayes' rule and a prior assessment to assess the likelihood that the system is secure. Hence, when outsider assessments of the control system's security are high, the non-managing owner is fairly certain the control system is secure and compensation payments are unnecessary and wasteful. Consequently, the owner will eschew paying opportunism-detering compensation and risk the firm's reputation by gambling on the control system working. The incentive effects of outsiders' assessments of the security of the control system work in the opposite direction for an owner-manager: When outsiders' assessments of the security of the control system are high, the prices of the firm's goods are high and thus the future profits risked by opportunistic behavior are larger. Therefore, increasing the outsider assessments improves the incentives of the owner-manager when the owner-manager knows that, in fact, the control system is insecure.

The balance between the commitment and ignorance effects produces two potential governance mechanisms: (1) insider ownership and insider control, and (2) ownership by "arms-length" outsiders coupled with management delegated to a professional. Insider ownership and control is optimal when the firm's control system is relatively secure and thus its manager has limited freedom of action. In contrast, arms-length ownership with delegated management is optimal when the control system is relatively insecure and the manager has considerable freedom of action. In this case, under the optimal governance mechanism, the separation between ownership and management is "wide:" Agents who are not privy to inner workings of the firm's control systems (e.g., an outsider board) retain decision control over some policies (e.g., man-

agement compensation and retention policies), while decision control over actions that directly impact the firm's reputation are entrusted to a professional manager who has intimate knowledge of the control system.

One might imagine from our discussion that an even better solution to governance problem would be to capture the value of commitment without the costs of ignorance through informed owners and delegated management. However, we show that this form of insider governance fails because, observable decisions made by non-managing *inside* owners, have inference effects, i.e., they reveal the insiders' private information about the security of the control system. We show that these inference effects are so large that, when insiders know the control system is insecure, they prefer to "cover up" by mimicking the optimal policies of firms with secure control systems. This cover up prevents insider-controlled firms from reaping the benefits of delegated management. Thus, our model predicts that delegated management will be correlated with governance institutions that vest control in outsider dominated boards. Not only is vesting directorial control in uninformed agents essential for delegated management, it is also not harmful under owner-management. Owner-managers who lack information about the security of the control system behave like informed owner-managers. Thus, vesting ultimate control in the hands of agents without private information about the workings of the control system is a weakly dominant policy.

To facilitate the comparison between delegated and owner-management, we derive the optimal compensation and retention policies for delegated managers. These contracts take the form of a "bullet payment" conditioned simply on the firm's reputation being untarnished at all dates prior to the bullet payment. Otherwise, the payment is fixed and independent of most of the parameters that determine firm value. Thus, managers are "bureaucrats" whose compensation only depends on the firm avoiding a scandal up to their bullet payment date. For a large range of model parameter values, the bullet payment date is close to or at the end of the manager's tenure and thus resembles the "hold-till-retirement" stock plans at firms like Deere and Citigroup or Supplemental Executive Retirement Plans (SERPs), under which deferred compensation is funded out of firm cash flows. The optimal retention policy is to terminate the manager if and only if the quality of the firm's output reveals that the control system is insecure. Terminating a professional manager who acts disreputably maximizes his penalty for jeopardizing the firm's reputation. This ex ante incentive effect ensures that termination following reputation damage is optimal. The combination of bullet payment and termination function much like the "efficiency wage" in Shapiro and Stiglitz (1984). The bullet payment raises the manager's payoff from reputable behavior above the manager's labor market reservation value and

thus provides the manager with rents. The threat of termination makes these rents contingent on the insecurity of the control system not being revealed. Since revelation is correlated with managerial opportunism, the bullet payment discourages managerial opportunism.

1.1 Related literature

A number of papers, like ours, have shown that changing the ownership structure of an organization can change the nature of the agency problem, and thereby increase economic efficiency. For example, Glaeser and Shleifer (2001) assume that organizing as a not-for-profit firm blocks direct diversion of funds. The cost of organizing as a not-for-profit is that blocking diversion forces owners to extract gains indirectly through inefficient perk consumption. When the commitment benefit outweighs the cost of inefficient perk consumption, the not-for-profit organizational form dominates the corporate form. In our analysis, as in Glaeser and Shleifer, by separating ownership and management, owners alter their ability to capture rents from opportunism. However, in contrast to Glaeser and Shleifer, in our model, separating ownership and management does not directly block diversion. In fact, the opportunities for diversion are the same for owners and non-owner-managers. Nevertheless, in our analysis, separation of ownership and management gives owners an incentive to commit to block opportunistic diversion and sometimes inhibits diversion. Levin and Tadelis (2005) focus on a setting where consumer monitoring of quality is imperfect and the firm's reputation for quality is fixed by hard-wired actions of its employees, who have heterogeneous agent-specific human capital. They demonstrate that the corporate form of organization may be dominated by a partnership. Our analysis also demonstrates that organizational form can affect firm performance. However, we focus on a very different economic environment; one in which human capital is general, managers are interchangeable, and the hard-wired attribute—security of the control system—is agent independent. In this environment, we identify conditions under which bureaucratic delegated management is optimal.

Our modeling approach closely follows that of the classic reputation models of Kreps and Wilson (1982) and Milgrom and Roberts (1982). This approach has been used previously in the finance literature (e.g., Maksimovic and Titman (1991)). In fact, the structure of our model—ex post but not ex ante observable quality and a finite multi-period time horizon—reflects our desire to make reputation formation in our model track as closely as possible the process of reputation formation in these papers. This ensures that our results on corporate governance (the central focus of the paper) are driven by our analysis of governance rather than

by how reputations form in our model. The key difference between our model and the classic reputation model is that, in our model, reputation adheres to the firm through its control system rather than the specific agents who own and manage the firm.² In fact, in our model, individual agents have no personal reputations. Managers are anonymous, fungible, and replaceable. However, their actions affect the inferences made by outsiders regarding the firm's control system and thus its reputation.

One consequence of our close adherence to the classic reputation model is that, for the firm to remain viable, firm actions cannot reveal that the control structure is insecure. This follows from the same logic as the classic model: If the firm is revealed to be insecure, backward induction leads to unraveling. Consumers will forecast that the firm will opt for low quality production strategies in all subsequent periods. This holds regardless of the compensation/retention policies chosen by the delegated-management firm or the size of the potential profits from reputable behavior contemplated by the owner-manager. In this respect, both our model and the classic reputation model rest on the following intuition: absent some level of confidence in the control system, neither incentive schemes, the threat of termination, nor the promise of profits, can enforce reputable corporate behavior. This shared intuition, to some extent, coincides with the management literature's perspectives on reputation maintenance which downplay or omit the role of personnel replacement while emphasizing control systems and culture (Beer, 2011).

In contrast to the classic reputation model, we posit a noisy relation between agent actions and output quality. Board and Meyer-ter Vehn (2013) posit both a noisy relation between agent actions and output quality as well as a stochastic relation between output quality and consumer information when they analyze reputation formation. In contrast to our analysis, they study the reputation of a single agent who undertakes all actions which affect reputation. They focus on reputation dynamics when firm investments affect product quality. We consider reputation when ownership and management are separated and thus the owner takes some actions that affect reputation while the manager takes others. Our concern is not with identifying possible reputation dynamics but rather with examining how reputational considerations affect the optimal choice of governance structure.

In our setting, a firm's control system is a "trans-individual" attribute that is not dependent on the agent

²This perspective on locus of reputation is standard in the management literature. For example, Gaines-Ross (2008) attributes corporate reputation loss to organizational failure, citing dozens of examples of reputations lost and reputations rebuilt through changes in governance, organization structure and culture. Reputation restoring structural changes can be targeted as high as board level oversight or as low as factory worker behavior.

managing the firm. Many researchers have considered how reputations might extend beyond individual agents. Kreps (1996) sketches a model in which corporate culture adheres to firms, and shows how corporate culture, which supports firm reputation, might arise endogenously from equilibrium agent behavior. Kreps' concept of corporate culture is similar to our concept of control system. In contrast to Kreps, we take the presence of control systems as given and analyze how they influence the optimal governance of firms. Tadelis (1999) and Hakenes and Peitz (2007) also consider how firm reputations can survive separately from reputed individuals. Tadelis (1999) shows that, when the sale of firms is only partially observable, current firm reputation can reflect the reputation of past owners. Hakenes and Peitz (2007) show that, when sales are observable, reputable buyers have a comparative advantage when buying reputable firms. Mailath and Samuelson (2001) also consider the question of reputation purchase. In contrast to Hakenes and Peitz (2007), in Mailath and Samuelson, when they are the good "competent type," firms also make an effort decision. In this setting, they show that good type firms buy firms with average reputations, while bad "inept" types buy firms with extremely high or low reputations. While these papers show that firm reputation can persist when ownership changes, Cremer (1986) considers how the internal structure of organizations can facilitate reputation persistence over time. His analysis shows that, in an overlapping generations framework, the reputation forming incentives of younger agents can counter the diminished reputation formation incentives of older agents and thereby support long-lived reputation equilibria. These papers are quite different from ours in that they do not consider the governance issues we analyze and instead focus on the foundations for trans-individual reputation formation rather than its effects.

The design of optimal compensation contracts in our paper resembles the efficiency wage contracts in Shapiro and Stiglitz (1984) in that it deliberately fixes compensation above the manager's reservation level in order to provide the manager with an incentive to value employment continuation. One difference between our design and Shapiro and Stiglitz is that in our model payments are delayed only until the end of the period over which reputable behavior is assured. A number of papers have derived conditions under which payment delay is optimal (e.g., Clementi and Hopenhayn, 2006; Hart and Moore, 1990). A number of authors have also pointed out problems with incentivizing agents with high-powered compensation contracts. For example, Holmstrom and Milgrom (1991) show that in a multi-tasking environment, high powered incentives can lead agents to inefficiently focus on tasks whose output is more easily measured. Our paper provides another rationale for the optimality of managerial compensation that is fairly fixed, delayed, and

generates managerial rents: reputation preservation.

The remainder of the paper is organized as follows: In Section 2 we describe our baseline model. Section 3 contains results on the effect of ownership and governance on reputation in the context of our baseline model. Section 4 provides insights into the effects of changes in the information structure of our baseline model. We examine the effect of changing our baseline assumptions about the lifespans of managers and firms in Section 5. Section 6 concludes the paper with a summary of our results and a discussion of possible extensions. Proofs of all claims are presented in the Appendix.

2 Model

Consider an economy populated by one firm and risk-neutral agents. The economy operates for the set of dates $\mathcal{T} = \{0, 1, 2\}$, and the agents are “patient” and do not discount future cash flows.³ We refer to the interval of time between adjacent dates $t - 1$ and t as “period t .” Later we extend the analysis to allow for more periods. There is no storage technology. Thus, any cash flow received in a period must be spent in that period, and a good produced in a period t , a “period t ” good, must be sold and consumed during the period.

The firm has a single owner. We first consider the case of an “outside owner” who delegates operating decisions to a professional non-owner-manager who has an information advantage. Later, we examine the effect of removing the owner’s information disadvantage, and allowing the owner to also operate the firm. Each period, the owner must choose whether to operate or shut down the firm for the period. At the beginning of each period in which the owner wants to operate the firm, she must provide the manager with operating capital equal to e .⁴ This equals the cost of a high-quality production technology the manager can implement in the period. The manager can instead implement a low-quality production technology costing $I < e$. Both production technologies produce one unit of a good at the end of the period. The good’s quality, either high,

³We have chosen a finite time setting so that our framework is comparable to that employed in seminal models of reputation. In these models, a finite time horizon facilitates a unique equilibrium. Our analysis reveals that a finite time horizon is not necessary to ensure a unique equilibrium under delegated management. We have assumed a zero discount rate to improve exposition. The assumption that all agents discount at the same positive rate would produce identical results.

⁴We have made this assumption in the interest of brevity. As will become clear below, the owner never has an incentive to inject more than e into the firm in a period since the extra funds cannot improve product quality. The owner never wants to inject less than e since the manager can then only implement the low-quality technology, which is less profitable than not operating, and also has no advantage over not operating from the perspective of producing information about the nature of the firm’s control system.

h , or low, l , depends on the manager's technology choice. The high-quality technology always produces a high-quality good. The low-quality technology produces a high-quality good with probability $\delta \in (0, 1)$ and a low quality good with probability $1 - \delta$.

