Spinoff Entry in High-tech Industries: Motives and Consequences

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Various theories have been advanced for why employees leave incumbent firms to found firms in the same industry, which we call spinoffs. We review the accumulating evidence about spinoffs in various high-tech industries, highlighting the central role often played by disagreements. Because existing theories have ignored them, we develop the foundations of a model of spinoff formation driven by disagreements. Doing so proves to be rather challenging, because disagreements are not possible among rational actors that talk to each other. We introduce a minimal degree of non-rationality, based on the concept of solipsism*, and ask whether such a concept is capable of generating predictions consistent with the empirical literature.*

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I. Introduction

In recent years interest has grown in the phenomenon of entrepreneurship. One does not have to look beyond Silicon Valley to see the importance of new enterprises, which seemingly have played a key role in the region's vitality. But where do new enterprises come from? Surprisingly, little is known about the origin of entrants, especially new enterprises. This is perhaps a legacy of the way entry is typically modeled in theories of competition. It has always been assumed that if entry is profitable, it will occur. It is not at all clear, though, whether such confidence is justified (Geroski [1995]).

Recent work suggests that entrants are quite diverse at birth, and their pre-entry experience persistently affects their performance (Carroll *et al.* [1996], Geroski, Mata, and Portugal [2002], Klepper [2002a, 2002b], Klepper and Simons [2000], Thompson [2004]). One class of entrants that perform distinctly well in some industries are firms founded by employees of incumbent firms in the same industry (Klepper [2002b], Agarwal et al. [2004], Walsh, Kirchhoff and Boylan [1996]). We shall call these firms spinoffs. While in some instances spinoffs are sponsored or linked to their "parent" firm, generally the founders of spinoffs do not maintain any link to their prior employers.

In some industries, spinoffs are legion. Indeed, in the semiconductor industry so many spinoffs can be traced back to one firm alone, Fairchild Semiconductor, they have been dubbed Fairchildren. Opinions differ greatly about the contribution of spinoffs to innovation and economic growth. Some perceive spinoffs as parasites, feeding off the innovative efforts of their unwitting "parents."[1] Scholars who interpret spinoffs as parasites fear that spinoffs can undermine the ability of their parents to appropriate the returns of their innovative efforts, thereby undermining the incentives of incumbents to innovate. Others see spinoffs as the font of innovation, compensating for the inertia that plagues many incumbents. To them, the Fairchildren jumped a sinking ship and led the semiconductor industry to new glory, fueling the juggernaut known as Silicon Valley.

Where does the truth about spinoffs lie? The answer presumably lies in a better understanding of the motives of spinoffs in innovative, high-tech industries and the process governing their formation. Why, in fact, do employees of high-tech firms leave to found firms in the same industry? Is it mainly to exploit innovations they worked on for their employers? Is it mainly because of the inability of their employers to perceive and/or act upon promising

[1] Ironically, this is the view of Intel, Fairchild's most famous spinoff. Intel goes to great lengths to harass employees that leave to start their own firms (Jackson [1998, pp. 211-338]).

technological developments in their industry? Alternatively, might spinoffs be a natural outcome of a world in which people have different perceptions about the best paths for organizations to follow? The main purpose of this paper is to explore the motivations behind spinoffs and the role they play in economic growth.

In Section II, we review empirical studies of spinoffs, many of which are quite recent, and extract a set of common patterns from the studies. One particularly prominent theme of the empirical literature is that spinoffs arise out of disagreements within existing firms that lead frustrated employees to pursue their ideas in their own firms. The existing theoretical literature, reviewed in Section III, has ignored the role of disagreements. In Section IV, we therefore develop the foundations of a model of spinoff formation driven by disagreements. Doing so proves to be rather challenging, because Aumann [1976] all but precludes disagreements among rational actors that talk to each other. We introduce a minimal degree of non-rationality, based on the concept of *solipsism*, and ask whether such a concept is capable of generating predictions consistent with the empirical literature. We show that the concept is indeed able to account for a number of distinctive empirical regularities concerning spinoffs. However, some predictions of the model are at odds with the data. In Section V, we therefore conclude with a discussion of new directions for development of our model.

