Employee Spinoffs and the Solipsistic Entrepreneur

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A team of managers engaged in production using technology x, is considering switching to technology y. The value of y is learned slowly over time, but constraints on the ability of individual managers to communicate their beliefs allow disagreements to emerge among team members. Managers who develop sufficiently strong disagreements with their colleagues choose to form new companies to implement their preferred strategy. Out of a symmetric model of disagreement, two distinct classes of spinoffs arise. A type 1 spinoff forms when an employee comes to believe it is worth switching to y but the firm does not. A type 2 spinoff arises when an employee sufficiently disagrees with the firm's decision to switch strategy that he is willing to invest in order to continue with x. The comparative dynamics of the formation of type 1 and type 2 spinoffs are distinct, and yield some novel testable implications.

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1. Introduction

It is well-known that employee spinoffs have played a significant role in the early evolution of many high-tech industries. They have frequently accounted for a significant fraction of entrants, and on average have out-performed other types of entrants. Because of their prominent role, a number of theories of spinoffs have been developed.[1] One class of theories proposes that new projects often have limited value to existing firms because their implementation would cannibalize existing rents [e.g., Christensen (1993), Klepper and Sleeper (2005)]. In a second class, employees learn from their employers and they exploit this knowledge by forming a spinoff [e.g., Agarwal *et al.* (2004), Franco and Filson (2006), Franco and Mitchell (2008)]. In the third class, an idea with uncertain value occurs serendipitously to an employee, who may induce his employer to develop and implement it, or who may develop it himself in a spinoff [e.g., Amador and Landier (2003), Hellman (2007)].

This paper belongs to the second and third classes. It develops a model in which firms engaged in one strategy, x, are presented with an opportunity to change strategy to y upon payment of a switching cost, c. The value of y is not known in advance, but must be learned over time from noisy signals. Firms are initially formed of like-minded individuals who subsequently observe diverse private signals about y. Although they communicate their signals to each other, communication is imperfect, so in the short-term disagreements about the firm's best strategy are inevitable. Spinoffs occur if disagreements become sufficiently profound to justify the cost, $k > c$, of forming a new firm.

This model builds on ideas developed in Klepper and Thompson (2009). In their model, firms maximize value by learning to match a decision with a target that is initially unknown [cf. Jovanovic and Nyarko (1995)]. Some firms are populated by individuals with superior ability, but this is not known to other managers. As a result, the opinions of superior employees are insufficiently incorporated into the decision-making process of their firms, inducing some of them to launch spinoffs. This paper develops their model in several new directions. First, disagreements do not depend upon the presence of an individual with superior ability. Instead, disagreements arise among managers with homogeneous ability, because all of them are solipsistic

[1] See Klepper (2001) and Franco (2005) for detailed reviews of the literature.

and underweigh the information of others relative to their own information.[2] Second, following Amador and Landier (2003), the model considers an explicit choice between alternative, mutually exclusive, strategies. Third, the model incorporates an explicit production technology, a feature that is absent from Klepper and Thompson (2009).

These new directions yield some distinctive implications. A novel feature of the model is that, out of a symmetric model of disagreement, two distinct classes of spinoffs arise. First, a type 1 spinoff forms when an employee comes to believe it is worth switching to the new strategy but the firm does not. Second, a type 2 spinoff arises when an employee sufficiently disagrees with the firm's decision to switch strategy that he is willing to invest in order to continue with the old strategy. The comparative dynamics of the formation of type 1 and type 2 spinoffs are distinct, and yield some novel testable implications.

In Klepper and Thompson (2009), spinoffs begin by making choices different from their parents', but they always end up doing the same thing after sufficient time has elapsed for the target to be learned. In the present paper, spinoffs also begin following a different strategy, but this is a permanent state of affairs for some of them. For example, many type 1 spinouts are mistakes in the sense that y is not sufficiently more valuable than x to justify the entry cost, k (in fact, this is true of the average spinoff). When this is the case, parent firms may, but usually will not, follow in the footsteps of their spinoff by adopting strategy y. Other type 1 spinoffs are not mistakes – y is indeed significantly better than x. In this instance the parent will eventually switch to y, so parent and spinoff eventually employ the same strategy.

The model yields a number of additional predictions, although some of these are common to several theories. For example, the hazard of a spinoff first rises rapidly before declining more gradually, eventually to zero. This is consistent with the evidence reviewed in, and the model of, Klepper and Thompson (2009), but it is also a feature of many models of employee learning [e.g., Jovanovic (1979)]. More distinctively, the hazard of type 1 spinoffs peaks earlier than the hazard of incumbent firms switching strategy, while the hazard of type 2 spinoffs peaks later. Put another way, spinouts that are founded early in their parents' lives are more likely to be innovative than those that are founded later. Given that firm and industry ages are in general

[2] See Thompson (2008) for an application to marital dissolution of solipsism-driven disagreement.

correlated, the same is true, although to a lesser extent, for spinoffs that appear early in an industry's life.

The model also makes a number of predictions about the quality of spinoffs and their parents. Type 1 spinoffs outperform their parents when the cost of adopting the new strategy, either for the incumbent firm or for the spinoff, is not trivial. However, when adoption costs are sufficiently low, type 1 spinoffs under-perform relative to their parents. Type 2 spinoffs also outperform their parents when the cost of launching a spinoff is high, but they perform worse than their parents when the incumbent's cost of switching strategy is sufficiently high. For both types of spinoffs, average performance is increasing in the quality of the parent, and this is true when we measure the initial or post-switching performance of the parents of type 2 spinoffs. The quality of parents also influences the likelihood of spinoffs. First, the model predicts that spinoffs are most likely to be spawned by parents of intermediate quality, a prediction at odds with much prior theorizing. Second, among firms that spawn spinoffs, high-quality parents are more likely than low-quality parents to spawn type 1 rather than type 2 spinoffs. There are no performance spillovers across strategies, in the sense that y is independent of x, and the correlation between parent quality and spinoff probabilities and performance is induced by pure selection effects.

2. The Model

The model of disagreements and spinoffs is based on an optimal stopping problem, in which a firm engaged in one strategy is considering switching to a second available strategy. The value of the second strategy is not known prior to adoption, but the firm learns about it over time through observation of noisy signals. The value of the second strategy is fully revealed after adoption. The model is developed in five subsections. Subsection A describes the technology. Subsection B analyzes the optimal stopping problem treating the firm as a single decision maker. Subsection C introduces a team of managers who may develop divergent beliefs about the value of the second strategy. Subsection D derives the implications of the model for the hazard of spinoff formation. Finally, Subsection E analyzes the qualities of spinoffs and their parents.

A. Technology

Let profits in period t for a firm's strategy, s, be given by

$$\pi(s,n) = \max_{n \geq 0} \operatorname{sgn}(s) \mid s \mid^{1-\gamma} n^{\gamma} - n \,, \tag{1}$$

where n is employment. Although labor is the numeraire, equation (1) contains no explicit output price, which is subsumed into s. Thus, s represents, *inter alia*, the value of technology choices that alter the physical productivity of labor, of technology choices affecting product quality, and of market strategies that also affect the firm primarily through the price of output.

If the firm implements strategy s, its value is known. Hence, optimal employment is

$$n(s) = \begin{cases} 0, & \text{if } s \leq 0 \\ \gamma^{1/(1-\gamma)} s, & \text{if } s > 0 \end{cases}, \tag{2}$$

and maximized profits are

$$\pi(s) = \begin{cases} 0, & \text{if } s \leq 0 \\ \phi s, & \text{if } s > 0 \end{cases}. \tag{3}$$

where $\phi = \gamma^{\gamma/(1-\gamma)}(1-\gamma)$. Prior to implementing strategy s, its value is not known, except that at time t it is believed to be a draw from some time-varying distribution $F_t(s)$. Then, expected profit is

$$E_t(\pi) = \int_{-\infty}^{\infty} \max\{0, \phi s\}\, dF_t(s) = \phi \int_{0}^{\infty} s dF_t(s) = \phi E_t\left[s^{+}\right], \tag{4}$$

where $E_t\left[s^{+}\right]$, by convention, denotes $\max\left\{0, E_t[s]\right\}$. The firm is currently implementing a strategy $s = x > 0$, where x is known. We refer to x as the quality of the firm. High-quality firms are more productive, they have higher employment and output and they generate more profit. Thus, quality, size, and profitability are interchangeable terms.

There also exists an alternative strategy, $s = y$, that the firm has not implemented. In any period the firm may abandon strategy x and adopt strategy y after payment of a cost, c. The realization of y is observed immediately upon switching, but in this section it is assumed that the switch to y is irreversible. However, if it turns out that $y < 0$, the firm chooses $n(y) = 0$; a decision to employ no workers will be considered an exit.

B. A Firm-Level Analysis

Let $V(F_t(y),t;x)$ denote the value to the firm of following strategy x at time t when beliefs about y are given by $F_t(y)$, and let $W(y)$ denote the time-independent value of having just switched to strategy y. Then

$$V\left(F_t(y),t;x\right)=\max\left\{\phi x+\beta\int_{-\infty}^{\infty}V\left(F_{t+1}(y),t+1;x\right)dF_t(y),\,-c+\int_{-\infty}^{\infty}W(y)dF_t(y)\right\}, \qquad (5)$$

where

$$\int_{-\infty}^{\infty}W(y)dF_t(y)=\frac{\phi}{1-\beta}E_t\left[y^+\right]. \qquad (6)$$

Under the customary assumption that $E_t\left[y^+\right]<\infty$, the stopping problem defined by (6) is standard. This is most easily seen by considering critical values of x, conditional on beliefs about y. Define x_t^* by

$$x_t^*=\max\left\{0,\min_x\left\{x:\phi x+\beta\int_{-\infty}^{\infty}V\left(F_{t+1}(y),t+1;x\right)dF_t(y)\geq -c+\frac{\phi}{1-\beta}E_t\left[y^+\right]\right\}\right\}. \qquad (7)$$

That is, x_t^* is the smallest value of x for which continuation with strategy x is preferred given the sequence of beliefs, $F_t(y)$ and $F_{t+1}(y)$. The left hand side of the inequality in (7) is a non-negative, strictly increasing function of x that is unbounded from above, while the right hand side is independent of x. Thus, x_t^* defines a stopping region, $x\in[0,x_t^*)$ such that low-quality firms with current strategies lying within this region switch to strategy y, while high-quality firms in the region $x\in[x_t^*,\infty)$ prefer continuation with x. Note in particular that, as the left hand side of (7) is non-negative, no firms switch strategy if $E_t\left[y^+\right]<c(1-\beta)\phi^{-1}$; for most sequences of beliefs the option value of continuation is strictly positive even for the lowest-quality firms, so $E_t\left[y^+\right]$ must be sufficiently greater than $c(1-\beta)\phi^{-1}$ to induce any firms to switch strategy.