The manager's technology choice is unobservable, and he may be able to unobservably divert the entire cost saving from implementing the low-quality technology, $c = e - I$, to personal consumption. The firm has a control system to restrict diversion. The control system can either be "secure," type-S, or "insecure," type-J. Only the manager observes the control system's type. At the beginning of the first period, both consumers and the owner share a prior belief that the control system is type-S with probability ρ_1 . If the control system is type-S, the manager cannot divert *any* of the firm's funds. He can divert c when the control system is type-J, but cannot deplete the firm's funds below I , the minimum expense consistent with operating through diversion. This assumption captures the idea that "excessive" diversion becomes observable. For example, if the manager took the owner's entire capital infusion and diverted it to personal consumption, no workers would be hired, no contracts signed, no supplies purchased. Such a high level of diversion would be obvious and, thus, actionable in a court of law. However, the diversion of marginal funds accompanied by hiring lower quality workers or buying lower quality supplies is undetectable.

Each good is sold to a continuum of consumers through Bertrand competition. Since consumers cannot observe the manager's technology choice, they do not know the good's quality when they set its price, p . The market price is common knowledge, verifiable and contractible. Consumer preferences are common knowledge: all consumers assign a value of 1 to a high-quality good and 0 to a low-quality good. Thus, a good's value equals its probability of being high quality. All agents learn a good's quality after consumers purchase it, which ensures that its quality is common knowledge at the start of the subsequent period. While a good's quality is observable, we assume that it is not verifiable for contracting purposes.⁵ Figure 1 provides a snapshot of the timing of decisions in the model and within each period.

The owner can offer the manager a compensation contract whose terms are set at the beginning of period one.⁶ All agents, including consumers, can observe the contract's terms. Later we examine the role of this

⁵For discussion of the "observable, but not verifiable" assumption we make on product quality here, see Grossman and Hart (1986) and Hart and Moore (1990).

⁶We make this assumption without any loss of generality. In an earlier version of this paper, in a setting with more than two periods, we derived the optimal contract when the owner cannot commit to a long-term contract and can only contract on a payment in the subsequent period. The optimal contract under this more restrictive condition is identical to the optimal contract we derive below. Also, as we demonstrate later, the owner's welfare cannot be increased by contracting payments at date t dependent on revenues realized before $t - 1$.

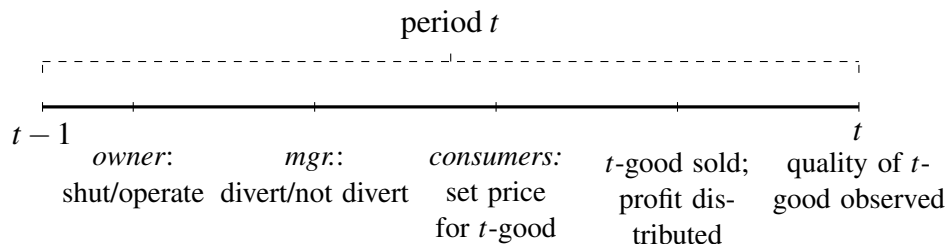


Figure 1: *Time Line*. This figure presents the sequence of actions within time period t under delegated management

assumption. Under the contract, in each period t , the payment, $B_t(p)$, depends on the period t good's price, p . When the firm operates, the price is the clearing price generated by consumers' Bertrand competition for the good. In periods where the firm does not operate, the price is assumed to equal 0. Because the firm only sells one unit of the good, the period t good's price is also the firm's period t revenue. We focus solely on contracts where B is non-decreasing in the good's price in each period. We assume that the manager has limited liability, which ensures that payments to the manager are non-negative. These restrictions are standard in the contracting literature (e.g., Innes, 1990; Nachman and Noe, 1995; DeMarzo and Duffie, 1999). Since directly contracting on output or net profit is not permitted, our framework is the most restrictive contracting environment consistent with any dependence between compensation and managerial actions.

To simplify the analysis, we normalize the manager's per-period reservation wage to zero. We assume that the manager is drawn from a continuum of managers with identical abilities and preferences, both of which are common knowledge. Thus, firm reputation is not dependent on the manager's characteristics, and the owner has all the bargaining power in compensation negotiations.⁷ Our assumption that the manager is drawn from a limitless pool of identical potential managers, raises the issue of manager turnover. The following analysis will transparently show that the owner has no incentive to replace the manager so long as she wants to continue operating the firm. Thus, in order to simplify our exposition, we will assume that the manager is not replaced.

In order to focus on the subset of the parameter space that yields interesting and insightful results, we impose the following restrictions on prior beliefs and the low-quality technology:

⁷The inability of the manager to capture rents from personal reputation lowers the minimum level managerial compensation and thus reduces the likelihood of reputable firm behavior under delegated management. In this sense, the assumption is conservative.

Assumption 1.

$$\rho_1 + (1 - \rho_1)\delta \geq e.$$

Assumption 2.

$$I > \delta > 0.$$

Assumption 3.

$$(1 - \delta)(\delta(1 - \rho) - e + \rho) - c\delta \geq 0.$$

Assumption 1 ensures that, given period 1 prior beliefs, even if consumers believe that the manager will always divert when the control system is insecure, the period 1 price they set will cover the cost of production. Assumption 2 ensures that the low-quality technology always produces a high-quality good with positive probability, but once the control system is revealed to be insecure, the probability of producing a high-quality good is too low for production to be profitable for the owner. Thus, the firm's only source of value is its reputation. Assumption 3 ensures that the firm does not want to shut down production simply to avoid paying the manager promised compensation. In essence, shutting down production suppresses information regarding the manager's performance at the cost of losing all operating profits for the period. If these operating profits are very small relative to compensation, cases exist in which the firm will prefer not to operate to avoid making promised payments. Such a policy is ex ante always suboptimal by our earlier assumptions. However ex post, when the benefits of manager decisions have already been captured, absent Assumption 3 such opportunism is sometimes optimal.⁸

When we examine the case where the owner also manages the firm, her information set is the union of the information sets of the owner and the manager under delegated management. Moreover, the owner chooses the production technology and decides whether to consume funds she allocated for production. Consumers cannot observe the owner's technology and diversion choices. Therefore, as is the case under delegated management, consumers are unable to determine the quality of the goods produced by the firm ex ante. Moreover, the owner cannot divert funds if the control system is secure.

⁸We considered this issue in earlier drafts of the paper but because it is tangential to the main issues considered and is only relevant when profits are very small relative to compensation payments, we abstract from this issue in the current draft by considering only cases where such opportunism is suboptimal.

3 Ownership structure and firm reputation

When the firm is managed by a professional, for a specific compensation contract, we define an equilibrium as a Bayesian Nash equilibrium, i.e., a set of owner and manager actions, prices for goods, and beliefs in each period such that:

- a. the owner's shut down/operate strategy is incentive compatible,
- b. the manager's divert/not divert strategy is incentive compatible,
- c. consumers set prices equal to the goods' expected quality conditioned on the owner's and manager's strategies, and
- d. belief updating by consumers and the owner is consistent with Bayes' rule.

A solution to the model is a contract and an associated equilibrium such that there exists no other contract with an associated equilibrium that produces a higher ex ante expected payoff for the owner. When the firm is owner managed, in equilibrium, the owner's shutdown and diversion strategies must be incentive compatible, while consumers' behavior and belief updating remains the same as under delegated management.

We now introduce some terminology and notation to facilitate exposition. We will refer to the firm and its control system as *revealed* once consumers learn that the control system is insecure. We will refer to histories of the game before low-quality output is observed as *unrevealed* histories, and histories after low-quality output is observed as *revealed* histories. Recall that, when the control system is insecure, the manager will undertake one of two actions if the owner finances operations for the period: (a) divert, consume c , and use the low-quality technology, or (b) not divert, not consume c and use the high-quality technology. When the control system is secure, if the owner finances operations, the manager can take only action (b). To simplify the discussion, we will sometimes use the phrase *the manager diverts* without any qualifications to represent the manager's choice of the following strategy: choose action (a) when the control system is insecure and choose action (b) when the control system is secure. Similarly, we will use the phrase *the manager does not divert* to represent the manager choosing action (b) both when the control system is secure and when it is insecure. Also to improve exposition, when consumers and the owner assess a high (low) probability to the control system being secure, we will refer to the control system as *robust (fragile)*.

To enable us to use more compact mathematical expressions, we use a state variable that directly represents a good's value and the price consumers are willing to pay rather than the probability ρ . This state

variable is P , where

$$P = \rho + (1 - \rho) \delta. \quad (1)$$

P clearly captures the price of a good, p , when consumers conjecture that, in the current period, the firm will operate and the manager will divert. If the consumers' conjecture is correct, P also represents the probability that the firm will remain unrevealed at the start of the next period. Because there is a one-to-one relation between P and ρ , we can define how Bayes' rule applies to P . Specifically, by Bayes' rule, when consumers conjecture that the manager will divert and the firm produces a high quality good in period t , the state variable at the start of period $t + 1$ will equal $\Gamma[P_t]$, where Γ is a function of P defined by

$$\Gamma[P] = 1 + \delta - \frac{\delta}{P}. \quad (2)$$

If either (a) the firm does not operate in period 1 or (b) consumers conjecture that the manager will not divert, the state variable at the start of period 2 will equal P_1 following the production of a high quality good in period 1. The firm is revealed if it produces a low quality good in period 1, in which case $P = \delta$ in period 2.

Note that $\Gamma[P] > P$. Moreover, if the firm operates in period 1, the expected value of the period 2 state variable equals the value of the period 1 state variable, i.e.,

$$P_1 \Gamma[P_1] + (1 - P_1) \delta = P_1. \quad (3)$$

Since consumers' posterior belief that the control system is type-S is never lower than ρ_1 after the firm produces high quality in period 1, Assumption 1 ensures that the owner will always operate the firm in period 2 so long as it remains unrevealed. Since $P = \delta$ in period 2 after a low quality good is produced in period 1, Assumption 2 ensures that the owner will shut down the firm in period 2 if the firm is revealed.

Since the preferences and abilities of the owner and manager are common knowledge, from the preceding discussion it is clear that the firm's reputation and hence the prices of its goods are based solely on consumers' assessment of the probability that the firm's control structure is secure, ρ . Since their assessment does not fall unless the firm produces a low-quality good, the firm will maintain its reputation so long as it does not produce a low quality good. Since managerial diversion generates a positive probability of

low-quality output, the reputation can only be assured if the manager completely eschews diversion. We will focus on solutions where the firm is assured of maintaining its reputation for the first period, and we will refer to an equilibrium in which the firm is assured of maintaining its reputation in the first period as a *reputation equilibrium*.

3.1 Reputation under delegated management

The manager's preferences and ability are common knowledge and thus he has no reputation. Moreover, competition with potential managers ensures the manager cannot capture any rents from ability and thus the manager's only income sources are diversion and incentive compensation. Therefore, only incentive compensation can induce the manager to eschew diversion. However, the effectiveness of incentive compensation is limited. Since consumers cannot observe the manager's technology choice, the period t good's price and thus the period t incentive payment will both be insensitive to the manager's period t action. Hence, a period t incentive payment cannot prevent diversion in period t itself. Consequently, the owner must rely on a period 2 incentive payment to curb diversion in period 1. Moreover, the owner cannot use incentive compensation to curb period 2 diversion and thus the manager will always divert in period 2.