II. Empirical Regularities Concerning Spinoffs

New studies of high-tech spinoffs in the automobile (Klepper [2003b, 2004], laser (Klepper and Sleeper [2004]), and disk drive (Franco and Filson [2000], Agarwal et al. [2004]) industries have added greatly to our knowledge about spinoffs. Using unique sources to identify all industry entrants and their characteristics, including their pre-entry backgrounds, these studies analyze the factors influencing the rate at which firms spawn spinoffs and the performance of the spinoffs. Another high-tech industry where spinoffs were prominent is semiconductors, and Brittain and Freeman [1986] study the factors influencing the rate of spinoffs from semiconductor firms in Silicon Valley. The only other high-tech industry where spinoffs have been considered is biotech. Stuart and Sorenson [2003] exploit data on the location of all biotech startups and on biotech firms that were acquired or engaged in IPOs to make inferences about the impetus for spinoffs without having to trace the heritage of the biotech entrants. Mitton [1990] also studies the origin of biotech startups in San Diego. Outside of the high-tech sector, Phillips [2002] studies spinoffs from Silicon Valley law firms. Cutting across industries, Gompers et al. [2003] use data on venture capital (VC) financed startups to analyze the rate at which publicly traded firms spawned VC-financed spinoffs. We review the main findings from these studies.

We consider first the automobile industry, which began in 1895. Through 1966 there were 725 entrants into the industry, nearly all of which entered before 1926. Spinoffs accounted for 20% of the entrants, with the percentage of spinoff entrants rising over time. Spinoffs performed comparably to entrants with pre-entry experience in industries related to autos and substantially better than the majority of entrants without any relevant pre-entry experience, and by the 1910s spinoffs produced a majority of the leading makes of automobiles. The top four firms in terms of the number of spinoffs spawned were the four early leaders of the industry, Olds Motor Works, Cadillac, Ford, and Buick (which was the cornerstone of General Motors when it was formed). Among all firms, the spinoff rate was greater in firms that produced leading makes of automobiles and that survived longer. The firm spinoff rate also increased with age through age 14 and then declined, was greater in firms that were acquired by either auto or nonauto firms (in a short window around the time of the acquisition), and was greater in firms located in the Detroit area, where the industry was heavily agglomerated (Klepper [2004]). The performance of the spinoffs in terms of their longevity was positively related to the performance of their parents, with 11 of the 13 spinoffs that produced leading makes of automobiles descended from Olds, Cadillac, Ford, and Buick/GM (Klepper [2004]). In a detailed study of these 13 spinoffs, Klepper [2003b] found that nine were formed by top level engineers and managers as the result of disagreements within the parent firm about the kinds of cars to produce or about the management of the firm, with the spinoffs sometimes continuing efforts their parent initiated but then abandoned. The 13 spinoffs played an important role in the technological advance of the industry, accounting for a majority of the 50 major innovations in the industry from 1902-1925 that were not introduced by the two leading firms, Ford and Buick/General Motors

The laser industry began in 1961, and through 1994 spinoffs accounted for 69 or 17% of the 465 entrants whose backgrounds could be traced. The spinoffs survived much longer than other startups and comparably to diversifying entrants with prior experience in industrial electronics, who were the longest-lived diversifying entrants. Dividing lasers into eight main categories (and a residual), Klepper and Sleeper [2004] note that spinoffs typically specialized initially in a type of laser produced by their parent firm. Firms tended to remain specialized and produce a narrow range of laser types, with spinoffs accounting for many of the leading producers of each type of laser as well as the top two firms in the industry, Spectra Physics and Coherent. Similar to autos, for each type of laser the rate at which firms spawned spinoffs rose to age 14 and then declined, was greater in firms acquired by laser or nonlaser firms (in a short window around the time of the acquisition), and was greater in Silicon Valley firms, where the industry was modestly agglomerated. Using reports from a monthly trade journal and supplemented by interviews with founders, Klepper and Sleeper [2004] discuss the impetus for eight spinoffs that were illustrative of the factors underlying spinoffs in each of the eight main laser types. Each had a founding team with at least one high level technical manager and some also had founders with high-level managerial backgrounds in marketing and operations. In five of the eight spinoffs, the founders left to develop a technology they worked on in their parent firm but the parent chose not to develop; with three of the spinoffs licensing technology from their parent. Two of the other three spinoffs were formed after the parent was acquired, in one instance to service customers the parent abandoned after being moved and in the other to compete directly with the parent.