It is of course more customary to define the optimal stopping time in terms of beliefs about y. Assume that these beliefs evolve as follows. In period 0, the firm's beliefs are described by a prior distribution, $F_0(y)$, that is normal with zero mean and variance σ^2. Each period the firm observes a signal, z_t, which is normally distributed with mean y and variance σ_z^2. Let $\overline{z}_t$ denote the mean of the t signals observed up to period t. The posterior belief, $F_t(y)$, is normal with mean $\overline{y}_t = t\sigma^2\overline{z}_t(\sigma_z^2 + t\sigma^2)^{-1}$ and variance $\sigma_{y,t}^2 = \sigma^2\sigma_z^2(\sigma_z^2 + t\sigma^2)^{-1}$; the pairs $\{\overline{y}_t, t\}$ and $\{\overline{z}_t, t\}$ are therefore each sufficient statistics for $F_t(y)$. Thus, the Bellman equation can be written as

$$V(\overline{y}, t; x) = \max\left\{\phi x + \beta\int_{-\infty}^{\infty} V\left(\overline{y}', t+1; x\right) dG_{t+1}(\overline{y}' \mid \overline{y}), -c + \frac{\phi}{1-\beta} E_t\left[y^+ \mid \overline{y}\right]\right\}, \quad (8)$$

where $G_{t+1}(\overline{y}' \mid \overline{y})$ is normal with mean $\overline{y}$ (by the law of iterated expectations) and variance $\sigma_{\overline{y},t+1}^2 = \sigma^2\sigma_{y,t}^2(\sigma_z^2 + (t+1)\sigma^2)^{-1}$.

Let $\overline{y}_t^*(x)$ denote the critical value of the subjective mean of y. Clearly, $\overline{y}_t^*(x)$ is increasing in x. However, it changes over time in a way that defeats explicit analysis. On the one hand, the term $E_t[y^+ \mid \overline{y}] = \int_0^\infty y dF_t(y \mid \overline{y})$ is increasing in σ_t^2, so the expected payoff from switching to y, conditional on $\overline{y}$, decreases with time. This causes $\overline{y}_t^*(x)$ to rise over time. On the other hand, the value of sticking with x declines over time because the conditional variance of $\overline{y}'$ declines with t. This effect causes $\overline{y}_t^*(x)$ to fall over time. It does not seem to be possible to show that one of these effects dominates the other, which creates difficulties for studying the hazard of switching as a function of time. In related stopping problems, Jovanovic (1979) and Thompson (2008) have implemented an approximate solution to the hazard problem by fixing the critical value for switching to y to its asymptotic value. We adopt their strategy here, and defer to the appendix an exploration of some alternative approximations. That is, let $\overline{y}_t^* = \lim_{t\to\infty} \overline{y}_t^*$ for all t, so the firm switches strategy in the first period that $-c + \phi\overline{y}_t(1-\beta)^{-1} > \phi x(1-\beta)^{-1}$. The critical value is then given by $\overline{y}_\infty^* = c(1-\beta)\phi^{-1} + x$. The appendix provides a numerical example indicating that $\overline{y}_t^* > \overline{y}_\infty^*$ for small values of t, although convergence to $\overline{y}_\infty^*$ appears to be rapid.

The following property of the stopping problem is immediately apparent from the fact that the critical value, $\overline{y}^*$, is increasing in x.

P1. *Among firms that switch to strategy y, the expected value of y is increasing in x.*

Firm employment and output are increasing in x and y. It then follows that firms that are larger than average prior to switching will be larger than average after switching. Larger firms have no advantage over smaller firms in securing a productive alternative strategy, but they do demand that the new strategy appear to be higher quality before choosing to switch.

To explore the timing and probability of switching, we require the distribution of the

Markov time, T, that satisfies

$$T = \min_{\tau} \left\{ \tau : \overline{y}_{\tau} \geq c(1-\beta)\phi^{-1} + x \right\}. \tag{9}$$

where $\overline{y}_t$ is a random variable with normally distributed increments in each period, having mean $t\sigma^2 y(\sigma_z^2 + t\sigma^2)$ and variance $\sigma^2_{\overline{y},t+1}$. This first passage problem is easier to analyze in the continuous-time analog to our problem. Define

$$\omega_t = \left(\frac{\sigma_z^2 + t\sigma^2}{\sigma_z \sigma^2} \right) \overline{y}_t - \frac{ty}{\sigma_z}. \tag{10}$$

The random variable ω_t is normal with zero mean and variance t, while the increments to ω_t are independent standard normals. The continuous time stochastic process $d\omega(t)$ that gives rise to the same distribution as ω_t at t=0,1,2, . . . , is a standard zero-drift Wiener process, $\omega(t)$, with boundary condition $\omega(0)$=0. The absorbing barrier for $\overline{y}_t$ is $c(1-\beta)\phi^{-1} + x$. Hence, the corresponding barrier for $\omega(t)$ is obtained by replacing $\overline{y}_t$ in (10) with $(1-\beta)\phi^{-1}c + x$. The transformed first passage problem is therefore given by the distribution of the Markov time, T, that satisfies

$$T = \min_{\tau} \left\{ \tau : \omega(\tau) \geq \zeta_1 + \zeta_2 \tau \right\}, \tag{11}$$

where

$$\zeta_1 = \frac{\sigma_z}{\sigma^2} \left(c(1-\beta)\phi^{-1} + x \right) \text{ and } \zeta_2 = \frac{1}{\sigma_z} \left(c(1-\beta)\phi^{-1} + x - y \right). \tag{12}$$

Equations (11) and-(12) define the problem for the first passage of a Wiener process to a single linear boundary, $\zeta_1 + \zeta_2 t$, that is moving away from the origin when $y < c(1-\beta)\phi^{-1} + x$ and toward the origin when $y > c(1-\beta)\phi^{-1} + x$ (see Figure 1). The distribution of first passage times, $P(T;\bullet)$, for this problem is given by the well-known Bachelier-Lévy formula [e.g., Cox and Miller (1965:221)],

$$P(T;\zeta_1,\zeta_2) = \Phi\left(-\frac{\zeta_1 + \zeta_2 T}{\sqrt{T}} \right) + e^{-2\zeta_1\zeta_2} \Phi\left(-\frac{\zeta_1 - \zeta_2 T}{\sqrt{T}} \right), \tag{13}$$

where $\Phi(\bullet)$ is the distribution function of a standard normal random variable. Equation (13) is straightforward to analyze, and has the following properties:

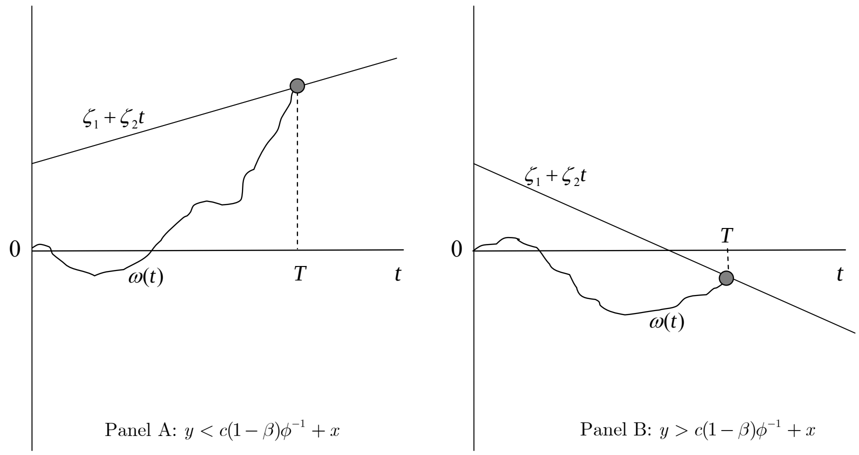

FIGURE 1. First passage problems for adoption of y. Sample paths are drawn excessively smooth for visual clarity.

P2. *The probability that the firm ever switches strategy is given by*

$$P^{\infty}(\zeta_1,\zeta_2) = \lim_{T\to\infty} P(T;\zeta_1,\zeta_2) = \begin{cases} 1, & \text{if } y \geq c(1-\beta)\phi^{-1} + x \\ e^{-2\zeta_1\zeta_2} < 1, & \text{if } y < c(1-\beta)\phi^{-1} + x \end{cases}. \quad (14)$$

All firms for whom it is *ex post* optimal to switch strategy will eventually do so; all that is needed is sufficient passage of time to learn y. However, a fraction of firms for whom it is not *ex post* optimal to switch strategy will do so as a result of observing misleading signals about y. When $y < c(1-\beta)\phi^{-1} + x$, P^{∞} is decreasing in $c(1-\beta)\phi^{-1}$: an undesirable switch into y is more likely when the discount factor is high, and when switching costs are low. P^{∞} is increasing in σ^2, so that a noisy prior induces more frequent switches that turn out to be unprofitable. A somewhat more surprising result is that the variance, σ_z^2, of the signals has no bearing on the probability of an *ex post* undesirable switch.

Equation (14) also shows that larger firms (with higher values of x) are less likely to switch strategies than smaller firms. First, firms with high values of x are less likely to draw a y that satisfies $y \geq c(1-\beta)\phi^{-1} + x$, so they are less likely to belong to the set of firms for which switching is (eventually) guaranteed. Second, P^{∞} is decreasing in x, so large firms that fall into the set $y < c(1-\beta)\phi^{-1} + x$ are less likely to switch.

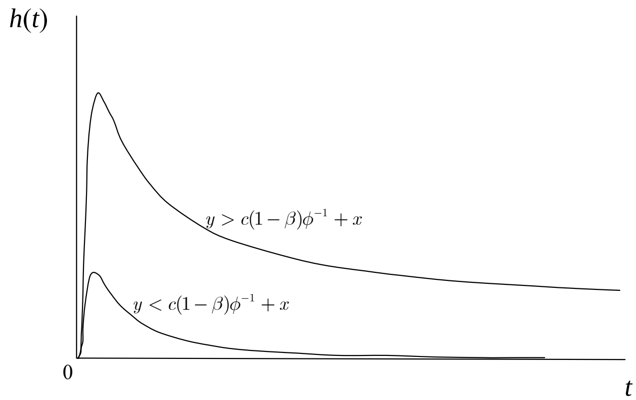

FIGURE 2. Hazard of switching to strategy y.