If a contract is effective in curbing period 1 diversion, the period 2 state variable $P_2 = P_1$. Otherwise, it may equal δ . Therefore, a "simple contract" that pays the manager a fixed payment b_2 in period 2 only if the firm is unrevealed until period 2 will be as effective in curbing diversion as any contract whose payment displays greater variation with the period 2 good's price.⁹ Now consider the manager's period 1 choice when the owner sets a period 2 incentive payment of b_2 . If the manager eschews diversion in period 1, the firm will remain unrevealed. Thus, the manager will receive the incentive payment b_2 and the owner will choose to operate the firm in period 2. Since the manager will divert in period 2, his expected payoff is the sum of the incentive payment and the expected gain from period 2 diversion, i.e.,

$$b_2 + c. \tag{4}$$

In contrast, if the manager chooses to divert in period 1, he will expect that the firm will be revealed and

⁹The contract design problem is more complex when there are more than two periods. However, in the appendix, we demonstrate that such "simple" contracts are in fact also optimal even when we extend the number of periods in the model.

shut down in period 2 with probability $1 - \delta$. Thus, the manager's expected payoff is

$$c + \delta (b_2 + c). \quad (5)$$

Hence, the lowest incentive payment that will induce the manager to eschew period 1 diversion is b_2^* , where

$$b_2^* = \frac{\delta c}{1 - \delta}. \quad (6)$$

Assumption 1 and equation (3) ensure that the owner will always operate the firm in period 1: By operating the firm in period 1 and paying the manager nothing, the owner can expect to earn $P_1 - e + P_1 \Gamma[P_1]$. In contrast, if he does not operate in period 1, the owner can expect to earn only $P_1 - e$. It is clear that the owner will either choose a compensation contract with no incentive payments or one that pays the manager b_2^* in period 2 if the firm is unrevealed. If the owner offers no incentive compensation, the manager will divert in each period the firm operates. In this case, if the firm is unrevealed at the start of period 2, consumers will have revised their beliefs about the probability that the control system is secure, and, thus, the unrevealed price of the good will rise from P_1 to $\Gamma[P_1]$. The probability that the firm will be unrevealed at the start of period 2 is P_1 . Since it is optimal for the owner to operate the firm in period 2 if it is unrevealed, the owner's expected payoff if she doesn't offer incentive compensation equals

$$P_1 - e + P_1 (\Gamma[P_1] - e). \quad (7)$$

If the compensation contract specifies the incentive payment b_2^* , the manager will not divert in period 1 and the owner will operate the firm in period 2. Because, in this case, it is common knowledge that the manager will not divert, the fact that the firm is unrevealed at the start of period 2 provides consumers with no information about the security of the control system. Thus, consumers will not revise their beliefs and the probability that the firm will be unrevealed at the start of period 2 is 1. Hence, the owner's expected payoff equals

$$1 - e + P_1 - e - b_2^*. \quad (8)$$

The owner will choose to incentivize the manager when the expected payoff (8) is larger than the expected payoff in (7). This leads to the following proposition:

Proposition 1. *If*

$$P_1 \leq 1 - \frac{\delta c}{(1 - \delta)(1 - e + \delta)}, \quad (9)$$

there exists a reputation equilibrium in which the owner will offer an incentive payment of $b_2^ = \frac{\delta c}{1 - \delta}$ in period 2 and the firm will use the high-quality technology in period 1. Otherwise, the owner will not offer incentive compensation and the manager will divert in period 1. If diversion is detected, the firm will shut down in period 2. Otherwise the firm will operate in period 2.*

Proposition 1 provides four primary insights. First, as described by Kreps (1996), a firm can maintain a reputation founded solely on its control system. Second, it can do so even when its management is separate from its ownership, and owners are uninformed. Third, it is optimal for an arms-length owner to bear the cost of incentive payments to reassure consumers about product quality when a firm’s control system is fragile. In contrast, when the control system is robust, it is optimal for the owner to eschew incentive compensation, and instead rely on the control system to maintain product quality.

3.2 The effect of ownership structure on firm reputation

We now demonstrate that owner-management and delegated management provide different incentives to maintain firm reputation. To model the implications of unifying firm ownership and management, we assume the owner has the same ability as a professional manager, and the owner’s ability and preferences are common knowledge. Moreover, the owner knows the control system’s type, and internalizes the entire cost of her technology choice on the firm’s current period profit as well as the entire benefit from the firm’s reputation.

Consider the owner-manager’s period 2 technology choice. Since consumers cannot observe the technology choice, the price cannot vary with the choice. Moreover, since the firm will not operate in the future, the choice has no reputational consequences. Therefore, in equilibrium, the owner-manager will always divert to maximize period 2 profit. She will do so irrespective of whether the firm has been revealed. Recognizing the owner’s incentives, in period 2, after the firm has been revealed by a low-quality period 1 good, consumers will set a price of δ which will make period 2 production unprofitable. Hence, the owner will halt period 2 production after the firm is revealed.

In period 1, the benefits from firm reputation can be strong enough that the owner-manager will prefer

the high-quality technology. To see this, consider the owner's period 1 choice when (a) consumers expect a high-quality good to be produced in the period and (b) the control system is insecure. The owner's expected payoff from choosing the high-quality technology in period 1 and diverting in period 2 equals $1 - e + P_1 - I$. If instead, she diverts in period 1, the firm's organizational structure will be revealed with probability $1 - \delta$. In this event, the owner will shut down the firm in the final period. Therefore, the owner-manager's expected payoff from diverting in period 1 is $1 - e + \delta(P_1 - I) + c$. It follows that the owner will choose the high-quality technology in period 1 if and only if

$$(1 - \delta)(P_1 - I) - c \geq 0. \quad (10)$$

Consequently, the owner will choose the high-quality technology in period 1 whenever the firm's initial reputation P_1 is sufficiently high. In expression (10), $(1 - \delta)(P_1 - I)$ represents the owner's opportunity cost of diverting in period 1.

Proposition 2. *Under owner-management, if*

$$\frac{c}{1 - \delta} < (P_1 - I). \quad (11)$$

there exist only reputation equilibria in which the owner-manager chooses the high-quality technology in period 1.

Proposition 2 demonstrates that an owner-managed firm assures its reputation when its control system is robust. In contrast, Proposition 1 demonstrates that an owner who delegates will pay incentive compensation and assure her firm's reputation when its control system is fragile. When the control system is robust, incentive compensation is no longer optimal and the firm's reputation will be in jeopardy. Thus, a fragile control system means a firm will maintain its reputation only if it delegates management, and a robust control system means that a firm will maintain only its reputation only under owner-management.

Proposition 3. (i) *If a firm's initial reputation, P_1 , is sufficiently fragile, i.e., if*

$$P_1 < \min \left[1 - \frac{\delta c}{(1 - \delta)(1 - e + \delta)}, I + \frac{c}{1 - \delta} \right], \quad (12)$$

then delegated management supports reputation equilibria and owner-management does not.

(ii) If the firm's initial reputation is sufficiently robust, then owner-management supports reputation equilibria and delegated management does not.

What drives the effect of ownership structure on reputation? The owner-manager's decision problem is one of optimal harvesting. If she opportunistically harvests the reputation to raise current period profit, she may reveal the firm's control system and eliminate future gains that flow from the reputation. When the control system is fragile, the future gains from reputation are small relative to the current gain from opportunism. Therefore, the owner-manager is unlikely to maintain the firm's reputation. Under delegated management, the owner is the victim not the beneficiary of opportunism. To assure consumers of quality, the owner has to pay the manager incentive compensation. When the control system is actually secure (insecure), the compensation is irrelevant (effective). Thus, when the control system is fragile, the compensation is cost effective and under delegated management the firm will use compensation to ensure reputation. This calculus reverses when the control system is robust. The owner-manager now has a strong incentive to maintain reputation by eschewing opportunism because the lost-future-profit cost of reputation harvesting is high. When the owner delegates management, she has to pay the manager relatively high compensation to guarantee product quality. However, there is high likelihood that the firm's control system alone is sufficient to prevent diversion. Thus, the owner will eschew incentive compensation, rely on the control system, and risk the firm's reputation.

4 Reputation under alternative information structures

Thus far, in our baseline model, we have assumed that an informed "inside" owner must also manage the firm, and an uninformed owner must delegate to a professional manager. We now consider the effects of breaking the link between being the manager and being informed about the control system. This exercise allows us to examine whether an informed owner can reap the reputation benefit of a delegated management structure, and whether the costs of owner-management are simply generated by the owner's private information regarding the control system. We also consider the consumers' information set and how it affects the viability and optimality of delegated management. This exercise permits us to explore the relation between corporate disclosure and corporate governance.

4.1 Reputation with an “insider” owner

In our baseline model, under delegated management, the separation between ownership and management is both operational and informational: while the manager observes the effectiveness of the control system, the owner, like an outsider, does not. This setup approximates a firm controlled by an outsider board and managed by a professional non-owner-manager. We now allow for an “insider non-managing owner.” To do so, we assume that both the owner and the manager know the security of the control system.

At a technical level, characterizing equilibria with an insider non-managing owner is complex. Because the owner has private information, in addition to affecting the manager’s incentives, the owner’s compensation policy choice also has an “inferential effect”—consumers can use the owner’s compensation choice to infer her private information. Thus, we have a signaling game where compensation policy is the “message” sent by the informed insider whose “type” is the state of the control system. The price of the good is the uninformed consumers’ response. Signaling games usually generate many equilibria, some of which are intuitively implausible. There is an extensive literature on refining the set of equilibria in static signaling games in which the informed agent’s message space and type space are finite. In order to rely on this literature, we restrict the insider owner’s message space to the following three alternatives: (i) operating and not offering incentive compensation, NC, (ii) operating and offering the optimal incentive contract derived in Section 3.1, C, or (iii) shutting the firm down, SH. Because, in period 2, compensation is ineffective and managerial incentives are not affected by consumer beliefs, we are left with a static single period signaling game. In this setting, we use the perfect Bayesian equilibrium (PBE) as our solution concept and refine the set of equilibria using the standard D1 refinement.

The technical details of this development are tedious, and we defer them to the appendix. However, our basic result is both striking and quite intuitive: insider ownership completely eliminates the ability of the delegated management structure to sustain corporate reputations.

Proposition 4. *Suppose that governance is exercised by an owner who is privately informed about the security of the control system. Then in any perfect Bayesian equilibria satisfying the D1 refinement:*

- (i) The manager will never receive incentive compensation.*
- (ii) The manager will always choose the low-quality technology in period 1 when the control system is insecure.*

The logic behind Proposition 4 is transparent. For compensation to ensure reputation, it must be sensitive to the period 2 good's price. However, if the insider owner only offers incentive compensation when the control system is insecure, by offering incentive compensation the owner will reveal that the control system is insecure and fix the period 2 good's price at δ . When the period 2 good's price is fixed, incentive compensation will not prevent diversion. It follows that no equilibrium can exist in which the insider owner only pays reputation-ensuring compensation when the control system is insecure. Consequently, if reputation-ensuring compensation is offered, it must be offered with positive probability both when the control system is secure and when it is insecure.

When the structure is secure, incentive payments have no effect on the manager's technology choice. Therefore, the owner will only offer incentive pay to positively influence consumer beliefs. This is possible if consumers believe that a firm that does not offer incentive compensation has an insecure control system. In this case, if the owner does not offer incentive pay, consumers will set a price for the period 1 good to δ , which will ensure a negative profit for the firm. Under these beliefs, consumers would attribute a high quality period 1 good to a lucky draw from the low-quality technology and set the period 2 good's price to δ as well. Given these beliefs, even the inside owner of a secure firm would pay incentive compensation, and PBE do exist in which reputation assuring compensation is offered. In these equilibria, not paying incentive compensation is off the equilibrium path and thus the resulting consumers' beliefs are not regulated by Bayes' rule. However, the belief that incentive compensation "signals" that the control system is secure even though a secure control system implies that such compensation has no fundamental purpose is clearly unreasonable. Not surprisingly, under the D1 restriction on off-the-equilibrium-path beliefs, no perfect Bayesian equilibria exist in which the insider-owner offers reputation-ensuring compensation.

Proposition 4 shows that, for delegated management to assure firm reputation, owners have to exercise control as outsiders. Insider control combined with delegation never assures reputation formation and simply permits managers to extract rents. Thus, delegation combined with insider control results in a lower payoff to owners as well as lower social welfare than simple owner-management. Consequently, outsider control is an essential feature of effective delegated management, and it is always optimal for an inside owner to manage the firm herself.

4.2 An uninformed owner-manager

In our baseline model, we assume that an uninformed owner delegates the firm's management to an informed professional manager. Suppose now that the owner remains uninformed about the security of her firm's control system but has the ability to run the firm. Since the owner does not know the security of the firm's control system, she is unsure whether an attempt at diversion will succeed. The owner only knows that an attempt to divert in period 1 can succeed with probability ρ_1 . If period 1 diversion is successful (unsuccessful), in period 2, the owner will know the control system is insecure (secure). If the owner knows the control system is insecure or if she is unsure about its security, she will always attempt to divert in period 2 since this maximizes her expected period 2 profit and entails no reputational cost.