In the disk drive industry, of the 153 entrants from 1977 to 1997, 26% were spinoffs. Five major "architectural" innovations that reduced the size of disk drives and opened up new markets servicing smaller computers were introduced in the period 1977-1997. All five were pioneered by spinoffs, who displaced the industry leaders and survived longer than entrants with other backgrounds (Agarwal et al. [2004]). All spinoffs had at least one founder with a high level technical background and sometimes other founders with a high level marketing or production background, similar to autos and lasers. The rate of spinoffs was greater in firms with better disk drives and that were quicker to produce the new drives. These firms in turn had spinoffs with better disk drives and that were quicker to enter subsequent new markets, consistent with better firms having better spinoffs. Older firms that entered by 1976 had a lower rate of spinoffs, but otherwise age did not affect the firm spinoff rate. Christensen's [1993] analysis of the slowness of incumbents to introduce the smaller disk drives is revealing about the impetus for the leading spinoffs. Based on over 60 interviews with executives, Christensen [1993, pp. 562-563] found that leading incumbent firms conceived and developed prototypes of the smaller disk drives but then abandoned them when their customers showed little interest in them. Engineers that worked on the smaller drives then left in frustration to start their own firms, which ended up pioneering the drives. Judging from King and Tucci's [2002] analysis of entry into new disk drive markets, though, this was not a general tendency. They found that more experienced firms were actually *more* likely to enter new markets at every point in time, consistent with their finding that the sales of entrants in the new markets increased with their prior experience.

In Silicon Valley semiconductor firms studied by Brittain and Freeman [1986], firms that produced a wider array of semiconductor devices had higher spinoff rates, similar to the findings for lasers. Firms that were earlier entrants into new product groups also had higher spinoff rates, similar to disk drives. Both findings are consistent with better firms having higher spinoff rates. The spinoff rate was greater in firms whose growth had slowed and in firms that were acquired by nonsemiconductor firms or that hired a new CEO from outside the semiconductor industry. Stuart and Sorenson [2003] analyze the effect of acquisitions and IPOs on the rate of formation of biotech firms. They found higher startup rates in regions near where biotech firms were acquired or engaged in IPOs, which they presumed was due to spinoffs. These effects were present only in states with greater restrictions on the enforcement of noncompete covenants and the effect of acquisitions on startups was restricted to acquistions where the acquirer came from outside of the biotech industry. Mitton [1990] documents how in San Diego biotech firms, control changes resulting from acquisitions by nonbiotech firms led to "cultural" differences that spurred top level managers to leave to start their own biotech spinoffs. Mitton also found that most of the San Diego biotech spinoffs were formed to develop technologies their parents declined to pursue.[2] The oldest parents of spinoffs in Mitton's study were 10 years old, and through age 10 the rate at which they spawned spinoffs increased with age, consistent with the findings for autos and lasers

Phillips' [2002] analysis of spinoffs from Silicon Valley law firms focused on how spinoffs affected the performance of their parents, but he also analyzed factors influencing the performance of spinoffs and briefly the factors influencing the rate at which firms spawned spinoffs. Firm spinoff rates increased through the age bracket 9-15 after which they declined. The length of survival was greater for spinoffs whose founders had greater status in their parent firm and less for spinoffs from failing firms. He also found that firms had higher hazards after spinoffs than comparable firms without spinoffs.