P3. *If* $y \geq c(1-\beta)\phi^{-1}+x$, *the expected time until switching is given by*

$$E\left[T \mid y \geq c(1-\beta)\phi^{-1}+x\right]=\frac{\sigma_z^2}{\sigma^2}\left(\frac{c(1-\beta)\phi^{-1}+x}{y-\left(c(1-\beta)\phi^{-1}+x\right)}\right). \tag{15}$$

Clearly, $E\left[T \mid y < c(1-\beta)\phi^{-1}+x\right]=\infty$. Factors that make an *ex post* undesirable switch into y more likely also increase the average speed with which *ex post* desirable switches are made. Among firms that will make a switch, $E[T]$ is decreasing in $y-x$. As y is independent of x, it follows that larger firms that switch will on average take longer to do so. In addition, noisier signals increase the expected time to make a switch, even though increased noise has no effect on the probability that a switch is ever made.

P4. *The hazard,* $h(T)$, *of switching initially rises. When* $y \leq c(1-\beta)\phi^{-1}+x$, *the hazard eventually declines to zero. When* $y > c(1-\beta)\phi^{-1}+x$, $\lim_{t\to\infty} h(t)=\omega_2^2/2$.

The hazard is given by $h(T)=P'(T;\omega_1,\omega_2)/(1-P(T;\omega_1,\omega_2))$. The density, P' is increasing until $\hat{T}=\left(\sqrt{4\omega_1^2\omega_2^2+9}-3\right)/2\omega_2^2$, and decreasing thereafter. As P is strictly increasing in T, the hazard must be strictly increasing until at least $\hat{T}$. The limiting values of the hazard are easily verified by direct calculation. Figure 2 illustrates two representative hazard functions, illustrating a rapid rise in the hazard followed by a more gentle decline. When $y > c(1-\beta)\phi^{-1}+x$, the hazard declines to a positive lower bound, consistent with the fact that in this case switching is eventually certain.

C. Team Decisions and the Evolution of Disagreement

Assume that a firm's management team is composed of m individuals, each of whom earns a fraction $1/m$ of the firm's profits. Each individual observes private signals about y and has some influence on the firm's decision about whether or not to switch strategy. In period t, individual i=1, 2, . . ., m, believes y is a draw from a normal distribution with mean $\overline{y}_{it}$ and variance $\sigma^2_{y,it}$. The "belief" that governs the firm's decision is a compromise, $\overline{y}_t = \sum_{i=1}^{m} \psi_i \overline{y}_{it}$, of everyone's beliefs. The parameters ψ_i are time-invariant weights attached to individual expectations, with $\sum_{i=1}^{m} \psi_i = 1$. The weight ψ_i can be interpreted as i's decision-making influence.

Although the signals about y differ across members of the firm, disagreements need not arise. Indeed, Aumann (1976) has shown that if the posteriors of Bayesians with common priors are common knowledge, their posteriors must be the same, while Geanakoplos and Polemarcharkis (1982) have shown that if agents with common priors repeatedly exchange their beliefs they will arrive at the common knowledge posterior. This result leave two ways in which disagreements can persist. First, one can drop the common prior assumption [e.g., Harrison and Kreps (1978), Van den Steen (2001, 2004)], but there has been some debate about whether doing so is reasonable [Aumann (1988), Gul (1988), Morris (1995)]. Second, one can drop the efficiency of individuals' information processing, which is the approach taken here.

Some authors have introduced inefficiency by assuming that individuals are overconfident, in the sense that the posterior mean is a biased estimate of the true mean [e.g., Malmendier and Tate (2002, 2003)]. Others have assumed that decision-makers overweigh the information content of their private signals relative to publicly available information; this approach has also been dubbed a form of overconfidence. The approach in this paper is of the second type. However, we propose a somewhat different nomenclature. We reserve the term "overconfident" to refer to individuals who underestimate the noise of any signals, whether their own or those inferred from their colleagues. We use the term solipsism to refer to asymmetric weighting of private and non-private signals (in favor of the former). The distinction between overconfidence and solipsism has substance: solipsism is a necessary condition for disagreement; overconfidence of the sort modeled here simply magnifies the size of disagreement.

There is a large empirical literature supporting the assumption of overconfidence and, to a lesser extent, what we have called solipsism. De Bondt and Thaler (1995) have gone so far as to claim that "perhaps the most robust finding in the psychology of judgment is that people are overconfident." Evidence of overconfidence has been reported among diverse professions, including entrepreneurs [Cooper, Woo, and Dunkelberg (1988)] and managers [Russo and Schoemaker (1992)], although entrepreneurs exhibit much more overconfidence than managers [Busenitz and Barney (1997)]. Odean (1998), and Daniel, Hirshleifer, and Subrahmanyam (1998) cite many other examples, and different forms of overconfidence. Our assumption that individuals overweigh private information relative to public information has found support in the laboratory [Anderson and Holt (1996)] and among financial analysts [Chen and Jiang (2003)]. Their findings are consistent with the broader notion that people expect good things (such as receiving accurate signals) to happen to them more often than they do to others [Weinstein (1980), Kunda (1987)].

Assume that in period 0 all m individuals share the same prior that y is a random draw from $N(0,\sigma^2)$. Once each period, these individuals receive private and noisy signals, z_{it}, with mean y and variance σ_z^2. Although all signals have variance σ_z^2, each individual believes his own signals to have variance $\mu\sigma_z^2$ and his colleagues' signals to have variance $\mu\lambda\sigma_z^2$. Individuals are overconfident if $\mu<1$, and solipsistic if $\lambda>1$. In the limit as $\lambda \to \infty$ individuals only respond to their own private signals.

Individual i's posterior after receiving t private signals is normal with mean $\overline{y}_{it} = t\sigma^2\overline{z}_{it}(\mu\sigma_z^2 + t\sigma^2)^{-1}$, and variance $\sigma_{y,it}^2 = \mu\sigma^2\sigma_z^2(\mu\sigma_z^2 + t\sigma^2)^{-1}$, where $\overline{z}_{it}$ is the mean of i's private signals to date t. As λ and μ are common to all decision-makers, the common-knowledge beliefs arrived at after repeatedly exchanging posteriors are the same as would be obtained if each individual's private signals were directly observable to his colleagues. In period t, therefore, individual i forms beliefs as though he has observed t private signals and $(m-1)t$ signals from his colleagues. As a consequence, i's expectation of the quality of strategy y is

$$\overline{y}_{it} = \frac{t\sigma^2}{\lambda\mu\sigma_z^2 + (\lambda + m - 1)t\sigma^2}\left(\lambda\overline{z}_{it} + \sum_{j\neq i}\overline{z}_{jt}\right), \tag{16}$$

while the firm's subjective mean, a weighted average of each team member's subjective mean, is

$$\overline{y}_t = \frac{t\sigma^2}{\lambda\mu\sigma_z^2 + (\lambda + m - 1)t\sigma^2}\left(\lambda\sum_{i=1}^{m}\psi_i\overline{z}_{it} + \sum_{i=1}^{m}\psi_i\sum_{j\neq i}\overline{z}_{jt}\right)$$

$$= \frac{t\sigma^2}{\lambda\mu\sigma_z^2 + (\lambda + m - 1)t\sigma^2} \sum_{i=1}^{m} \left(1 + (\lambda - 1)\psi_i\right) \overline{z}_{it} \; . \tag{17}$$

Hence, i's disagreement with the firm is given by

$$d_{it} = \overline{y}_{it} - \overline{y}_t = \frac{(\lambda - 1)t\sigma^2}{\lambda\mu\sigma_z^2 + (\lambda + m - 1)t\sigma^2} \left((1 - \psi_i)\overline{z}_{it} - \sum_{j \neq i} \psi_j \overline{z}_{jt} \right). \tag{18}$$

If $\lambda = 1$, then $d_{it} \equiv 0$. That is, without solipsism, disagreement is not possible. However, given any sequence of signals, greater overconfidence increases the absolute magnitude of i's disagreement with the firm's belief. The unconditional variance of d_{it} is obviously zero before any signals have been observed; it then rises monotonically to a maximum at $t = \lambda\mu\sigma_z^2\sigma^{-2}(\lambda + m - 1)^{-1}$ before declining asymptotically to zero. Thus, it takes time for disagreements to emerge, but eventually learning dominates the effects of signal noise. Significant disagreements are more likely when signals are noisy, when the prior beliefs about y are imprecise, in small management teams, and when individual i has little decision-making authority.[3] The variance of disagreements is also increasing in $\sum_{j \neq i} \psi_j^2$: when decision-making authority is unequally distributed among team members $j \neq i$, especially if it is concentrated in just one or two members of the team, individual i is more likely to disagree with the team.

D. Spinoff Probabilities

Suppose the firm, as before, can switch strategies at cost c. And suppose that individuals in the firm can form a spinoff at cost $k > c$. If a spinoff is formed, the founder heads a new team of m individuals, so he continues to have a claim to a fraction $1/m$ of the new firm's profits. A spinoff may be attractive under two circumstances. First, a team member may come to believe that y is sufficiently profitable to justify payment of k when the firm has never yet decided that it justifies payment of c. That is, individual i forms a spinoff at

$$T_s^1 = \min_{\tau} \left\{ \tau : \overline{y}_{i\tau} \geq k(1 - \beta)\phi^{-1} + x \wedge \left\{ \overline{y}_t < c(1 - \beta)\phi^{-1} + x \;\forall t \leq \tau \right\} \right\}.$$

$$= \min_{\tau} \left\{ \tau : \overline{y}_{i\tau} \geq k(1 - \beta)\phi^{-1} + x \wedge T > \tau \right\}, \tag{19}$$

[3] Taylor and Zimmerer (1992) surveyed 646 managers about why productive middle managers voluntarily leave their jobs. Although perceived causes of turnover varied across organizational levels, the most common explanations were a lack of control and input on the job.

where T is the time the firm switches to y, and T_s^1 denotes the time of a type 1 spinoff.

Second, individual i forms a spinoff if the firm comes to believe that switching to y justifies the payment of c, he has not previously found y attractive enough to justify implementing it himself through a type 1 spinoff, and at the time the firm switches he believes that y is sufficiently unattractive that payment of k to continue with strategy x is warranted. That is, i launches a type 2 spinoff at

$$\begin{aligned} T_s^2 &= \min_\tau \Big\{ \tau : \overline{y}_\tau \geq c(1-\beta)\phi^{-1} + x \wedge \overline{y}_{i\tau} < (c-k)(1-\beta)\phi^{-1} + x \\ &\qquad\qquad \wedge \left\{ \overline{y}_{it} < k(1-\beta)\phi^{-1} + x \ \forall t \leq \tau \right\} \Big\} \\ &= \begin{cases} T, & \text{if } \overline{y}_{i\tau} < (c-k)(1-\beta)\phi^{-1} + x \wedge T_s^1 > T \\ \infty, & \text{otherwise} \end{cases}. \end{aligned} \tag{20}$$

Because x is known, type 2 spinoffs can only be launched out of parents with $x > k(1-\beta)\phi^{-1}$.