Suppose consumers believe that the uninformed owner-manager will not divert in period 1. If the owner-manager chooses not to divert, her expected payoff is

$$1 - e + \rho_1(P_1 - e) + (1 - \rho_1)(P_1 - I). \quad (13)$$

If instead, if the owner-manager attempts to divert in period 1, her expected payoff is

$$\rho_1(1 - e + P_1 - e) + (1 - \rho_1)(1 - I + \delta(P_1 - I)). \quad (14)$$

The owner will not divert only when her expected payoff from eschewing diversion is higher, i.e.,

$$(1 - \rho_1)((1 - \delta)(P_1 - I) - c) > 0. \quad (15)$$

This condition is identical to condition (10), which ensures reputation equilibria under owner-management when the owner knows the control system's type.

Proposition 5. *The set of parameters that supports reputation equilibria under owner-management when the owner knows whether the control system is secure is identical to the set of parameters that supports reputation equilibria under owner-management when the owner is uninformed.*

Proposition 5 demonstrates that even an uninformed owner can assure a firm's reputation by taking on the role of its manager. However, like an informed owner-manager, she will only succeed in assuring the

firm's reputation when the cost of reputation loss is relatively high, i.e., when the firm's control structure is robust. Thus, when the control structure is fragile, an uninformed owner can only assure her firm's reputation by delegating to a professional manager.

Propositions 3, 4, and 5 together point to the superiority of outsider arms-length ownership in assuring firm reputation. They demonstrate that, while inside ownership can assure a firm's reputation only when the its reputation is robust, outsider arms-length ownership can assure firm reputation both when it is robust and when it is fragile. This prediction echoes the predictions and evidence in Noe et al. (2012) on the benefits of uninformed arms-length ownership from the perspective of corporate reputation.

4.3 Unobservable compensation policy

From an ex ante perspective, observable compensation policy is in the owner's best interest since it assures consumers about product quality even in periods before optimal quality-assuring compensation payments are made. In the context of modern corporate governance standards, which aim for transparency, it is natural to assume that consumers observe management compensation. All that is needed is a mechanism to verify an owner's report of compensation policy. Accounting systems can and do perform this function in most developed economies. Delegated management clearly cannot function if compensation payments cannot be verified at all because, ex post, owners have an incentive to renege on period 2 compensation promises made in period 1 as such promises have no effect on period 2 output. However, environments might exist in which compensation policy can be verified but only through mechanisms that consumers cannot observe. In such environments, an owner may misreport compensation to manipulate consumer expectations. Thus, it is worthwhile exploring reputation under delegated management when compensation policy is not observable by consumers.

Changing our assumption about the observability of compensation policy has no effect on the manager's information set or his diversion strategy. Thus, based on Proposition 1, the optimal reputation-ensuring compensation is a period 2 payment of $\frac{\delta c}{1-\delta}$ if the period 2 good's price equals P_1 . However, by limiting the information available to consumers, our changed assumption influences the owner's incentive to pay reputation-ensuring compensation. In a reputation equilibrium, consumers will correctly conjecture that the owner will pay reputation-ensuring compensation and thus will set a price of 1 for the period 1 good. It

follows that the owner's payoff from paying incentive compensation in a reputation equilibrium is given by

$$1 - e + P_1 - e - \frac{\delta c}{1 - \delta} = 1 - I - c + P_1 - I - \frac{c}{1 - \delta}.$$

Since compensation is unobservable, the owner can deviate from the candidate equilibrium policy by refraining from compensating the manager. This deviation saves the owner the compensation cost. However, she faces the possibility that the low-quality technology will reveal the firm with probability $1 - \delta$ and force it to shut down in period 2. Because the owner's deviation is unobservable, the price of the period 1 good will remain unchanged and the owner's expected payoff is

$$(1 - I - c) + P_1 (P_1 - I - c).$$

A necessary and sufficient condition for a reputation equilibrium under unobservable compensation is that the owner's expected payoff is higher if she pays incentive compensation. Algebraic simplification shows that this requirement is satisfied if and only if

$$\frac{(P_1 - I)(1 - P_1)(1 - \delta) - c(1 - P_1)(1 - \delta)}{1 - \delta} > 0. \quad (16)$$

While there is a large range of model parameters that satisfies condition (16), it is harder to satisfy than condition (9), which ensures reputation equilibria with observable compensation. Moreover, condition (10), which ensures reputation equilibria under owner-management is always satisfied when condition (16) is satisfied. Thus, the inability of consumers to observe compensation erodes the owner's incentive to pay reputation-ensuring compensation to a professional manager so much that it completely eliminates the advantage of delegated management over owner-management.

Proposition 6. *When management compensation policy is not observable by consumers, the set of parameters that supports reputation equilibria under owner-management contains the set of parameters that supports reputation equilibria under delegated management.*

The intuition underlying Proposition 6 is straightforward: Non-observability attenuates the owner's incentive to pay reputation-ensuring compensation most when the firm's reputation is fragile. This follows because, under non-observability, the entire benefit of reputation-ensuring compensation derives from con-

tinuation payoffs. When the control system is fragile, i.e., P_1 is small, the period 2 price is low. Thus, even though the increase in the probability of continuation induced by paying reputation-ensuring compensation, given by $1 - P_1$, is large, this increased probability is multiplied by a small continuation payoff, leading to a small expected payoff increase. At intermediate degrees of robustness, continuation gains are still fairly large and compensation has a significant effect on the likelihood of receiving these gains. Thus, even without observability the owner will pay reputation-ensuring compensation and delegated management can support reputation equilibria. However, for these parameter values even owner-management supports reputation equilibria.

The analysis in this subsection demonstrates that, if we interpret the public observability of compensation policy as transparency, then transparency increases the effectiveness of delegated management for maintaining firm reputation. While transparency is not essential for delegated management to lead to reputable firm behavior, in the absence of transparency owner-management is more likely than delegated management to assure reputation.

5 Reputation with long-lived firms and managers

Thus far we have restricted ourselves to a setting where the firm lasts for only two periods and can be operated for its entire existence by the same manager. In this setting, reputation only affects behavior in the first period. To obtain insight into the time profile of reputation incentives and reputable behavior under owner and delegated management, we now loosen these assumptions. Specifically, we consider an economy where both the firm and its manager last for $T > 2$ periods. We also discuss how firms can maintain their reputation when owners/managers have shorter horizons than firms. Our analysis demonstrates that, even in these new settings, delegated management can assure a firm's reputation only when the firm's control system is initially fragile and owner-management can assure a firm's reputation only when the firm's control system is initially robust.

5.1 Reputation when firms and managers survive $T > 2$ periods

When both the firm and manager last for two periods, we have demonstrated that (i) if the firm operates in period 2, the owner/manager always diverts, and (ii) the firm does not operate (in period 2) once it is

revealed. In the following lemma we describe how each of these results extends transparently to a setting where both the firm and manager last for $T > 2$ periods:

Lemma 1. (i) *The owner/professional manager will divert in period T .*

(ii) *The owner/professional manager will divert in every period after the firm is revealed.*

(iii) *The firm will shut down after its control system is revealed, i.e., the owner will not fund the firm's operation in any subsequent period once the control system is revealed.*

The intuition behind Claim (i) in Lemma 1 is identical to the intuition behind period 2 diversion in a two period setting: The owner-manager will not bear any loss if she loses her reputation in period T and a professional manager's expected payoff cannot fall if he diverts in period T . The intuition behind Claim (ii) is frequently encountered in reputation models—*unraveling*. Once the firm is revealed, consumers know that the owner/professional manager will divert in period T . This fixes the price of the period T good at δ , the lowest possible price. Therefore, an owner who diverts in period $T - 1$ will not face any period T cost even if her diversion is discovered. Similarly, the manager faces a fixed compensation in period T that is insensitive to his period $T - 1$ action. These arguments extend backwards to any period after the firm is first revealed. Claim (iii) follows directly from Claim (ii) and Assumption 2 because production is unprofitable once consumers price goods at δ .

The shift to a $T > 2$ period setting raises the following questions that we now focus on answering: (i) What is the optimal timing of incentive payments under delegated management? (ii) How are these payments structured? (iii) Is managerial turnover optimal? (iv) For how many periods will an owner/professional manager behave reputably? (v) Is it still the case that delegated (owner) management assures reputation only when the firm's initial reputation is fragile (robust)?

5.1.1 Delegated management

We first examine delegated management. Under delegated management, reputable behavior in each period is driven by the manager's incentives. The manager's gain from diversion is an increase in his current period consumption. Its cost is the possibility that revelation will eliminate future diversion opportunities and compensation payments. This loss is proportional to the manager's continuation value. Once the control structure has been revealed, the manager's continuation value is 0 since the firm shuts down and his

reservation wage is 0.

Define $v_M(t)$ as the manager's value function when the control structure is insecure and the firm has not been revealed up to period t . In period t , if the firm is unrevealed, the expected value of the manager's payoffs is the sum of his current period payoff and continuation value, i.e.,

$$v_M(t) = b(t) + \max [v_M(t+1), \delta v_M(t+1) + c], \quad (17)$$

where $b(t)$ is the period t incentive payment to the manager given the unrevealed price of the good in period t is $p(t)$, i.e., $b(t) = B(p(t))$. The first term in the maximum expression on the right-hand side of equation (17) reflects the manager's expected payoff if he does not divert in period t . The second term reflects the manager's expected payoff if he diverts. Since

$$v_M(t) = b(t) + \max [v_M(t+1), \delta v_M(t+1) + c] \geq \max [v_M(t+1), \delta v_M(t+1) + c] \geq v_M(t+1), \quad (18)$$

the manager's continuation value, $v_M(t)$, is weakly decreasing in t . The manager's continuation value declines with each passing period because he has fewer periods in which he can expect to receive a payoff before the terminal period, T .

By comparing the two terms in the maximum expression in equation (17), it follows that the manager is more likely to prefer eschewing diversion in period t when $v_M(t+1)$ is larger. Hence, because the manager's continuation value falls as the terminal period approaches, his incentive to divert increases over time. Consequently, the set of periods in which the manager diverts is always an order interval. By Lemma 1, this interval always includes the final period, T . In the interest of clearer exposition we refer to t^+ , the last period in which the manager does not divert, as the *reputation cutoff period*, and we refer to a compensation policy that deters diversion through period t^+ as a t^+ -policy. By Lemma 1, $t^+ < T$. We interpret $t^+ = 0$ as representing the case where the manager diverts in all periods. From the maximum expression in equation (17), it follows that the manager will not divert in period $t \leq t^+$ if and only if

$$(1 - \delta) v_M(t^+ + 1) \geq c. \quad (19)$$

Equation (19) indicates that there is essentially no role for replacing the manager. Replacement following

revelation is meaningless since the firm ceases to operate and the manager is effectively replaced. Replacement is suboptimal while the firm remains unrevealed since anticipated future replacement will lower the manager's continuation value and thus make the incentive compatibility condition for non-diversion, (19), harder to satisfy. Moreover, since replacement managers have identical ability and preferences, there is no other incentive in the model for replacing the manager.

We demonstrate in the following proposition that an optimal contract will make a single payment to the manager in the period following the reputation cutoff period, i.e., the manager will be paid only in period $t^+ + 1$. Under the optimal t^+ -policy, the period $t^+ + 1$ payment, $b^*[t^+](t^+ + 1)$, is a fixed bonus that is paid only if the firm is unrevealed until period $t^+ + 1$. In some cases, it is not optimal for the firm to pay compensation at any date; in which case, we define the reputation cut off period as $t^+ = 0$. Thus, the compensation contract associated with reputation cutoff period t^+ , defined for $t \in \{0, 1, \dots, T - 1\}$, is given by

$$b^*[t^+](t^+ + 1) = \begin{cases} b^*(t + 1) & \text{if } P_{t+1} \geq P_1 \text{ and } t^+ \geq 1 \\ 0 & \text{otherwise.} \end{cases} \quad (20)$$

The next proposition provides a complete solution to the optimal contracting problem and shows that this sort of single payment ‘‘bullet’’ compensation is, in fact, optimal.

Proposition 7. *There exists an optimal compensation policy for the firm with the following characteristics:*

- a. *There exists $t_*^+ \in \{0, 1, \dots, T - 1\}$ such that the compensation policy has the form $b^*[t_*^+]$ specified in equation (20). Thus, the manager is paid a single incentive payment made at date $t_*^+ + 1$ contingent only on the good's price in period $t_*^+ + 1$ being at least equal to its price at date 1. Under this contract, when the control system is insecure, the manager never diverts during or before period t_*^+ and always diverts after period t_*^+ . Moreover, no policy that provides positive payments in more than one period is optimal.*
- b. *The single incentive payment is given by*

$$b^*[t_*^+](t_*^+ + 1) = \frac{c\delta^{T-t_*^+}}{1-\delta}.$$

- c. *Under this contract, the firm always operates when it is unrevealed.*

d. The optimal reputation cutoff period, t_*^+ is the period following the largest $t^+ \in \{1, \dots, T-1\}$ such that

$$\frac{(1-P_1)(1-e) + ((1-P_1)(e-\delta) - c)\delta^{T-(t^++1)}}{1-\delta} \geq 0. \quad (21)$$

If no such t^+ exists, then $t_*^+ = 0$.

Although the proof of Proposition 7 is fairly tedious and thus deferred to the appendix, the logic underlying the proof is straightforward. First, consider part (a) of the Proposition. Given a unique reputation cutoff period t^+ , the optimal t^+ -policy must be optimal relative to all t^+ -policies, all of which lead to the same reputation cutoff period, i.e., the optimal t^+ -policy must minimize expected payments to the manager over all t^+ policies. Since the owner does not know whether the control system is secure, the payment to the manager is made both when the structure is secure and when it is insecure. When the control system is secure, these payments are wasted as they are unnecessary. When the control system is insecure the payments must satisfy the incentive constraint for t^+ , condition (19). Consequently, an optimal t^+ contract minimizes payments conditioned on the control system being secure subject to the condition that when the system is insecure, the incentive constraint is satisfied.

Since any payment made before the reputation cutoff period t^+ does not contribute to satisfying the t^+ incentive constraint, it is clear that an optimal t^+ -contract will not specify any payments before t^+ . Now consider compensation payments made after $t^+ + 1$, say at $t^+ + 2$. When the control system is insecure, the manager will divert at $t^+ + 1$ and the contribution of the $t^+ + 2$ payment to satisfying the manager's incentive constraint will equal the probability the firm is unrevealed at the start of $t^+ + 2$ times the incentive payment $b(t^+ + 2)$ provided when the firm is unrevealed, i.e., the payment will contribute $\delta b(t^+ + 2)$ to meeting the incentive constraint. In contrast, if the control system is secure, since the manager cannot divert at $t^+ + 1$ in this case, the payment will be received with certainty. Thus, the payment's expected cost conditioned on the control system being secure is simply $b(t^+ + 2)$. Next consider a payment made at date $t^+ + 1$. Since under a t^+ contract, the manager does not divert under the insecure structure until $t^+ + 1$, the payment will contribute $b(t^+ + 1)$ to meeting the incentive constraint when the control structure is insecure and provide the manager with an expected payment of $b(t^+ + 1)$ when the control system is secure. Thus, for each dollar of expected payments to the manager conditioned on the control system being secure, payments at $t^+ + 1$ contribute more to satisfying the incentive constraint. For this reason, payments at $t^+ + 2$ are never part of an

optimal t^+ contract. The same logic extends obviously to even later periods. Hence, as claimed in part (a), optimal t^+ contracts take the form of a bullet payment made at date t^+ . The exact level of the payment required for implementing the optimal reputation cutoff period specified in part (b) is determined by solving for the $t^+ + 1$ bullet payment that satisfies the incentive constraint (19) as an equality. Since the optimal contracts specified in part (b) produce positive owner profits in every period in which the firm is unrevealed, it is always optimal, as asserted in part (c), for the owner to operate the firm while it is unrevealed.

Given parts (a), (b), and (c) the optimal contracting problem reduces to the problem of solving for the optimal reputation cutoff period, t_*^+ . This problem is a simple optimization problem. Solving this problem shows that the gain from extending the non-diversion period from $t^+ - 1$ to t^+ , which we refer to as a t^+ -shift, is given by expression (21). This expression viewed as a function of t^+ is monotonic, either weakly increasing or weakly decreasing depending on the sign of $(1 - P_1)(e - \delta) - c$. Thus, as asserted in part (d), the optimal choice of the reputation cutoff period can simply be determined by finding the last date at which such an extension of the non-diversion period generates a positive gain.

We can now identify the conditions for a reputation equilibrium, i.e., an equilibrium in which diversion does not occur till period T . When the control system is insecure, the manager will not divert before period T if and only if the owners optimal policy is to implement the $T - 1$ reputation cutoff. The condition for this choice of reputation cutoff is provided by part (d) of Proposition 7. Expression (21) demonstrates that, when the firm's initial reputation, P_1 , is low enough to satisfy $(1 - P_1)(e - \delta) - c \geq 0$, all t^+ -shifts increase firm value. Therefore, when the firm's initial reputation is sufficiently fragile, it is optimal for the owner to defer compensation until period T , ensuring no diversion through period $T - 1$, i.e., a sufficiently fragile initial reputation supports a reputation equilibrium under delegated management. In contrast, expression (21) is negative for values of t^+ approaching T when P_1 approaches one. Consequently, when the firm's initial reputation is sufficiently robust, the cost of deferring the incentive payment becomes prohibitively high close to period T . Thus, the owner will make the incentive payment before period T , meaning that the manager will divert in at least one period before period T . Expression (21) also implies that the cost of reputation ensuring compensation decreases to 0 as the owner's horizon, T , increases without bound. Thus, for a sufficiently long horizon, T , there will always exist at least one period in which the owner will offer the manager incentive compensation. These results are summarized in Proposition (8).

Proposition 8. *Reputation formation under delegated management has the following characteristics:*

(i) Whenever initial firm reputation, P_1 , is sufficiently fragile, i.e.,

$$P_1 < 1 - \frac{c}{e - \delta}, \quad (22)$$

the owner will offer the manager a single incentive payment paid conditional on the firm remaining unrevealed at the start of period T . The bonus payment will equal $(\delta c)/(1 - \delta)$. When the control structure is insecure, the manager will not divert in any period before T .

(ii) Whenever initial firm reputation is sufficiently robust, the owner will never offer the manager a bonus payment conditioned on remaining unrevealed until period T . When the control structure is insecure, the manager will always divert in some period before period T .

(iii) For any set of admissible parameters of the model excluding T , there exists T^* such that if $T > T^*$, the owner will offer reputation-ensuring incentive compensation in at least one period.

5.1.2 Ownership structure and firm reputation

We now demonstrate that owner-management continues to assure firm reputation only when the firm's initial reputation is high. To see this, consider the owner's choice in period $T - 1$ when (a) consumers expect a high-quality good in the period, (b) the firm is unrevealed, and (c) the control system is insecure. The owner's expected payoff from choosing the high-quality technology in period $T - 1$ equals $1 - e + p(T) - I$. If she diverts instead, the firm will be revealed with probability $1 - \delta$. In this event, from Lemma 1 it follows that the firm will shut down in the final period. Therefore, the owner-manager's expected payoff from diverting in period $T - 1$ is $1 - e + \delta(p(T) - I) + c$. It follows that the owner will choose the high-quality technology in period $T - 1$ if and only if

$$(1 - \delta)(p(T) - I) \geq c. \quad (23)$$

Given that equilibrium prices are updated according to Bayes' rule, $p(T) \geq P_1$ in equilibrium. Hence the owner will choose the high-quality technology in period $T - 1$ whenever the firm's initial reputation P_1 is sufficiently high. In expression (23), $(1 - \delta)(p(T) - I)$ represents the owner's opportunity cost of diverting in period $T - 1$. This opportunity cost is higher in earlier periods since the owner forgoes more periods of profitable production if the firm fails to produce a high-quality good. In contrast, the owner's gain from diverting in a given period remains fixed at c . Thus, if the owner finds it profitable to eschew diverting in

a period, she will also find this choice optimal in every prior period. Consequently, when the firm's initial reputation is high enough to satisfy condition (23), the owner-manager will eschew diverting in every period until period T . That is, when the firm's control system is robust, there exist only reputation equilibria, i.e., equilibria in which diversion only occurs in period T . Moreover, since the owner's opportunity cost of diverting rises along with the remaining horizon, successively weaker conditions on the firm's reputation ensure that the owner-manager will eschew diverting in earlier periods.

Proposition 9. *Under owner-management,*

(i) *In any period t , the firm will produce high quality whenever*

$$c \leq (p(t) - I) (1 - \delta^{T-t}). \quad (24)$$

(ii) *Only reputation equilibria in which only high quality is produced until period $T - 1$ exist if and only if*

$$\frac{c}{1 - \delta} < (P_1 - I). \quad (25)$$

(iii) *If*

$$\frac{c}{1 - \delta} \geq \max_{s=\{0,1,\dots,T-t\}} (1 - I - c)s + \frac{(1 - I) (1 - \delta^{T-t-s})}{1 - \delta} \quad (26)$$

then, at date t , the firm will adopt the low-quality technology.

Proposition 9 demonstrates that owner-managed firms can maintain reputations founded solely on their control systems. They are likely to do so when their control systems are robust. Owner-managed firms are also more likely to ensure product quality when their owners' horizons are long. The contrast between these results and the results in Proposition 8 once again demonstrate that a firm's governance can have a significant effect on its ability to maintain its reputation. They also demonstrate that delegated management is the only option for the firm to maintain its reputation when its control system is fragile.

5.2 Reputation when firms operate longer than managers

We have shown that when the firm's operating horizon, T , is the same as that of its owner/manager, the owner/manager always diverts in period T . Does this continue to be the case when the firm can continue operating for T periods but the owner's/manager's horizon is shorter than T ?

There is an extensive literature on reputation in long-lived firms with short-lived owners that demonstrates how owners will completely eschew opportunism, even in their final period of existence (Tadelis (1999), and Mailath and Samuelson (2001)). The basic insight in their papers is that an owner-manager with a short horizon will be willing to eschew opportunism to maintain her firm's reputation beyond her lifetime because she is able to sell the firm during her lifetime for a higher price if it maintains its reputation. This sale enables her to realize the future value of the firm's reputation during the operating horizon. When the difference between the price of a reputable and disreputable firm is sufficiently large, the owner will completely eschew diversion. The introduction of a market for firms in our model will assure firm reputation with a short-lived owner-manager in all but period T . In this final period, the firm's owner will not have the inducement of either maintaining the firm's reputation and enjoying the attendant higher profits in his lifetime or selling the firm for a higher price to capitalize on the future value of its reputation.

Kreps (1996) and Cremer (1986) describe how a short-lived professional manager may be induced to maintain the reputation of a long-lived firm. The basic intuition is easily extended to our model. To illustrate the intuition suppose that managers live for only two periods but the firm can operate for $T > 2$ periods. Suppose that the firm employs a new manager each period, each manager is employed only in the first period of his life, and is paid in the second period of his life if the firm maintains its reputation. It is clear from our previous analysis that a sufficiently high payment will induce the manager to eschew diversion. The owner will be willing to make the now periodic payments so long as the price gain from reputation is larger than the cost of the incentive compensation. As we have shown in our baseline model, this tradeoff will favor the maintenance of firm reputation when the firm's initial reputation is sufficiently low and thus the expected gain from maintaining reputation is large. As is the case under owner-management, the owner will not be able to prevent diversion in period T since she will be not able to incentivize the period T manager with deferred compensation.

6 Conclusion and extensions

In this paper, we develop a model in which a firm's reputation is based solely on its organizational and institutional structure, and the control and ownership of its reputation can be separated. Our model extends the classic economic reputation framework where, in contrast to our work, reputation is based entirely on perceived characteristics of agents who both control the firm's reputation and enjoy all the costs and benefits of the reputation. We find that professional delegated management, which separates ownership and control of reputation, can assure socially-efficient reputable firm behavior even in an environment where only firm revenue and compensation policy are verifiable. Moreover, delegated management can assure reputable behavior even in cases where owner-management, which completely unifies ownership and control, cannot. For a firm to successfully maintain its reputation under delegated management, its ownership must rest with arms-length outsiders. These arms-length owners must set management compensation and retention policies. The superiority of delegated management also requires sufficient corporate transparency to permit outsiders to observe compensation policies set by arms-length owners.