Calculating the probabilities of spinoffs is somewhat challenging for two reasons. First, the random variables $\overline{y}_{it}$ and $\overline{y}_t$ are not in general independent: the extent to which they are correlated depends on the parameters of the model, most especially the amount of solipsism, λ, and the decision weights, ψ_i. Second, a spinoff may be formed by any of m individuals, so the distributions of spinoff times depend on the order statistics $\overline{y}_{(1)t} = \min\{\overline{y}_{1t}, \overline{y}_{2t}, \ldots, \overline{y}_{mt}\}$ and $\overline{y}_{(m)t} = \max\{\overline{y}_{1t}, \overline{y}_{2t}, \ldots, \overline{y}_{mt}\}$. We therefore proceed with the simpler case in which only one individual, i, may form a spinoff, and the random variables, $\overline{y}_{it}$ and $\overline{y}_t$, are independent. This requires that (i) i has no weight in the firm's decision making (i.e., $\psi_i = 0$), and (ii) solipsism is at its worst (i.e., $\lambda \to \infty$).

With these simplifying assumptions, expectations about y are given by

$$\overline{y}_t = \frac{t\sigma^2}{\mu\sigma_z^2 + t\sigma^2} \sum_{j \neq i} \psi_j \overline{z}_{jt} , \tag{21}$$

and

$$\overline{y}_{it} = \frac{t\sigma^2 \overline{z}_{it}}{\mu\sigma_z^2 + t\sigma^2} . \tag{22}$$

Transforming the problem into one consisting of standard Wiener processes yields barriers

$$B(t) = \frac{\mu\sigma_z}{\sigma^2\left(\sum_{j\neq i}\psi_j^2\right)^{1/2}}\Big(c(1-\beta)\phi^{-1}+x\Big) + \frac{t}{\sigma_z\left(\sum_{j\neq i}\psi_j^2\right)^{1/2}}\Big(c(1-\beta)\phi^{-1}+x-y\Big), \tag{23}$$

$$B_s^1(t) = \frac{\mu\sigma_z}{\sigma^2}\Big(k(1-\beta)\phi^{-1}+x\Big)+\frac{t}{\sigma_z}\Big(k(1-\beta)\phi^{-1}+x-y\Big), \tag{24}$$

and

$$B_s^2(t) = \begin{cases} \frac{\mu\sigma_z}{\sigma^2}\Big((c-k)(1-\beta)\phi^{-1}+x\Big) + \frac{t}{\sigma_z}\Big((c-k)(1-\beta)\phi^{-1}+x-y\Big), & \text{if } x \geq k(1-\beta)\phi^{-1}, \\ -\infty, & \text{otherwise} \end{cases} \tag{25}$$

where $B(t)$ is the absorbing barrier for the firm, $B_s^1(t)$ is the absorbing barrier for a type 1 spinoff, and $B_s^2(t)$ is the (non-absorbing) boundary for a type 2 spinoff. Let $\omega(t)$ and $\omega_i(t)$ denote the independent diffusion processes for the firm and for individual i respectively. A type 1 spinoff is formed if $\omega_i(t)$ hits $B_s^1(t)$ before $\omega(t)$ has hit $B(t)$. A type 2 spinoff is formed if $\omega(t)$ hits $B(t)$, $\omega_i(t)$ has not yet hit $B_s^1(t)$, and $\omega_i(t)$ lies below $B_s^2(t)$ when the parent switches strategy.

Figure 3 illustrates some sample paths for the spinoff problem. $B(t)$ has a positive slope, so the figure illustrates the case $y < c(1-\beta)\phi^{-1}+x$; in this case, $B_s^2(t)$ may have a positive or negative slope, as long as $x > k(1-\beta)\phi^{-1}$. The figure has been drawn with $B_s^1(t)$ lying everywhere above $B(t)$. This need not be the case. The relative locations of these two barriers depend on the values of, *inter alia*, $(k-c)$ and $\sum_{j\neq i}\psi_j^2$. Large values of $(k-c)$ tend to place $B_s^1(t)$ above $B(t)$, but this is offset by the fact that small values of $\sum_{j\neq i}\psi_j^2$ shift $B(t)$ upwards. A single sample path for the firm, $\omega(t)$, is plotted showing a switching time of T. Four possible sample paths, $\omega_i^j(t)$, $j = 1, 2, 3, 4$, are illustrated for individual i's beliefs. Sample path $\omega_i^1(t)$ hits boundary $B_s^1(t)$ before T, so this path corresponds to a type 1 spinoff at time T_s^1.

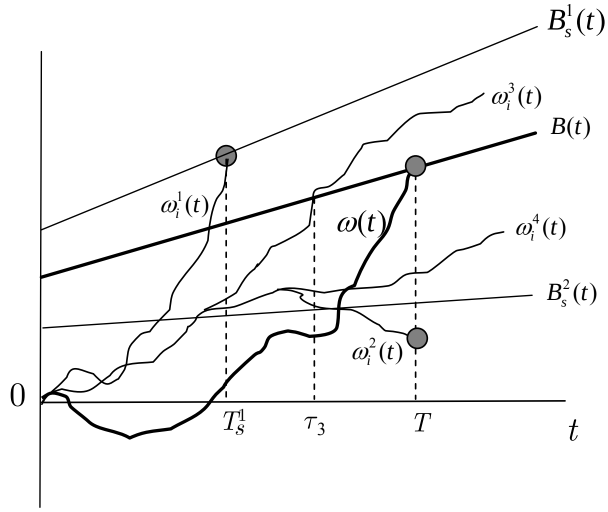

FIGURE 3. Sample paths for type 1 and type 2 spinoffs. Paths are drawn excessively smooth for visual clarity.

Sample path $\omega_i^2(t)$ lies below $B_s^2(t)$ at time T, without having previously crossed $B_s^1(t)$; this sample path yields a type 2 spinoff at time $T_s^2 = T$. The paths illustrated by $\omega_i^3(t)$ and $\omega_i^4(t)$ do not produce a spinoff by individual i. With beliefs $\omega_i^3(t)$, i begins to believe the firm should pay c to switch strategy from time τ_3, but he is not willing to pay the greater cost, k, of launching a type 1 spinoff at any time before T. With beliefs $\omega_i^4(t)$, he does not think the firm should switch strategy at T, but his disagreement with the firm's choice is not sufficiently strong to induce him to launch a type 2 spinoff.

The distributions of the first passage times to $B(t)$ and $B_s^1(t)$ are given by (13), with (23) and (24) providing the appropriate values for ζ_1 and ζ_2. Let $P_s^1(T)$ denote the distribution of the first-passage time to $B_s^1(T)$, and let $P(T)$ denote the corresponding distribution for $B(T)$; let $p_s^1(T)$ and $p(T)$ denote their corresponding densities. Then, because of the independence of $\omega(t)$ and $\omega_i(t)$, the probability there is a type 1 spinoff at time t is $\tilde{p}_s^1(\tau) = p_s^1(\tau)(1 - P(\tau))$, so the distribution of the time that i forms a type 1 spinoff is given by

$$\tilde{P}_s^1(T) = \int_0^T p_s^1(\tau)(1 - P(\tau))d\tau \,. \tag{26}$$

Numerical evaluation of (26) yields the following results:

S1. *The probability of a type 1 spinoff by time T:* (1) *is increasing in the variance of prior beliefs* (σ^2), *the quality of the new strategy* (y), *the degree of overconfidence* (i.e., *a reduction in* μ), *and the cost of switching strategy* (c); (2) *is decreasing in the cost of spinoff formation* (k), *and the concentration of decision-making authority* ($\sum_{j \neq i} \psi_j^2$); (3) *is decreasing in the variance of the signal* (σ_z^2) for $T < \infty$; (4) *exhibits an inverted* $\cup$*-shaped relationship with* x.

These are, on the whole, intuitive results, although not all could have been unambiguously anticipated in advance. For example, Property P2 of the firm's first passage problem established that the variance of the signals has no effect on the probability that the firm ever switches strategy, although firms that do switch are likely to do so later. There was no obvious reason to anticipate that this result would translate to the probability of type 1 spinoffs, but Property S1(3) shows that it does. The effect of concentration of decision-making authority had *ex ante* ambiguous consequences for the probability of spinoff formation. On the one hand, individual i is more likely to disagree with a decision derived from concentrated authority; on the other, a firm with concentrated authority is more likely to mistakenly switch strategy, thereby precluding the formation of a type 1 spinoff. S1(2) concludes that the latter effect dominates.

Property S1(4) states that the probability of a type 1 spinoff is increasing in the quality of the parent when x is small, but decreasing when x is large. This result holds both when conditioning on the realization of y and when taking expectations over all possible values of y. When x is low, no one in the management team is likely to conclude that x is better than y, leaving little likelihood that the firm would stick with x when individual i prefers to switch. Conversely, when x is high, it is unlikely that individual i will find switching to y attractive. Thus, the model predicts that type 1 spinoffs are more likely to be spawned by parents of middling quality than by low- or high-quality parents.

The evidence on parent quality and spinoff probabilities is mixed,[4] and in any case

[4] Klepper and Thompson (2006) conclude that higher-quality firms produce more spinoffs, but note that this might be because larger firms have a larger pool of potential spinoff founders. Agarwal et al. (2004) conclude that, in the disk-drive industry, parents tend to be those with

simple extensions to our model can modify the effect of x on the spinoff hazard. For example, one might suppose that the size of the management team is positively correlated with the size of the firm, and all members of the team may potentially form a spinoff. Alternatively, one might suppose that y is stochastically increasing in x. If either correlation were sufficiently strong, the negative effect of increasing parent quality at high values of x would be reversed. These are not difficult extensions to pursue but, as they would be designed simply to improve the model's concordance with only suggestive evidence, we shall not do so here. In any case, such extensions would do no more than create the *possibility* that spinoffs emerge more frequently from the highest-quality parents.

In contrast to the ambiguous effect of changes in x, increases in the realized value of y always raise the probability of a type 1 spinoff. Thus, when the new opportunities are more attractive, innovative spinoffs are always more likely. This lack of ambiguity is a little surprising in view of the prominence of the difference, $x-y$ in the expression for the barrier, $B_s^1(t),$ of the first-passage problem. As with a reduction in x, an increase in y raises the probability that the incumbent firm switches to y, (which precludes a type 1 spinoff), and it raises the probability that a type 1 spinoff is formed if the parent does not switch. However, the latter effect always dominates.[5]

Evaluating the probability of a type 2 spinoff is just a little more complex. A type 2 spinoff occurs when the firm switches strategy, i has never launched a type 1 spinoff, and $\omega_i(t)$ lies below $B_s^2(t)$ at the time the firm switches strategy. Let T denote the time the firm switches strategy, with distribution function $P(T)$, and let $\omega_i(T)$ denote the value at this time of the Weiner process for individual i. For any admissible $\tilde{\omega}$, the probability that $\omega_i(T)=\tilde{\omega}$ without having first triggered a type 1 spinoff is given by the complement to the crossing probability of a Brownian bridge that begins at $\omega_i(0)=0,$ terminates at $\omega_i(T)=\tilde{\omega},$ and has an absorbing boundary $B_s^1(t)$. This is a well-known distribution [e.g., Scheike (1992), Proposition 3], given by

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higher technological knowledge or higher market pioneering knowledge. However, parents with endowed with both types of knowledge are *less* likely to create a spinoff. Their analysis suggests that the relationship between parent quality and the spinout rate may be rather more complex than the simple regularity reported in Klepper and Thompson.