The benefit of separating ownership from management comes from the "commitment effect." Under delegated management, owners are separated from opportunities to act opportunistically since they no longer make operating decisions and thus cannot capture opportunism gains. Instead they become potential victims of opportunism since management can act opportunistically and threaten the firm's reputation. By choosing to pay opportunism-detering compensation, non-managing owners publicly commit management to reputable actions and protect themselves from being victimized by managerial opportunism. A failure to pay opportunism-detering compensation will immediately impact consumers' perception of product quality and thus prices. Hence, owners will pay opportunism-detering compensation even when the cost of reputation loss is too small to deter owner-managers from acting opportunistically.

There are a number of potential directions for extending our work. One direction is to allow for heterogeneous agents who have private information regarding their own degree of honesty. If we also assumed a competitive labor market that valued honesty, these agents would have an motivation to build a reputation for being honest even if they were not and this motivation could discourage opportunism. Corporate reputation reform activities might also crowd out this motivation. Because such reform activities make honest behavior a weaker signal of agents' internal preference for honesty by strengthening external control, they

would lower the returns from employee reputation building.

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Appendix

Proof of Proposition 1. Suppose that consumers and the owner believe that the manager will not divert if he is offered an incentive payment of b_2^* in period 2. In period 2, consumers believe that the firm is secure with probability $P_1(\delta)$ if the firm produces a high (low) quality good in period 1. Also suppose that the owner operates the firm in period 2 only if it is unrevealed.

By Assumptions 1 and 2, this operating policy is incentive compatible for the owner. Given the owner's operating policy and the incentive payment, from expressions (4) and (5) it follows that it is incentive compatible for the manager to eschew diversion and thus the conjecture about the manager's behavior is correct. Moreover, condition (9) ensures that the owner's payoff from offering the manager the incentive payment exceeds his payoff from offering a lower or no incentive payment, or not operating the firm in period 1 or in period 2 if it is unrevealed. The owner's payoff must be lower if he offers an even larger incentive payment. Thus, there is no other contract that produces a higher expected payoff for the owner. Therefore, all the agents' actions are incentive compatible and belief updates follow Bayes' rule. This establishes the claim about the existence of the reputation equilibrium when condition (9) is satisfied.

When condition (9) is not satisfied, it is clear that the minimum payment that induces the manager to eschew diversion leaves the owner worse off than offering no compensation. Thus, there cannot exist a reputation equilibrium and the manager will divert in period 1. □

Proof of Proposition 2. Suppose that in period 2, consumers believe that the firm is secure with probability $P_1(\delta)$ if the firm produces a high (low) quality good in period 1. Also suppose that the owner operates the firm in period 2 only if it is unrevealed.

The period 2 operating policy is clearly incentive compatible for the owner. Condition (11) ensures that the owner's payoff from eschewing diversion in period 1 is higher. Thus, it is incentive compatible for the owner to eschew diversion in period 1 and divert in period 2. Hence, all the agents' actions are incentive compatible and belief updates follow Bayes' rule. This establishes the claim about the existence of the reputation equilibrium when condition (11) is satisfied.

Suppose that consumers believe that the owner will divert with positive probability in period one. Then, the period two state variable $\Gamma[P_1] > P_1$ if the firm produces a high quality period 1 good. But from the discussion immediately preceding the proposition it is clear that, in this case, the owner's payoff from

eschewing diversion in period 1 will exceed his payoff from diverting if condition (11) is satisfied. Thus, there can only exist reputation equilibria when condition (11) holds. \square

Proof of Proposition 3. The proof follows directly from comparing the conditions for reputation equilibria in Propositions 1 and 2. \square

Preamble to proof of Proposition 4. Many features of the baseline model are unaffected by the change in the information structure. The size of the optimal incentive payment, $b^* = c \frac{\delta}{1-\delta}$, remains unchanged as the manager's incentives are only affected by his contract and, thus, are not directly affected by consumer or owner beliefs. Moreover, except in a degenerate case discussed below, conditioning the incentive payment on the good's price in period T exceeding δ is still sufficient to ensure that the incentive payment will be made if and only if output quality in the previous period is high.

To interpret the model as a signaling game, we can view the owner as an informed first-mover who sends one of three messages, $m \in \mathcal{M} = \{C, NC, SH\}$, where message C denotes that the owner chooses an optimal contract, NC represents the decision not to pay incentive compensation, and SH represents the decision to shut down the firm in period 1. The owner's type is $\theta \in \Theta = \{S, J\}$. Consumers are uninformed responders. Their response is a price for the period 1 good. Let v_O represent the owner's payoff function at the start of the game, the beginning of period 1. A strategy for the owner, $\sigma(\cdot|\theta)$, is a probability measure over \mathcal{M} conditioned on the owner's type. Consumers' beliefs are represented by the function $\rho : \mathcal{M} \rightarrow [0, 1]$, where $\rho(m)$ represents their assessment of the probability the firm is secure conditioned on message m . Let $p^* : \mathcal{M} \rightarrow [\delta, 1]$ represent the period 1 good's price when quality is not assured by compensation. A Perfect Bayesian Equilibrium (PBE) is a triple, (σ^*, ρ^*, p^*) , satisfying the following conditions:

- i. If $\sigma^*(m|\theta) > 0$, then m is a best response for type θ , i.e.,

$$v_O(m, p^*(m), \theta) = \max_{m \in \mathcal{M}} v_O(m, p^*(m), \theta).$$

- ii. Prices are based on beliefs, i.e. $p^*(m) = \rho^*(m) + (1 - \rho^*(m)) \delta$.
- iii. Whenever, under σ^* , a message m is selected with positive probability, ρ^* is consistent with Bayes' rule.

To complete the description of the signaling game, we have to define the owner's payoff function. The need to redefine the owner's payoff function arises because of complications that arise when consumers

have a very low assessment of a good's quality. If they believe that a given compensation policy signals that the control system is insecure with probability 1, then high quality output will not lead them to revise their assessment. Consequently, the period T good's price will equal δ regardless of the quality of the period 1 good. It follows that incentive compensation will not motivate the manager. As long as consumers' assess a non-zero probability to the control system being secure, a high quality period 1 good will result in a strictly higher period T good price than a low quality period 1 good. However, the period T price might still be less than the cost of production, so the firm will shut down in period T . Accounting for these cases, we obtain the following payoff function for the owner:

$$v_O(m, p, \theta) = \begin{cases} (p - I - c) + \delta \max[\Gamma(p) - I - c, 0] & \text{if } m = \text{NC} \ \& \ \theta = \mathcal{J}, \\ (p - I - c) + \max[\Gamma(p) - I - c, 0] & \text{if } m = \text{NC} \ \& \ \theta = \mathcal{S}, \\ (1 - I - c) + \max[\Gamma(p) - I - c, 0] - b^* & \text{if } m = \text{C} \ \& \ p > \delta, \\ 0 & \text{if } m = \text{C} \ \& \ p = \delta, \\ 0 & \text{if } m = \text{SH}, \end{cases} \quad (\text{A-1})$$

where $\Gamma(p) = 1 + \delta - \frac{\delta}{p}$ and $b^* = c \frac{\delta}{1-\delta}$. □

To complete the proof of Proposition 4, we need to first establish the following results:

Lemma A-1. *In any D1-PBE in which incentive compensation is offered with positive probability, choosing to not provide incentive compensation, NC is on the equilibrium path.*

Proof. Suppose instead that $m = \text{NC}$ is off the equilibrium path in a D1-PBE in which $m = \text{C}$ is on the equilibrium path. Note that expression (A-1) shows that

$$v_O(m, p, \mathcal{S}) = v_O(m, p, \mathcal{J}), \quad m = \text{C} \ \text{or} \ m = \text{SH}. \quad (\text{A-2})$$

Because $m = \text{NC}$ is off the equilibrium path, this implies that the equilibrium payoff v_O^* of $\theta = \mathcal{J}$ equals equilibrium payoff of $\theta = \mathcal{S}$, i.e.,

$$v_O^*(\mathcal{S}) = v_O^*(\mathcal{J}). \quad (\text{A-3})$$

Next note that expression (A-1) shows that

$$v_O(\text{NC}, p, \mathcal{S}) \geq v_O(\text{NC}, p, \mathcal{J})$$

and if $\Gamma(p) > I + c \Rightarrow v_O(\text{NC}, p, \mathcal{S}) > v_O(\text{NC}, p, \mathcal{J})$. (A-4)

Expressions (A-3) and (A-4) imply that

$$v_O(\text{NC}, p, \mathcal{S}) - v_O^*(\mathcal{S}) \geq v_O(\text{NC}, p, \mathcal{J}) - v_O^*(\mathcal{J})$$

and if $\Gamma(p) > I + c \Rightarrow v_O(\text{NC}, p, \mathcal{S}) - v_O^*(\mathcal{S}) > v_O(\text{NC}, p, \mathcal{J}) - v_O^*(\mathcal{J})$.

If $\Gamma(p) \leq I + c$ then, because $p < \Gamma(p)$ when $p > \delta$ the payoff to both types from selecting NC is negative and thus less than the payoff from shutting down. So the set of market responses to NC that will induce either type to deviate is a subset of the set of responses, p , for which $\Gamma(p) > I + c$. Over this subset, $v_O(\text{NC}, p, \mathcal{S}) - v_O^*(\mathcal{S}) > v_O(\text{NC}, p, \mathcal{J}) - v_O^*(\mathcal{J})$ and $p \leftrightarrow v_O(\text{NC}, p, \theta)$ is continuous. If consumers responded to the off equilibrium message NC with $p = 1$, then $v_O(\text{NC}, p, \mathcal{S}) - v_O^*(\mathcal{S}) > 0$. So the set of responses that will induce \mathcal{S} to deviate from the equilibrium is also not empty. Thus, the set of market responses p for which \mathcal{S} strictly gains from deviation to NC includes the set of consumer responses under which type \mathcal{J} weakly gains from deviating from the equilibrium. D1 then requires that market assign the belief that $p^*(\text{NC}) = 1$ and thus $p^*(\text{NC})$ equals 1. However, under this belief, the unique best response of type \mathcal{S} is to choose $m = \text{NC}$, contradicting the assumption that NC is off the equilibrium path □

Lemma A-2. *In every D1-PBE, $\Gamma(p^*(\text{NC})) > I + c$.*

Proof. Suppose not. First note that, if $\Gamma(p^*(\text{NC})) \leq I + c$, then shutting down produces a strictly higher payoff than selecting $m = \text{NC}$ for both types. Lemma A-1 shows that $m = \text{NC}$ is played in equilibrium. Thus, because equilibrium strategies are best responses, it must be the case that $\Gamma(p^*(\text{NC})) > I + c$. □

Lemma A-3. *In every D1-PBE, the equilibrium payoffs received by types \mathcal{J} and \mathcal{S} are positive.*

Proof. Expressions (A-2), Lemma A-2, and (A-4), imply that in any equilibrium, whenever NC is a best response for type \mathcal{J} it is the unique best reply for type \mathcal{S} . Thus, the probability that type \mathcal{S} chooses NC is weakly higher than the probability that type \mathcal{J} plays NC. Lemma A-1 shows that NC is a best reply for

some type. Thus, the probability that type \mathcal{S} chooses NC is weakly higher than the probability that type \mathcal{J} chooses NC and this probability is positive. Bayes' rule then implies that $p^*(\text{NC}) \geq P_1$. Expression (A-1) and Assumption 1 show that $p^*(\text{NC}) \geq P_1$ implies that the payoff from selecting NC is positive for both types. Thus because both types play best replies, the equilibrium payoff for both types must be positive. \square

Lemma A-4. *In every DI equilibrium in which the equilibrium payoff to both types is positive, $m = C$ is selected with zero probability.*

Proof. Suppose not. Note that it must be the case that type \mathcal{J} is selecting NC with positive probability. Otherwise choosing NC, by Bayes' rule, would reveal that the control system is secure and, thus, imply that $p^*(\text{NC}) = 1$. In which case, type \mathcal{S} would strictly prefer $m = \text{NC}$ to $m = C$. But if type \mathcal{S} strictly prefers NC over C, then C would only be selected by type \mathcal{J} . In which case selecting C would reveal the structure to be insecure and, thus, generate a payoff of 0, contradicting the payoff being positive for both types.

The hypothesis that C is played with positive probability combined with our result that type \mathcal{J} is selecting NC with positive probability imply that (a) NC is a best response for \mathcal{J} and that (b) C is a best response for some type. Expressions (A-2), Lemma A-2, and (A-4) imply that

$$v_O(\text{NC}, p^*(\text{NC}), \mathcal{S}) - v_O(C, p^*(C), \mathcal{S}) > v_O(\text{NC}, p^*(\text{NC}), \mathcal{J}) - v_O(C, p^*(C), \mathcal{J}). \quad (\text{A-5})$$

(a) and (b) and (A-5), imply that NC is the unique best response for \mathcal{S} . (b) then implies that C is a best response for type \mathcal{J} . Because NC is the unique best response for type \mathcal{S} . C is not a best response for type \mathcal{S} . Bayes' rule thus implies that $p^*(C) = \delta$ and thus $v_O(C, p^*(C), \mathcal{J}) = 0$, which is not possible given that C is a best response for type \mathcal{J} and type \mathcal{J} 's equilibrium payoff is positive. \square

Proof of Proposition 4. The proof follows from Lemmas A-1 through A-4. \square

Proof of Proposition 5. The proof of the existence of a reputation equilibrium with an uninformed owner-manager is virtually identical to the proof of Proposition 2. Condition (15) identifies the set of parameters supporting these reputation equilibria and is identical to condition (11), which identifies the set of parameters supporting reputation equilibria with an informed owner-manager. \square

Proof of Proposition 6. To establish this claim we will show that condition (16) which ensures existence of reputation equilibria with unobservable compensation is satisfied if and only if condition (10), which ensures

existence of reputation equilibria under owner-management, is satisfied. To see this, let $Sgn > 0$ represent the difference between the left hand sides of the conditions (16) and (10), where

$$Sgn = ((P_1 - I)(P_1 - \delta) - cP_1)(1 - \delta) + c\delta \quad (\text{A-6})$$

Next note that Sgn is an affine function of c . Evaluating this expression at the two extreme limiting feasible values of c , $c = 0$ and $c = P_1 - I$ yields

$$c = 0 \Rightarrow Sgn = (P_1 - I)(1 - \delta)(P_1 - \delta) > 0, \quad (\text{A-7})$$

$$c = P_1 - I \Rightarrow Sgn = \delta^2(P_1 - I) > 0. \quad (\text{A-8})$$

Since Sgn is positive at the extremes and is affine it is always positive. Thus, (16) is satisfied if and only if condition (10) is met. \square

Proof of Lemma 1. Proof of Claim (i). Suppose that management is delegated to a professional. If the T -good's price is $p(T)$, the manager is contracted to receive an incentive payment $B_T(p(T))$ in period T . Note that $p(T)$ and thus both the firm's revenue and the manager's incentive payment are unaffected by his technology choice. However, if the manager diverts, he receives an additional c . Therefore, the manager maximizes his payoff in period T by diverting.

Now consider owner-management. The owner's period T payoff from diverting is $p(T) - I$, which is higher than his payoff from choosing the high-quality technology, $p(T) - e$ since $I \leq e$. Therefore, in period T , the owner will always divert since this is the dominant strategy for period T .

Proof of Claim (ii). Consider a firm under delegated management. Once the firm is revealed, consumers know that the manager will divert in period T . This fixes the price of the period T good at δ . Therefore, the manager's period T compensation is fixed whether or not he is discovered to have diverted in period $T - 1$. Therefore, period $T - 1$ diversion is optimal for the manager. This argument extends backwards to the period in which the firm is first revealed and establishes that the manager will divert in every period that the firm operates after it is revealed.

Now consider owner-management. Since it is a dominant strategy for the owner to divert in period T , consumers will pay δ in period T and the owner will not produce in the period. Therefore, in period $T - 1$,

the owner can divert without incurring any change in her future expected payoff, making diverting her best response in period $T - 1$ if she chooses to produce. It is clear that the consumers' best response in period $T - 1$ is to pay δ , which will block production. By induction, it is clear that the owner will not choose the high-quality technology in any period subsequent to the revelation that the firm is insecure. Moreover, consumers will pay only δ blocking production in every period.

Proof of Claim (iii). Claim (ii) establishes that, regardless of the firm's ownership structure, the price of the period- t good will equal δ if the firm produces in period t after it is revealed. By Assumption 2, period t production is not profitable if the t -period good's price is δ . Therefore, if the control system is known to be insecure in period t , the firm will shut down. \square

Proof of Proposition 7. We first establish parts (a), (b), and (c) of the Proposition. To establish these parts, we first solve a "full commitment problem." The full commitment problem assumes that the owner can contract a "payment schedule" at date 0. A payment schedule is a non-negative vector $\mathbf{b} = (b(1), b(2), \dots, b(T))$ of compensation payments, where $b(t) \geq 0$ is the payment received by the manager if the firm is unrevealed at the start of period t . In addition, the firm can contract on the operating decision on the unrevealed path, i.e., specify at date 0, the choice between shutting down an operating at date t when the firm is unrevealed. Essentially, this problem is the same as the "actual problem" modeled in the paper save for two differences: (a) in the actual problem, payments cannot be conditioned directly on revelation but rather must depend only on the price history up to the date when the payment is made, and (b) the operating decision is made ex post not ex ante.

We will first derive the necessary conditions for an optimal compensation and operating policy for the full commitment problem and show that these conditions imply a bullet payment to the manager. Next, we will point out that the compensation/operating policy for the full commitment problem is exactly the same as our candidate solution to the actual problem. Finally, we will show that the full commitment payment schedule can be implemented by price-history contingent contracts and that the operating policy under the full commitment policy is ex post incentive compatible. Since the actual problem features more constraints than the full-commitment problem, its solution cannot produce a higher payoff to the owner than the optimal solution under full commitment. Thus, the payment schedule and operating policy specified by the solution to the full commitment problem is an optimal solution to the actual problem modeled in the paper, and the contracted payments to the manager in the actual problem must satisfy the necessary and sufficient

restrictions on payments in the full commitment problem.

First, consider the full commitment policy compensation schedule assuming that the owner's operating policy is to never shut down when unrevealed. For any given compensation schedule, \mathbf{b} , let $v_M[\mathbf{b}](t)$ represent the manager's value function when the control system is insecure and the firm has not been revealed up to period t , i.e., until period t the firm has never produced a low-quality good. If the manager does not divert in period t , then it must be the case that the manager's value from diversion is no greater than the value from not diverting. The manager's payoff from diverting in period t is

$$b(t) + c + \delta v_M[\mathbf{b}](t+1). \quad (\text{A-9})$$

The manager's payoff from not diverting is

$$b(t) + v_M[\mathbf{b}](t+1). \quad (\text{A-10})$$

Thus, not diverting is incentive compatible if and only if

$$(1 - \delta)v_M[\mathbf{b}](t+1) \geq c. \quad (\text{A-11})$$

Next note that the value function is non-increasing in t . This follows because, in period t , the manager can always secure a value of

$$b(t) + v_M[\mathbf{b}](t+1).$$

by not diverting. Because the manager chooses the optimal policy in period t

$$v_M[\mathbf{b}](t) \geq b(t) + v_M[\mathbf{b}](t+1) \geq v_M[\mathbf{b}](t+1). \quad (\text{A-12})$$

Thus, if equation (A-11) is satisfied at t , it is satisfied for $s < t$. Next note because, at $t = T$, the manager's continuation value is 0, diversion is always optimal at date T . Hence, regardless of the schedule of payment's selected by the firm, there will exist a period, $t^+ \in \{0, 1, \dots, T-1\}$, such that at $t^+ + 1$, the manager diverts and before t^+ the manager does not divert. If $t^+ = 0$ then the manager diverts in all periods and the optimal compensation policy conditioned on the manager diverting in all periods is clearly to pay zero compensation.

A necessary condition for a payment schedule to be optimal is that over all payment schedules inducing the same reputation cutoff period, it maximizes the payoff to the owner. The anticipated value to the owner at date 0 equals gross firm profit (firm profit excluding the cost of management compensation) less managerial compensation. Under our assumptions that the firm has committed to a policy of not shutting down on the unrevealed path, expected gross profit is fixed. Thus, an optimal schedule must minimize expected payments to the manager over all schedules that implement the same reputation cutoff period.

If the control system is secure, the expected payments to the manager simply equal the sum of payments promised on the unrevealed path, i.e., expected payments, EP^S are given by

$$EP^S[\mathbf{b}] = \sum_{t=1}^T b(t).$$

If the control system is insecure, then up to period $t^+ + 1$, the expected payment also equals the sum of payments. Subsequent to period $t^+ + 1$ payments may not be received by the manager because revelation occurs with probability $1 - \delta$ in each such period. Thus, the expected payments to the manager given the control structure is insecure are given by

$$EP^J[\mathbf{b}] = \sum_{t=1}^{t^+} b(t) + b(t^+ + 1) + \sum_{t=t^++2}^T \delta^{t-(t^++1)} b(t).$$

Expected payments to the manager, $EP[\mathbf{b}]$, equal the expectation over the secure and insecure states, i.e.,

$$EP[\mathbf{b}] = \rho_1 EP^S + (1 - \rho_1) EP^J. \quad (\text{A-13})$$

The manager's value at $t^+ + 1$, equals the value obtained from following the diversion strategy after date t^+ . Under the diversion strategy, if the control system is insecure, the manager captures c and all compensation payments so long as the firm remains unrevealed, i.e.,

$$v_M[\mathbf{b}](t^+ + 1) = c + b(t^+ + 1) + \sum_{t=t^++2}^T \delta^{t-(t^++1)} (c + b(t)). \quad (\text{A-14})$$

An optimal schedule \mathbf{b} must satisfy the condition that it minimizes payments to the manager subject to the incentive constraint, (A-11), i.e., an optimal schedule that induces a reputation cutoff period of t^+ must solve

the following problem:

$$\begin{aligned} & \text{Min}_{\mathbf{b} \geq 0} \text{EP}[\mathbf{b}], \\ & \text{s.t. } (1 - \delta)v_M[\mathbf{b}](t^+ + 1) \geq c. \end{aligned} \tag{A-15}$$

The Lagrange, \mathcal{L} for this problem is

$$\mathcal{L}[\mathbf{b}] = \text{EP}[\mathbf{b}] - \lambda ((1 - \delta)v_M[\mathbf{b}](t^+ + 1) - c). \tag{A-16}$$

Now let $\delta_t \mathcal{L}$ represent the partial derivative of the Lagrange with respect to $b(t)$, differentiating, using equation (A-14), yields

$$\delta_t \mathcal{L} = \begin{cases} 1 & \text{if } t < t^+ + 1, \\ \rho_1 - ((1 - \delta)\lambda - (1 - \rho_1)) & \text{if } t = t^+ + 1, \\ \rho_1 - \delta^{t-t^+-1} ((1 - \delta)\lambda - (1 - \rho_1)) & \text{if } t > t^+ + 1. \end{cases} \tag{A-17}$$

First note that the fact that $\delta_t \mathcal{L} > 0$, for $t < t^+ + 1$ implies, by the Kuhn-Tucker conditions that $b(t) = 0$, for all $t < t^+ + 1$. Next, note the following two items: (i) Because positive compensation must be paid in at least one period to ensure non-diversion, it must be the case that $\delta_t \mathcal{L} \leq 0$ for some period $t \geq t^+ + 1$. (ii) Because infinite compensation is not optimal, it must be the case that, for all t , $\delta_t \mathcal{L} \geq 0$. Condition (i) implies that $(1 - \delta)\lambda - (1 - \rho_1) > 0$ which, in turn, implies that $\delta_{t+1} \mathcal{L} < \delta_t \mathcal{L}$, for $t > t^+ + 1$. This implies, combined with (ii) that (a) $\delta_{t+1} \mathcal{L} = 0$ and (b) $\delta_t \mathcal{L} > 0$, for $t > t^+ + 1$. By the Kuhn-Tucker conditions, (b) implies that $b(t) = 0$ for all $t > t^+ + 1$. Thus, we have shown that if \mathbf{b} is an optimal payment schedule over all payment schedules, and, under \mathbf{b} , the last non-diversion period is t^+ , then the performance schedule will call for one positive payment at date $t^+ + 1$. This payment will exactly satisfy the incentive compatibility condition and thus, the contract will specify $b(t) = 0$ for $t \neq t^+ + 1$ and specify a payment $b(t^+ + 1)$ that verifies

$$(1 - \delta) \left(c + b(t^+ + 1) + \sum_{t=t^++2}^T \delta^{t-(t^++1)} c \right) = c. \tag{A-18}$$

Simple algebra shows that this contract design coincides with the payments specified in part (b) of Proposition 7 when $t^+ = t^*_+$.