[5] Note that a change in x alters both the intercepts and slopes of the barriers, $B(t)$ and $B_s^1(t)$, while a change in y alters only the slopes.

$$\Pr\left\{\omega_i(t) < B_s^1(t)\forall t \in [0,T] \mid \omega_i(T) = \tilde{\omega}\right\} = 1 - \exp\left\{-2\widehat{\zeta}_1(\widehat{\zeta}_1 + \widehat{\zeta}_2 T - \tilde{\omega}) / T\right\}, \qquad (27)$$

where $\widehat{\zeta}_1$ and $\widehat{\zeta}_2$ are the coefficients in $B_s^1(t) = \widehat{\zeta}_1 + \widehat{\zeta}_2 t$ from (24). As the unconditional distribution of $\omega_i(T)$ is normal with mean zero and variance T, it follows that the joint probability that $\omega_i(T) < B_s^2(T)$ and $\omega_i(t)$ had not previously crossed $B_s^1(t)$ is given by

$$g(T) = \int_{-\infty}^{\tilde{\zeta}_1 + \tilde{\zeta}_2 T} \left(1 - \exp\left\{-2\widehat{\zeta}_1(\widehat{\zeta}_1 + \widehat{\zeta}_2 T - \omega) / T\right\}\right) \frac{e^{-\omega^2/2T}}{\sqrt{2\pi t}} d\omega\,, \qquad (28)$$

where $\tilde{\zeta}_1$ and $\tilde{\zeta}_2$ are the coefficients in $B_s^2(t) = \tilde{\zeta}_1 + \tilde{\zeta}_2 t$ from (25). The probability of a type 2 spinoff is therefore given by

$$\tilde{P}_s^2(T) = \int_0^T \int_{-\infty}^{\tilde{\zeta}_1 + \tilde{\zeta}_2 T} 1 - \exp\left\{-2\widehat{\zeta}_1(\widehat{\zeta}_1 + \widehat{\zeta}_2 T - \omega) / T\right\} \frac{e^{-\omega^2/2T}}{\sqrt{2\pi t}} d\omega\; dP(T)\,. \qquad (29)$$

Equation (29) is numerically evaluated to produce the following results:

S2. *The probability of a type 2 spinoff by time T*: (1) *is increasing in the variance of prior beliefs* (σ^2), *the quality of the new strategy* (y), *the degree of overconfidence* (i.e., *a reduction in* μ), *and the concentration of decision-making authority* $\sum_{j\neq i}\psi_j^2$); (2) *is decreasing in the cost of spinoff formation* (k), *and the cost of switching strategy* (c); (3) *is decreasing in the variance of the signal,* (σ_z^2), *for small T but increasing in the variance for large T*; (4) *exhibits an inverted* ∪-*shaped relationship with x.*

The majority of the results for type 2 spinoffs parallel those for type 1 spinoffs, but there are some notable exceptions (Table 1 summarizes). First, an increase in the cost of switching strategy (holding constant the cost of launching a spinoff) raises the probability of a type 1 spinoff, but reduces the probability of a type 2 spinoff. This is intuitive: a type 1 spinoff must occur before the firm switches strategy, and an increase in c tends to delay the latter event and make it less likely over any time horizon; a type 2 spinoff can only occur conditional upon the firm switching strategy. Second, an increase in the concentration of decision-making authority reduces the probability of a type 1 strategy while raising the probability of a type 2 strategy. Greater concentration in decision-making authority increases the likelihood of disagreement between individual i and the firm. However, this effect is in both cases more than offset by the effect of concentration on inducing earlier switches in firm strategy. Finally, increases in signal noise unambiguously reduce the probability of a type 1 spinoff at all finite time horizons, but has ambiguous effects on the probability of a type 2 spinoff. Type 2 spinoffs are more likely when signals are noisy but those that occur will tend to occur later.

TABLE 1. *Effects of parameters changes on spinoff hazards and probabilities*

	TYPE 1	TYPE 2
Variance of prior beliefs, σ^2	+	+
Quality of new strategy, y	+	+
Degree of overconfidence (low m)	+	+
Cost of spinoff formation, k	−	−
Quality of parent, x	+, small x	+, small x
	−, large x	−, large x
Cost of switching, c	+	−
Concentration of decision-making, $\sum_{j\neq i}\psi_j^2$	−	+
Signal noise, σ_z^2	−	−, small t
		+, large t

Figure 4 illustrates representative hazard functions for the parent switching strategy and for type 1 and type 2 spinoffs, for the case in which a fully-informed firm would be indifferent between continuing with x and switching to y (values of y greater than or less than $c(1-\beta)\phi^{-1}+x$ yield similar hazard plots). The hazard of type 1 spinoff formation first rises then falls with firm age, as does the hazard of a type 2 spinoff. Because a type 1 spinoff must happen before the firm switches strategy, it is not surprising that the hazard of a type 1 spinoff peaks earlier than the hazard of strategy switching. In contrast, the hazard of a type 2 spinoff peaks a little later than the hazard of strategy switching. All three hazard functions decline asymptotically to zero, but the spinoff hazards do so much more rapidly.

E. Spinoff and Parent Quality

The model's predictions for the survival rates of spinoffs are straightforward. As x is known, the probability of exit of a type 2 spinoff is zero. In contrast, for a type 1 spinoff, y is stochastically increasing in x, so $\Pr[y<0\mid x]$ is decreasing in x:

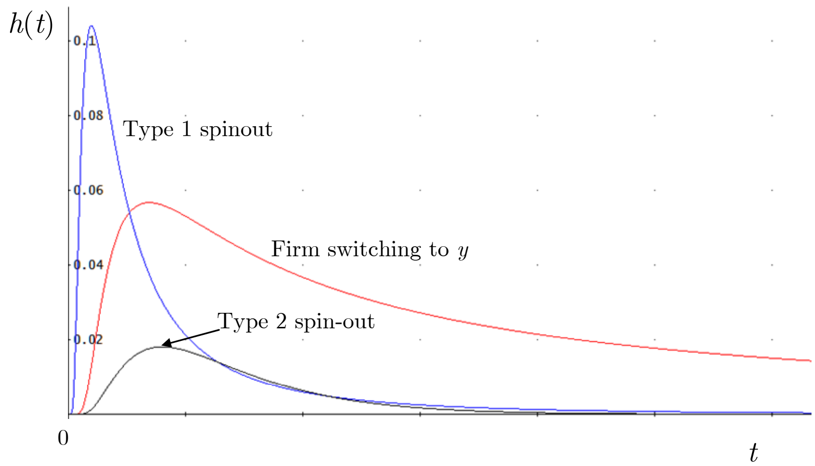

FIGURE 4. Hazards of parent switching strategy and the formation of type 1 and type 2 spinoffs. Parameter values: x=10, y=15, σ=10, σ_z=10, c=100, k=150, β=0.95, ϕ=1, μ=1, and $\sqrt{\sum_{j\neq i}\psi_j^2} = 0.5$.

Q1. (1) *The probability of failure of a type 1 spinoff is greater than the probability of failure of a type 2 spinoff.* (2) *The probability of failure for a type 1 spinoff is decreasing in the quality of its parent.*

We turn now to the average quality of spinoffs. Property P1 stated that the firm's productivity after switching to y is stochastically increasing in the quality, x, of the firm. An analogous property holds for spinoffs. The quality of a type 2 spinoff is x, so in this case spinoff quality is identical to the quality its parent had immediately prior to switching and positively correlated with its parent's post-switching quality, y. For a type 1 spinoff, the critical threshold of $\overline{y}_{it}$ necessary to induce an individual to form a spinoff is increasing in x. Because y and $\overline{y}_{it}$ are positively correlated (this holds even after conditioning on the fact that $\overline{y}_t$ is too low for the firm to switch strategy), the expected value of y among type 1 spinoffs is increasing in x. Note also that the probability that a parent ever switches strategy is increasing in y; equivalently, y is on average higher for parents that switch. Hence type 1 spinoffs, which implement y, are on average higher quality if their parents subsequently switch. These observations are summarized in Q2:

Q2. (1) *The expected quality of a spinoff is increasing in the quality of the parent.* (2) *The quality of type 1 spinoffs whose parents subsequently switch strategy is higher* *than for spinoffs whose parents do not subsequently switch strategy.*

Recall that quality is synonymous with profits, output and employment size; Q1 therefore implies that larger and more profitable firms produce larger and more profitable spinoffs.

A growing empirical literature has documented the superior average performance of spinoffs relative to other *de novo* producers. The present model predicts that the average spinoff is a mistake. But these are not necessarily incompatible. The average spinoff is a mistake in the sense that any decision made by an individual is less likely to be correct than the decision made by the average of m decision makers. If m decision makers conclude it is not worth spending c to switch to y, then an individual who believes it is worth spending $k > c$ to do so is likely to be mistaken. Similarly, m decision makers who conclude it is worth spending c to switch to y are more likely to be correct than an individual who concludes it is worth spending $k > c$ to avoid switching.

While the average founder of a spinoff may subsequently regret his decision, the post-entry performance of a spinout does not directly depend on k, which is a sunk cost. However, there is a selection effect of k. If it is large, the threshold of beliefs about y for a type 1 spinoff is relatively high; in this case the quality, y, of a type 1 spinoff is greater than the quality, x, of its parent, even though spinoffs are on average mistakes. Conversely, if k is low, the threshold for beliefs about y are low, so mistakes in spinoff formation dominate the selection effect of spinoff-launching costs; in this case, y will on average be lower than x.

Although spinoffs do not pay the cost, c, of switching by incumbent firms, this also affects the expected quality of a type 1 spinoff. When the switching cost is low, signals observed by individual i's colleagues must be quite unpromising for the firm not to switch and thereby to make it possible for individual i to launch a type 1 spinoff. In this case, misleading signals observed by i are the dominant stimulus to spinoff formation. As c rises, firms will choose not to switch despite more promising signals about y, and this has the effect of raising the average quality of spinoffs

These claims about costs and the quality of type 1 spinoffs can be easily verified by numerical means. Recalling that the population distribution of y is Normal with mean zero and variance σ^2, the expected quality of the spinoff conditional on the quality of the parent is

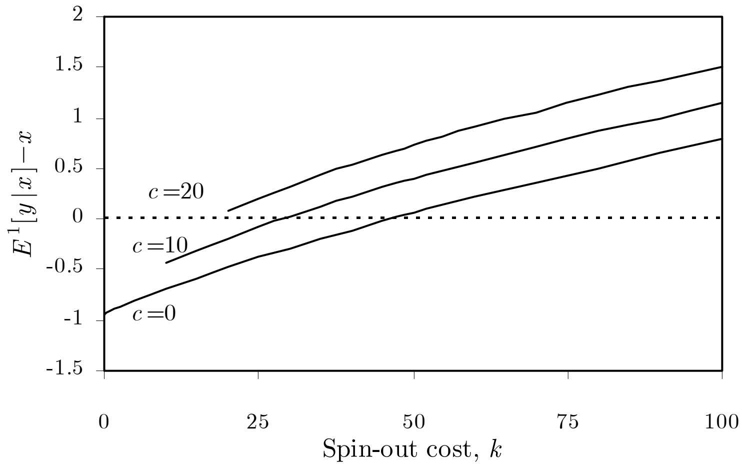

FIGURE 5. Expected value of type 1 spinoff minus value of parent. Parameter values: x=10, σ=10, σ_z=10, β=0.95, ϕ=1, μ=1, and $\sqrt{\sum_{j\neq i}\psi_j^2}=0.5$. Note that, by assumption $k\geq c$.

$$E_s^1[y \mid x] = \frac{1}{\int_{-\infty}^{\infty} \tilde{P}_s^{1\infty}(x,y)d\Psi(y)} \int_{-\infty}^{\infty} y\tilde{P}_s^{1\infty}(x,y)d\Psi(y)\,, \tag{30}$$

where $\tilde{P}_s^{1\infty}(x,y) = \lim_{T\to\infty} \tilde{P}_s^1(T \mid x,y)$ denotes the probability that a type 1 spinoff of quality y is ever spawned by a firm of quality x, and $\Psi(y)$ is the distribution of y. Figure 5 plots the difference between type 1 spinoff quality and parent quality, $E_s^1[y \mid x]-x$, as a function of k for various values of c; the remaining parameters have the same baseline values as in Figure 4. As claimed, increases in c and k are associated with rising spinoff quality, and average spinoff quality is less than parent quality only when both c and k are sufficiently low.

These observations about the quality of type 1 spinoffs are summarized in Q3:

Q3. (a) *The average quality of type 1 spinoffs may be higher or lower than the quality of their parents.* (b) *The average quality of a type 1 spinoff is increasing in the spinoff cost, k, and the incumbent switching cost, c.*

Q3 implies that in environments where the adoption of new technologies or strategies is costly (and hence in which doing so is not common), spinoffs perform better: they

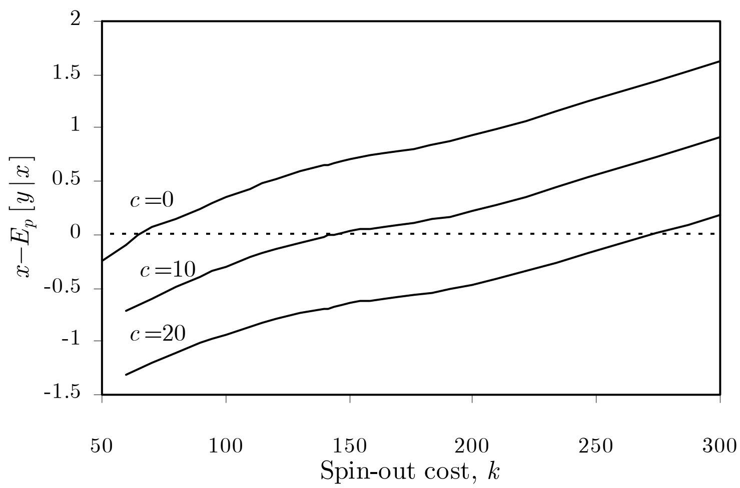

FIGURE 6. Expected value of type 2 spinoff minus value of parent. Parameter values: x=10, σ=10, σ_z=10, β=0.95, ϕ=1, μ=1, and $\sqrt{\sum_{j\neq i}\psi_j^2} = 0.5$. Note that, by assumption $k \geq c$.

are more likely to outperform their parents, and they are less likely to exit.

A somewhat different logic applies to type 2 spinoffs. As in the case of type 1 spinouts, a low launching cost, k, induces lower quality spinoffs for any given quality of parent. But changes in the switching cost, c, have two effects that together induce an ambiguous effect of c on the quality of type 2 spinoffs relative to the quality of their parents. First, when c is low, parent firms switch despite only modestly good news about y, and this induces type 2 spinoffs even for modest values of x; this effect moves the average quality of parents (post-switching) and spinoffs in the same direction. Second, recall that individual i launches a type 2 spinoff in part to avoid paying cost c; when this is low, a spinoff is attractive only for high values of x, thereby inducing a positive effect of spinoff quality relative to parent quality. We have not been able to deduce analytically the net effect of c on spinoff quality. However, numerical examples, illustrated in Figure 6, show that increases in c reduce the quality of type 2 spinoffs, x, relative to the expected quality, $E_p[y \mid x]$, of their parents. Figure 6 also confirms prior intuition that the average relative quality of type 2 spinoffs is increasing in k, and that the average spinoff quality is less [greater] than the quality of its parent when k is low [high] or c is high [low].

These observations about the quality of type 2 spinoffs are summarized in Q4:

Q4. (a) *The average quality of type 2 spinoffs may be higher or lower than the quality of their parents.* (b) *The average quality of a type 2 spinoff relative to its parent is increasing in k, and decreasing in c.*

Figure 5, which compares the average quality of type 1 spinoffs with the quality of their parents, is also by construction a plot of the average quality of type 1 spinoffs relative to the quality of type 2 spinoffs conditional on the initial quality of the parent. Intuition therefore suggests that, at least when c or k is large, type 1 spinoffs are on average higher quality than type 2 spinoffs, even though type 1 spinoffs have a higher failure rate. This is consistent with the notion that being innovative yields higher but riskier returns to costly investment.

However, intuition is complicated by the fact that the distribution of x among firms that spawn type 1 spinoffs is not the same as the distribution of x among firms that launch type 2 spinoffs. Figure 7 plots the relative frequency of spinoffs for different values of x. What this implies for the distribution of x conditional on the formation of each type of spinoff depends upon the assumptions made about the distribution of x in the population.[6] However, Figure 7 suggests that, whatever this distribution, x is stochastically greater for parents of type 1 spinoffs than for parents of type 2 spinoffs. In conjunction with Figure 5 and the fact that the expected values of both types of spinoffs are increasing in x, we can conclude that type 1 spinoffs have higher average quality than type 2 spinoffs as long as c and k are not trivially small.

Q5. *The average quality of type 1 spinoffs is greater than the average quality of type 2 spinoffs.*

As x is also the initial quality of parents, Figure 7 also implies the following relationship between parent quality and the type of spinoffs likely to be produced:

Q6. *The average initial quality of the parents of type 1 spinoffs is greater than the average quality of the parents of type 2 spinoffs.*

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[6] Explicit formulae are given in Appendix B, under the assumption that the population distribution of x is consistent with the population distribution of y.

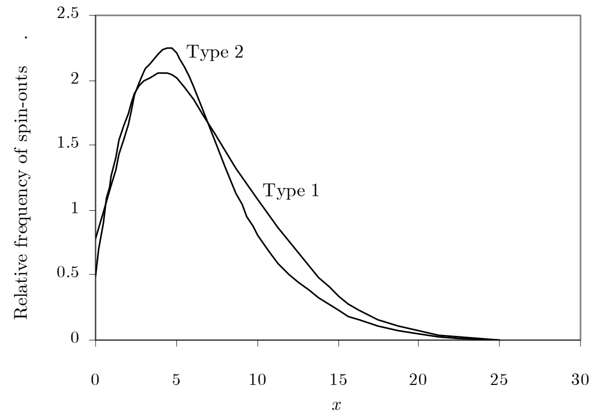

FIGURE 7. Relative frequencies of spinoffs as a function of x.

We have been unable to generate results comparing the post-switching quality of parents of the different types of spinoffs. Expressions for the expected contemporaneous quality of the parents at the time of the spinoff are given in Appendix C, but it has not so far proved possible to evaluate accurately the expected value of the parents of type 2 spinoffs.[7]

3. Discussion

This paper has developed a model in which a team of managers engaged in production using technology x, is considering switching to technology y. The value of y is learned slowly over time, but constraints on the ability of individual managers to communicate their beliefs allow disagreements to emerge among team members. Managers who develop sufficiently strong disagreements with their colleagues choose to form new companies to implement their preferred strategy. The model extends a recent theory of disagreement and intra-industry spinoff formation [Klepper and

[7] Computations in this paper have been carried out using Derive™ 6.0. Derive approximates integrals with an extrapolated adaptive Simpson's rule. The algorithm can produce serious computational errors if a low order derivative of the integrand has any discontinuities or singularities. A helpful feature of Derive is that it recognizes when such computational errors are possible and alerts the user.

Thompson (2009)] in a direction that makes explicit the strategies pursued by parents and spinoffs. The outcome is a model in which two distinct classes of spinoffs arise: type 1 spinoffs that implement y when their parents do not (yet) want to, and type 2 spinoffs that are formed to continue with x when the parent is switching to y.

3.1 Data Challenges for Empirical Work

The model makes a number of distinctive predictions comparing type 1 and type 2 spinoffs and their parents. Type 1 spinoffs are, in a quite precise way, more innovative than type 2 spinoffs. The model also predicts distinctive behaviors for the two types of spinoffs. For example, type 1 spinoffs tend to outperform type 2 spinoffs, they have higher failure rates, and they are spawned by younger parents. The model also predicts that both types of spinoffs are spawned out of parents of intermediate quality, although the quality of the parents of type 1 spinoffs stochastically dominates the parents of type 2 spinoffs. More subtly, the model reveals some distinctive comparative statics for the two types of spinoffs. These are, in principle, empirically testable propositions.