Next, note that, ex ante, shutting down production is never optimal. This result is an easy consequence of (i) Assumption 1, which implies that per-period profit on the unrevealed path is positive, and (ii) the incentive compatibility condition for non-diversion, (A-11): Reducing the number of unrevealed periods in which the firm operates, lowers the manager's continuation value after the reputation cutoff period and thus increases the compensation payment required to ensure that the manager does not divert up to the reputation cutoff period. Because shutting down on the unrevealed path strictly lowers gross profits and weakly increases expected managerial compensation, shutting down on the unrevealed path is strictly suboptimal ex ante for the owner. Thus we have established the following result:

Result 1. The payments received by the manager and the operating policy under an optimal solution to the full commitment problem are identical to the payments and policies specified in Proposition 7.

To complete the proof of parts (a), (b), and (c), we need only show that (i) the full-commitment schedule of payments can be implemented with price-history-dependent contracts and (ii) under a full-commitment optimal contract, the ex post optimal operating policy coincides with the ex ante optimal policy. Establishing (i) is straightforward: A contract that promises to pay $b(t)$ at date t if and only if the good's price at least equals p_1 will provide a payment to the manager of $b(t)$ if and only if the firm is unrevealed at date t .

Next consider (ii). First note that the fact that the manager can always divert c in any period implies that $v_M[\mathbf{b}](t^+ + 1) \geq c$. Thus, equation (A-11) implies the following result:

Result 2. A compensation payment of $\frac{c\delta}{1-\delta}$ always satisfies (A-11) for any reputation cutoff period, t^+ . Thus, schedules that solve the full commitment problem will never specify higher payments to the manager than $\frac{c\delta}{1-\delta}$ at any date.

Now consider the ex post operating decision. First, consider dates $t < t^+ + 1$. At such dates, no payments are received by the manager; the probability of the manager diverting is 0 and thus beliefs about the security of the control system are not revised. Thus, Assumption 1 ensures that it is never optimal ex post to shut down. Now consider $t \geq t^+ + 1$. In this case, the operating decision will affect the belief revision process, i.e., if the firm operates at date $t^+ + 1$ then, either the firm will be revealed with probability $1 - P_1$ and will shut down, or with probability P_1 , the firm will remain unrevealed and if the firm also operates in period $t^+ + 2$, the price of the period- $t^+ + 2$ good will equal $\Gamma[P_1]$. So, assuming the firm operates when unrevealed at $t^+ + 1$, its gross expected profit in period $t^+ + 2$ conditioned on operating in period $t^+ + 2$ when unrevealed

is given by

$$P_1(\Gamma[P] - e) + (1 - P_1)0 > P_1(\Gamma[P] - e) + (1 - P_1)(\delta - e) = P_1 - e, \quad (\text{A-19})$$

where the last equality follows from (2) and (3). However, the right-hand side of equation (A-19) equals the expected gross profit at $t^+ + 2$ conditioned on the firm shutting down at $t^+ + 1$ and operating when unrevealed at $t^+ + 2$. Thus, the expected gross profit at $t^+ + 2$ conditioned on the firm operating when unrevealed at $t^+ + 2$ is always higher conditioned on operating when unrevealed at $t^+ + 1$ than it is conditioned on shutting down when unrevealed at $t^+ + 1$. This implies, by an easy backward induction argument, that operating at any date $t \geq t^+ + 1$ leads to a higher gross continuation value. Because no payments are made to the manager under the full-commitment schedule after date $t^+ + 1$, continuation value is thus always higher if the firm operates rather than shuts down when unrevealed.

Now consider the current period payoff: At all dates $t \geq t^+ + 1$ except date $t^+ + 1$ no compensation is paid and thus, by Assumption 1, the current payoff to the owner from operating exceeds the current payoff from shutting down. Thus, operating is ex post optimal for the owner. At date $t^+ + 1$, the current payoff to the owner equals

$$P_1 - e - b(t^+ + 1).$$

By Result 2, the owner's current payoff is greater than

$$P_1 - e - \frac{c\delta}{1 - \delta}. \quad (\text{A-20})$$

Assumption 3 ensures that (A-20) is nonnegative. Thus, the owner's current payoff from operating is no less than 0, the owner's current payoff from shutting down. Because, as already demonstrated, the owner's continuation value is higher from operating, operating at $t^+ + 1$ is ex post incentive compatible. Thus, the full commitment optimal payment schedule and operating policy is identical to the payment schedule specified in Proposition 7, and the full commitment policy satisfies the ex post incentive compatibility conditions on operation and can be implemented with price-history-dependent contracts. Hence, it is feasible for the more constrained actual problem and thus is optimal for that problem. Consequently parts (a), (b), and (c) have been established.

Now consider part (d) of the proposition. Define a " t^+ -shift": incrementing the reputation cutoff pe-

riod t^+ by one period to $t^+ + 1$. The change in the manager's compensation is the change in expected compensation under $b^*[t^+ + 1]$ and $b^*[t^+]$. Using part (b), we see that this difference is given by

$$c \delta^{T-(t^++1)}. \quad (\text{A-21})$$

If the firm is unrevealed, let $p(t)$ represent the price consumers are willing to pay for the good in period t . Note that $p(t)$ also represents the probability that the firm will remained unrevealed until period $t + 1$. The owner's expected gross profit in period t under the t^+ -policy, which we represent by $\bar{\pi}[t^+](\cdot)$, equals

$$\bar{\pi}[t^+](t) = (p[t^+](t) - e) \prod_{s=0}^{t-1} p[t^+](s), \quad t = \{1, 2, \dots, T\}, \quad (\text{A-22})$$

and the owner's gross value is simply a sum of these gross profits across all periods. Since the good's price under both the t^+ and $t^+ + 1$ policies equals 1 when $t \leq t^+$, $\bar{\pi}[t^+ + 1](t) = \bar{\pi}[t^+](t)$ for all $t \leq t^+$. Since the Bayes' operator goes into effect with a one period delay under the $t^+ + 1$ -policy, $\bar{\pi}[t^+ + 1](t + 1) = \bar{\pi}[t^+](t)$ for $T > t > t^+$. Thus, the difference in gross value induced by a t^+ -shift is a telescoping sum given by

$$\bar{\pi}t^+ - \bar{\pi}[t^+](T) = (1 - e) - \bar{\pi}[t^+](T). \quad (\text{A-23})$$

Since, under the t^+ -policy, the manager diverts in all periods after t^+ and does not divert in any period before t^+ , the good's price is given by $p[t^+](\cdot)$, where

$$p[t^+](t) = \begin{cases} 1 & t \leq t^+ \\ \Gamma^{(t-(t^++1))}(P_1) & t > t^+ \end{cases}, \quad (\text{A-24})$$

$P_1 = \rho_1 + \delta(1 - \rho_1)$, and $\Gamma^{(n)}$ is the n -fold composition of the Bayes' operator defined in equation (2), which is explicitly represented by solving a difference equation yielding

$$\Gamma^{(n)}(P) = \frac{(P - \delta) + (1 - P) \delta^{n+1}}{(P - \delta) + (1 - P) \delta^n}. \quad (\text{A-25})$$

Using equations (A-24), (A-25), and (A-22), we see that

$$\bar{\pi}[t^+](T) = \frac{(P_1 - \delta)(1 - e) - (1 - P_1)(e - \delta)\delta^{T-(t^++1)}}{1 - \delta}. \quad (\text{A-26})$$

Thus, the effect on the gross value of the owner of a t^+ -shift is given by

$$(1 - e) - \frac{(P_1 - \delta)(1 - e) - (1 - P_1)(e - \delta)\delta^{T-(t^++1)}}{1 - \delta} = \frac{(1 - P_1)(1 - e) + (1 - P_1)(e - \delta)\delta^{T-(t^++1)}}{1 - \delta}. \quad (\text{A-27})$$

Combining the effects of a t^+ shift on compensation and gross firm value shows that the net effect on the owner is given by

$$\frac{(1 - P_1)(1 - e) + ((1 - P_1)(e - \delta) - c)\delta^{T-(t^++1)}}{1 - \delta}. \quad (\text{A-28})$$

Thus, if $(1 - P_1)(e - \delta) - c \geq 0$, all t^+ -shifts increase the owner's value and the owner will set $t^+ = T - 1$. Otherwise, $(1 - P_1)(e - \delta) - c < 0$. In which case, the effect of a t^+ shift on the owner's value is strictly decreasing. Thus, the set of t^+ -shifts that increase the owner's value is a (possibly empty) downward directed order interval. The owner will pick the unique t^+ , which we denote by t_*^+ , which satisfies the following conditions: if some t^+ -shift lowers owner value, t_*^+ is the smallest $t^+ \in \{0, 1, \dots, T - 1\}$ such that the effect of a t^+ shift is to lower the owner's value, or, if all t^+ shifts increase owner value, then $t_*^+ = T - 1$. This is exactly the assertion made in part (d). Thus the proof is complete. \square

Proof of Proposition 8. The proof for each claim follows directly from the discussion preceding the proposition. \square

Proof of Proposition 9. The owner will choose the high-quality technology in period t in a given equilibrium whenever

$$c + \delta v_O(t + 1) < v_O(t + 1), \quad (\text{A-29})$$

where the owner's continuation value, $v_O(t + 1)$, is based on an optimal continuation strategy. A feasible strategy for the owner is to divert in all periods subsequent to t . All updating rules consistent with Bayes' rule produce $p(s) > p(t)$ for $s > t$. Thus a lower bound on the owner's continuation payoff is given by, $v_O(t + 1)$, where

$$v_O(t + 1) = \sum_{j=1}^s \delta^{j-1} (p(t) - I) = \frac{(p(t) - I)(1 - \delta^{T-t})}{1 - \delta}. \quad (\text{A-30})$$

Consequently,

$$v_O(t+1) \geq v_O(t+1) = \frac{(p(t) - I)(1 - \delta^{T-t})}{1 - \delta}. \quad (\text{A-31})$$

It follows that if

$$c \leq (p(t) - I)(1 - \delta^{T-t}), \quad (\text{A-32})$$

at any date t , then condition (A-29) is satisfied and the owner-manager will choose high quality. This establishes claim (i).

Note that because equilibrium beliefs are updated according to Bayes' rule, $p(t) \geq P_1$. Moreover, since $\delta < 1$, $\delta \geq \delta^{T-t}$ for all $t \leq T-1$. Therefore, condition (A-29) is satisfied for all periods whenever (25) is satisfied. This establishes claim (ii).

The owner-manager will divert in period t whenever

$$\frac{c}{1 - \delta} > v_O(t+1). \quad (\text{A-33})$$

An upper bound on the owner's payoff is given by the owner's payoff when $P = 1$ and the owner optimally chooses in each period whether to produce high or low quality. The value function associated with this policy is increasing in the number of remaining periods because the per period payoff is positive. Moreover, the cost of investing in high quality is fixed while the benefit of high quality, the increase the probability of being unrevealed, is proportional to continuation value. Thus, assuming the upper bound $P = 1$ in every period, the owner's optimal technology choice will be to produce high quality for the first s periods after t and low quality for the remainder, with $s \in \{0, 1, \dots, T\}$. The owner's payoff from the policy of choosing the high-quality technology up to and including s periods after t is given by

$$\sum_{j=1}^s (1 - I - c) + \sum_{j=s+1}^{T-t} \delta^{j-s-1} (1 - I) = (1 - I - c)s + \frac{(1 - I)(1 - \delta^{T-t-s})}{1 - \delta}. \quad (\text{A-34})$$

Thus, an upper bound on the continuation payoff of the owner, $\bar{v}_O(t+1)$, is given by

$$\bar{v}_O(t+1) = \max_{s=\{0,1,\dots,T-t\}} (1 - I - c)s + \frac{(1 - I)(1 - \delta^{T-t-s})}{1 - \delta}. \quad (\text{A-35})$$

Because, $\bar{v}_O(t+1)$ is an upper bound for $v_O(t+1)$, a sufficient condition for low quality production at date

t is that

$$\frac{c}{1-\delta} > \bar{v}_O(t+1). \quad (\text{A-36})$$

Claim (iii) follows.

□