However, data requirements for the study of spinoffs are unusually demanding. First, information is required for the early years of an industry (when entry is greatest), for the youngest and smallest firms (to avoid sample selection problems resulting on conditioning on minimum size requirements), and in industries where spinoffs are sufficiently common. Second, detailed information is required about the founders of firms, including their previous place of employment. Constructing such datasets is frequently time consuming. Moreover, it is only feasible for industries that have been the subject of careful documentation by hobbyists or in trade publications and encyclopedias. Researchers have naturally been opportunistic, resulting in a small but broad scattering of datasets on heterogeneous industries including semiconductors [Brittain and Freeman (1986)], biotechnology [Mitton (1990), Stuart and Sorenson (2003)], law firms [Phillips (2002)], disk drives [Agarwal et al. (2004); Franco and Filson (2006)], automobiles [US - Klepper (2007); Great Britain - Boschma and Wenting (2007)], tires [Buenstorf and Klepper (2007)], lasers [US - Sleeper (1998), Klepper and Sleeper (2005); Germany - Buenstorf (2007)], medical devices (Chatterji [2005]), and wine producers (Australia - Roberts et al. [2006]).

However, because previous theories of spinoff formation did not distinguish types of spinoffs, the available datasets do not provide a characterization of spinoff types that allows us to test our theory. Moreover, the traditional definition of spinoffs results in a sampling of firms that is likely too narrow for our purposes. Consider, for example, the historical US automobile industry. Klepper (2007b) constructs a dataset from directories of the automobile industry, and reports 725 entrants into the industry, of which 145 were founded by individuals who had previously worked in the industry and 120 were firms that diversified from other industries, notably engine, carriage and bicycle manufacturing. In addition to the traditional, narrowly-defined, spinoffs, Klepper's sample allows us to identify an additional, particularly clean, set of type 1 spinoffs where an employee of a firm in a feeder industry founds an automobile firm. However, it does not allow us to observe an important class of type 2 spinoffs, where a firm in a feeder industry enters automobiles and this induces an employee to establish a new firm in the feeder industry. Consequently, a sample built out of a master list of automobile firms would (for our purposes) suffer from unacceptable selection biases. To observe all type 2 spinoffs, we would need a comparable master list of firms in feeder industries. To this end, we have begun to construct a dataset combining information on the British automobile industry and one of its feeders (and subsequently one of its suppliers), the coach-building industry; however, the data construction efforts remain far from complete.

3.2 Examples of Type 1 and Type 2 Spinoffs

Although we are not ready to conduct formal tests of the model, we can illustrate by means of examples how both types of spinoffs can arise.

• *Type 1 Spinoffs.* We reviewed case studies of spinoffs provided in previous work on three industries−disk drives [Christensen (1993)], semiconductors [Klepper (2007a)], and lasers industries [Klepper and Sleeper (2005)]. Most are type 1, the spinoffs being formed because parents were for one reason or another unwilling to utilize new technologies.

In the disk drive industry, established manufacturers generally integrated the development of component technologies to assist their entry into a new product architecture market. However, when new component technologies became available, leading firms proved reluctant to employ these technologies across their product lines, because [Christensen (1993) argues] their products targeted at current customers were supported by established technologies and were less costly and risky to adopt. In the meantime, there existed non-integrated disk drive manufacturers that were aggressively pursuing innovative system designs requiring the support of new component technologies. As these independent manufactures had little access to new-technology components directly via the leading integrated firms, spinoffs occurred as former engineers at integrated firms formed new start-up companies to produce and sell advanced components to these "bleeding-edge" disk drive manufacturers in the original equipment market.

IBM, for example, was the first to introduce the thin-film head, and led a group of integrated firms to focus on the development of this technology. After commercializing the new component in a limited number of high-end models, these integrated firms became very slow to incorporate this technology in other product lines as they chose to stick with their current market position with traditional technologies. In contrast, demand for the thin-film technology increased among independent manufacturers such as Maxtor and Micropolis whose strategy was less conservative and focused on the remote market. In response to market demand, spinoffs such as Komag (eventually the leading thin-film disk manufacturer) and Read-Rite (eventually the leading thin-film head manufacturer) emerged as component suppliers for these non-integrated disk drives makers. In this case, IBM and other integrated firms were aware of the value of this new component technology, but their process of product design did not catch up with the pace at which they developed component technologies. As a result, IBM refused to initially adopt this technology and eventually turned out to be the slowest in the industry to utilize this component broadly across its product lines.

In the semiconductor industry, leading parent firms' reluctance to develop new technology is also one of the driving forces behind many spinoffs [Klepper (2007a)]. The industry's first spinoff, Fairchild, was formed to exploit silicon transistors after its parent, Shockley Laboratories, abandoned this technology strategy. Fairchild's first transistors, based on silicon mesa, were not very successful. It later made an enormous improvement on those transistors with the planar process and became the pioneer in this technology, which made the production of transistors much easier and cheaper with high performance.

Fairchild was also a leader in the development of Integrated Circuits (ICs), but initially chose to focus on its component business because of the initial inferior performance of ICs and fear that making ICs would cannibalize its current business. A group of its engineers, however, were confident about the future of ICs, and therefore formed Amelco and Signetics to commercialize the technology. Because of its small size, higher reliability, and lower power need, the IC technology was soon favored by the Department of Defense. As a result, Signetics became profitable by producing and selling circuits to military contractors. Its parent, Fairchild, eventually, entered the IC market and managed to take over the leadership of this market from Signetics by massively producing Signetics' standard circuits and selling them at lower prices. Signetics continued to pursue its innovation in the IC technology, although it never regained its leadership in this market.

Another famous spin-off from Fairchild, Intel, was formed partly because Fairchild was pessimistic about the future of the Metal Oxide Semiconductor field-effect transistors (MOSFE) technology. Although Fairchild was among the earliest to develop this technology, it did not enter the production of the MOS devices due to the instability of the technology. However, after the resolution of technical problems, the MOS devices eventually become popular for many applications. In a similar case, former employees of Advanced Micro Devices formed Cypress to pursue the development of high speed CMOS SRAMS, a new technology that was neglected by its parent and other existing semiconductor firms.

The origin of spinoffs in the laser industry is somewhat different from what has been described above. As documented by Klepper and Sleeper (2005), spinoffs tended to produce laser types that were closely related to what had been previously produced by their parents. A common practice of these spinoffs was to develop a variant of the parent's laser, using technology which their parents had previously explored but eventually abandoned due to either manufacturing difficulties or the uncertainty of future market. For example, among the spinoff cases studied in detail by Klepper and Sleeper (2005), Uniphase was formed by former employees at Spectra Physics to produce a variant of Spectra's HeNe laser when its parent gave up this effort because of the uncertain future market for HeNe. Lexel originated from a disagreement with its parent, which abandoned its effort, because of manufacturing problems, to pursue improvements to its ion laser. Similarly, Laser Diode Laboratories was formed to continue developing a semiconductor laser for defense applications after its parent gave up on it due to technical difficulties. As Bhaskarabhatla and Klepper (2008) document, new lasers developed by spinoffs can often find their application in a submarket that is different from their parents' target. Thus, the majority of these parent firms were able to continue their production of original laser types for a long time after the entry of spinoffs.

• *Type 2 Spinoffs.* We were able to identify very few examples of type 2 spinoffs from previous work. The examples that follow, drawn from our own on-going data collection efforts in the British automobile and coach-building industries, are based on information provided in Georgano *et al.* (2000).

The first example is the formation of the Austin Motor Company. Its founder, Herbert Austin, had been a very successful manager at the Wolseley Motor Company. He designed the horizontal-engined Wolseley cars, which sold very well at first. Later on, as losses started to occur, the company was considering a switch to vertical engines. But Austin did not like the proposed switch, which led to his breakup with Wolseley in 1906 and the formation of his own firm, the Austin Motor Company. Wolseley replaced Austin with a new general manager, John Siddeley, who had been making vertical-engined cars in his own company. Directed by Siddeley, Wolseley soon brought out the new vertical-engined cars, under the name of Wolseley-Siddeleys Output grew dramatically, and in 1911, nearly 1,600 of these cars were produced. Ironically, Austin never continued production of horizontal-engined cars at his own company. Perhaps because he later realized the value of the vertical-engined design, all Austin models he made actually had vertical engines.

The second example also involves a disagreement about horizontal and vertical engines. Francis Leigh Martineau was one of the original partners at James & Browne Ltd. He designed the early James & Browne cars, which had mid-mounted horizontal engines. In 1905, Martineau left and joined Pilgrim to make Pilgrim(i), also a horizontal-engined car, but with cylinder heads set forward. Although history does not specify the reason for Martineau's departure, it is recorded that around this time, the parent James & Browne switched to a conventional vertical-engined car called Vertex. As there were already many good conventional cars in the market, this switch did not turn out to be successful, and few Vertexes were sold. Martineau was not much more successful, selling only eighteen Pilgrim(i) cars before Pilgrim went into receivership.

The third example relates to Ralph Jackson, who had started as a cycle maker, and later invented a tricar with a 2.25hp single-cylinder engine. These tricars were called the Century Tandem, and were built at the Century Engineering Co. until 1901. In 1901, Century was under control of Sydney Begbie, who was the first importer of Aster engines into England. It appeared that the company soon changed its focus away from Jackson's tricars. In 1903, Begbie launched the first Century cars with 8 or 12hp 2-cylinder Aster engines, French transmissions, and English-built chassis and bodies. Jackson left the company in 1901 and started a new company, the Eagle Engineering Motor Co., where he made a thinly disguised version of the Century Tandem tricar under the name of Eagle.

The last example we list here is probably more about a disagreement over production strategy than choice of technology. Frazer Nash and H.R. Godfrey founded G.N Motors Ltd. in 1910 and made the first British cyclecars. In 1913, sporting models of these cyclecars came out and, by the outbreak of war in 1914, the G.N. had become the best-known of British cyclecars. Sales fell after the war and in 1922 the company was bought by a Mr. Black, who wanted to move away from sports cars and focus on the mass production of a water-cooled 4-cylinder shaft-drive tour model. Both Godfrey and Nash preferred to continue making sports cars and therefore left to start their own car companies. Nash founded Frazer Nash Ltd., where he built his sports model with a chain-drive system that he had employed on the G.N. Godfrey founded Godfrey-Proctor Ltd., where he made sports cars in the style of a miniature Aston Martin with an Austin engine and gear box. As for G.N. Motors, its switch to shaft-drive touring cars was not a success for two reasons. First, there were already many of these cars in the market. Second, traditional G.N. owners preferred the older designs. Despite attempts to improve the G.N., production soon ended.

3.3 Concluding Comments

The paper has focused on the *mechanics* of spinoff formation. As a result, our analysis has not addressed numerous issues that are relevant to disagreements and spinoffs. For example, we have not explored contractual arrangements that might influence spinoff formation [see, e.g., Amador and Landier (2003), Hellman (2007)], or the strategic transmission of information to influence others [cf. Crawford and Sobel (1982)]. Nonetheless, even without these extensions, our setting yields some distinctive implications for organizational behavior and policy. Consider, for example, the model's implications for the attitudes that potential parents and policymakers should have toward spinoffs. Employee spinoffs of all colors are potential competitors to their parents; they may lead to undesirable duplication of investment that serves only to dissipate rents, and be a disincentive for research in incumbent firms. Thus, parents frequently discourage them, by means of contractual sticks such as non-compete covenants, legal sticks such as filing suits for intellectual property infringement, and carrots such as schemes to reward employees for revealing their ideas. In many jurisdictions, policymakers support parent firms by creating the institutional and legal support for the sticks that parents use. The present model features a potential offsetting benefit to parents that has to date received relatively little attention. Type 1 spinoffs, by engaging in an activity that the parent is unwilling to do without waiting to accrue more information, offer something like a free experiment for the parent whenever the performance of the spinoff is observable. When competition effects are not too strong, the information value of spinoffs may even be enough to make parents and policymakers supportive of individuals that choose to launch them. Type 2 spinouts provide no new information, so the model predicts that incumbent firms are likely to expend less effort to discourage or fight innovative spinoffs, and that policy should treat type 1 spinoffs more favorably.

Appendix

A. Alternative Approximations to $\overline{y}_t^{*}$

In the main text, $\overline{y}_t^{*}$ was approximated by its limit value:

$$\overline{y}_{\infty}^{*} = c(1-\beta)\phi^{-1} + x\ , \quad t = 1,\, 2,\, 3,\, \ldots\, . \tag{A.1}$$

We consider two approximations which provide lower bounds on the sequence $\overline{y}_t^{*}$. Consider first the stopping criterion, $\overline{y}_t^{**}$, satisfying

$$\frac{\phi x}{1-\beta} = -c + \frac{\phi}{1-\beta}\int_0^{\infty} y dF_t(y \mid \overline{y}_t^{**})\ . \tag{A.2}$$

Equation (A.2) incorporates the fact that the expected payoff from switching conditional on $\overline{y}_t$ is increasing in the variance of y. However, it does not incorporate the option value of not switching, which is also increasing in the variance of $\overline{y}_t$. Thus, (A.2) provides an underestimate of the correct critical value. As the variance of $\overline{y}_t$ is decreasing over time, the size of the error declines to zero for large t.

The second approximation is the solution to the one-step-look-ahead rule (1sla). The rule involves comparing stopping in the current period with the expected value of continuing one period, and then stopping. That is, the 1sla stopping criterion, $\overline{y}_t^{***}$, is the solution to

$$-c + \frac{\phi}{1-\beta}\int_0^{\infty} y dF_t(y \mid \overline{y}_t^{***}) = \phi x + \beta\left[-c + \frac{\phi}{1-\beta}\int_{-\infty}^{\infty}\int_0^{\infty} y dF_{t+1}(y \mid \overline{y}')dG_t(\overline{y}' \mid \overline{y}_t^{***})\right] \tag{A.3}$$

When 1sla indicates continuation, then continuation is optimal because there exists at least one strategy that dominates stopping. When the 1sla prescribes stopping, stopping may or may not be optimal.[8] Thus, $\overline{y}_t^{***}$ must also be an underestimate of the correct

[8] For all finite-horizon monotone optimal stopping problems and most infinite-horizon monotone problems with discounting, 1sla is optimal. However, the problem in this paper is not

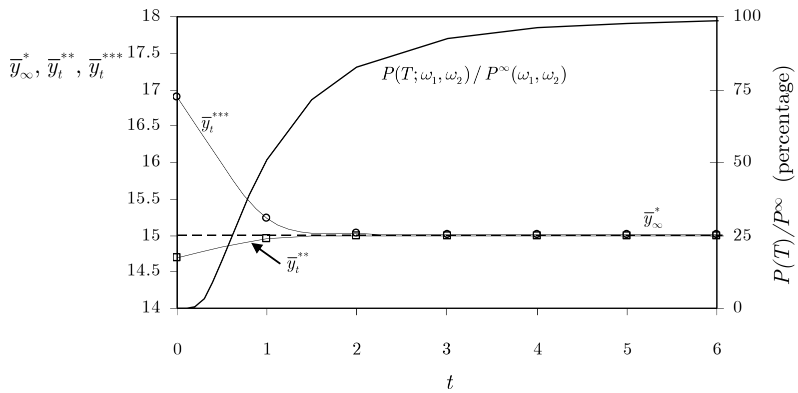

FIGURE A1. Lower bound approximations to critical values, and the fraction of firms that will eventually switch that have switched by time t. Parameter values: x=10, σ=10, σ_z=10, c=100, β=0.95, ϕ=1. These values yield a limiting critical value of 15, and P^∞ is approximately 1.75 percent.

critical value. However, in many applications it performs quite well.[9]

Figure A.1 provides a numerical comparison of (A.1)-(A.3). The parameter values used yield $\overline{y}_\infty^* = 15$ and $P^\infty(\omega_1,\omega_2) = 0.0175$; thus switching is relatively rare. To provide context, the fraction of switching firms that have already switched at each point in time is also plotted for these parameter values. The 1sla, $\overline{y}_t^{***}$, consistently exceeds $\overline{y}_\infty^*$, while $\overline{y}_t^{**}$ is less than $\overline{y}_\infty^*$. As 1sla is either optimal or an underestimate of $\overline{y}_t^*$, it follows that $\overline{y}_t^{**}$ is a worse approximation than $\overline{y}_\infty^*$. This is not surprising – it incorporates a feature of the stopping problem that reduces the estimated critical values but ignores the option value that works in the opposite direction. The 1sla results show that, for these parameter values at least, $\overline{y}_t^* > \overline{y}_\infty^*$, with the largest differences at small values of t. The 1sla critical values do converge rapidly on to the limiting value, but this good news is offset by the fact that $P(T)\,/\,P^\infty$ rises rapidly. It would be possible to improve upon the constant critical value used in the main text by means of piecewise linear corrections to the absorbing barrier. Wang and Pötzelberger (1997) have derived an explicit formula for the distribution of the first passage time to a piecewise linear barrier, However, although it "can be very easily calculated, for example by using the Monte Carlo simulation method" [p.55], it is far more complicated than the distribution used in the main text.

A third approximation modifies (A.2) to produce an upper bound for $\overline{y}_t^*$. Let $\overline{y}_t^{****}$, be

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monotone.

[9] With normal priors and signals, the precision of beliefs rises with time at a declining rate, so the expected gain in precision secured by waiting one more period is monotonically decreasing in t. As a result, we suspect (but cannot prove) that the 1sla is optimal.

the solution to

$$\phi x + \beta E_t\left[v \mid \overline{y}_t^{****}\right] = -c + \frac{\phi}{1-\beta}\int_0^\infty y dF_t(y \mid \overline{y}_t^{****}), \tag{A.4}$$

where $E_t\left[v \mid \overline{y}_t^{****}\right]$ is the expected value of waiting one more period under the counterfactual assumption that doing so fully reveals y. That is,

$$E_t\left[v \mid \overline{y}_t^{****}\right] = \int_{-\infty}^\infty \max\left\{\frac{\phi x}{1-\beta}, -c + \frac{\phi y}{1-\beta}\right\} dF(y \mid \overline{y}_t). \tag{A.5}$$

Because $E_t\left[v\right]$ must exceed the true continuation value, the solution to (A.4) yields overestimates of the correct sequence of critical values. Unfortunately, (A.4) does not provide a precise characterization for $\overline{y}_t^*$, because it yields critical values far in excess of the lower bound, $\overline{y}_t^{***}$. For example, using the same parameter values as in Figure A1, one obtains $\overline{y}_0^{****} = 26.5$, $\overline{y}_1^{****} = 23.2$, and $\overline{y}_5^{****} = 19.73$. The sequence converges on to $\overline{y}_\infty^*$ as it should, but at a very slow rate. So far we have been unable to devise a more informative upper bound.

B. Expected Qualities of Type 1 and Type 2 Spinoffs

Assume that, consistent with the Normal prior distribution of y and with free exit, the initial quality of parent firms has a half-Normal distribution obtained by taking random draws from $N(0,\sigma^2)$ and discarding all negative values. Then, the unconditional expected quality of a type 1 spinoff is, from (30),

$$E_s^1[y] = \int_0^\infty \left[\frac{1}{\int_{-\infty}^\infty \tilde{P}_s^{1\infty}(x,y)d\Psi(y)} \int_{-\infty}^\infty y\tilde{P}_s^{1\infty}(x,y)d\Psi(y)\right] \frac{\sqrt{2}e^{-x^2/2\sigma^2}}{\sqrt{\pi}\sigma} dx \tag{B.1}$$

Similarly, the unconditional expected quality of a type 2 spinoff is

$$E_s^2[x] = \int_{-\infty}^\infty \left[\frac{1}{\int_0^\infty \tilde{P}_s^{2\infty}(x,y)\frac{\sqrt{2}e^{-x^2/2\sigma^2}}{\sqrt{\pi}\sigma}dx} \int_0^\infty x\tilde{P}_s^{2\infty}(x,y)\frac{\sqrt{2}e^{-x^2/2\sigma^2}}{\sqrt{\pi}\sigma}dx\right] d\Psi(y), \tag{B.2}$$

where $\tilde{P}_s^{2\infty}(x,y) = \lim_{T\to\infty} \tilde{P}_s^2(T \mid x,y)$ denotes the probability that a type 2 spinoff of quality x is ever spawned by a firm that has quality y upon switching.

C. Expected Qualities of Parents of Type 1 and Type 2 Spinoffs

The expected qualities of the parents of spinoffs have forms similar to (B.1) and (B.2). We continue to assume that x has a half-Normal distribution. The unconditional expected quality of the parents of type 1 spinoffs is

$$E_p^1[x] = \int_{-\infty}^{\infty} \left[\frac{1}{\int_0^{\infty} \tilde{P}_s^{1\infty}(x,y) \frac{\sqrt{2}e^{-x^2/2\sigma^2}}{\sqrt{\pi}\sigma} dx} \int_0^{\infty} x\tilde{P}_s^{1\infty}(x,y) \frac{\sqrt{2}e^{-x^2/2\sigma^2}}{\sqrt{\pi}\sigma} dx \right] d\Psi(y) , \tag{C.1}$$

and the unconditional expected quality *after switching* of parents of type 2 spinoffs is

$$E_p^1[y] = \int_0^{\infty} \left[\frac{1}{\int_{-\infty}^{\infty} \tilde{P}_s^{2\infty}(x,y) d\Psi(y)} \int_{-\infty}^{\infty} y\tilde{P}_s^{2\infty}(x,y) d\Psi(y) \right] \frac{\sqrt{2}e^{-x^2/2\sigma^2}}{\sqrt{\pi}\sigma} dx , \tag{C.2}$$

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