Gompers et al. [2003] found that publicly traded firms in Silicon Valley and Massachusetts, both hotbeds of entrepreneurial startups, and firms that were themselves VC-financed had higher rates of VC-financed spinoffs. The former result is consistent with the higher rate of auto spinoffs in Detroit and laser spinoffs in Silicon Valley and may simply reflect the greater ease of forming a founding team and securing advice and financial support in regions with a larger number of related startups. The spinoffs of Silicon Valley and Massachusetts firms and VC-backed firms were less likely to be engaged in technologies related to their parents than the spinoffs of other firms. It was also found that less diversified firms had a higher spinoff rate and that slowed growth heightened firm spinoff rates, similar to the Silicon Valley semiconductor firms. Firm spinoff rates also declined with age, which is consistent with the findings for autos and lasers if publicly traded firms were generally over 14 years old.

Certain patterns consistently emerge from the various industries studied. Around 20% of all entrants were spinoffs, and the spinoffs were distinctly good performers. They generally had at least one founder who was a high level technical manager and sometimes also had founders with high level marketing and operational experience. Better firms had a higher spinoff rate and their

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[2] In contrast to autos, lasers, and disk drives, however, 40% of the startups were financed in part by their parents.

spinoffs were better performers. Disagreements over what technologies to develop and sometimes about management practices were the principal impetus for the leading spinoffs. Spinoffs were less likely to occur in older firms, but it appears that initially the spinoff rate increased with firm age. Acquisitions induced an increase in the likelihood of spinoffs during a short window around the time of the acquisition, especially when the acquirer was from another industry. A new CEO from another industry, an IPO, and slowed growth also appear to have increased the rate of firm spinoffs.

III. Existing Theories of Spinoff Formation

How well do existing theories explain the common patterns in the various studies of high-tech spinoffs? With the growing interest in spinoffs, various models have been proposed to explain them.[3] These models tend to fall into three camps. In the first, an employee makes a serendipitous discovery of some economic value. This discovery is in principle more valuable to the incumbent firm than it would be to a startup, but information asymmetries of one form or another frequently persuade the employee to implement the discovery through his own startup rather than reveal it to his employer.[4] In the second type of model, the discovery is common knowledge within the firm but it is less valuable to the incumbent than it would be to a start-up, because its implementation would cannibalize existing rents or because the firm has limited competency to evaluate the idea, particularly when the idea is tangential to the firm's main activities.[5] In the third type of model, employees learn from their employers about how to profitably compete in their industry, especially when their employer is successful. They exploit this knowledge by setting up their own firm in the same industry.[6]

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[3] The traditional explanation for who becomes an entrepreneur is based on ability (Lucas [1978], Holmes and Schmitz [1990]). While it is obvious that ability may be enhanced by working for an incumbent in the industry (Irigoyen [2002]), this literature does not explain why only a small fraction of the many employees with the requisite experience and entrepreneurial ability leave their employers to found a new firm.

[4] See Anton and Yao [1995], Wiggins [1995], Bankman and Gilson [1999], Gromb and Scharfstein [2002], Hellman [2002], and Amador and Landier [2003]. Common themes are (i) firms cannot commit to a contingent contract that adequately rewards the employee for a discovery and the subsequent employee effort needed to implement it, and (ii) non-contingent contracts that are *ex ante* acceptable to the firm will not always be sufficient to prevent a departure by the employee.

[5] See Pakes and Nitzan [1983], Tushman and Anderson [1986], Henderson and Clark [1990], Christensen [1993], Klepper and Sleeper [2004], and Cassiman and Ueda [2002].

[6] See Franco and Filson [2000] and Agarwal et al. [2004].

None of these theories seems to capture the process underlying most spinoffs. The first type of theory predicts that employees that found spinoffs will not reveal their ideas to their employers. However, the evidence suggests that at least among the leading spinoffs, the employer often knows precisely what the employee's idea is but does not want to pursue it. Indeed, a common theme of studies that focus on the motives of spinoffs is that they arise from frustration by employees over rejection of their ideas by their employers (Garvin [1983, p. 6], Lindholm [1994, p. 163]).[7] Moreover, it is not clear how the first type of theory can explain why acquisitions, IPOs, and slowed growth should heighten the chance of spinoffs or why age should have a non-monotonic effect on the firm spinoff rate.

The second type of model is consistent with firms rejecting the ideas of their employees. This could happen if established firms are unable to evaluate certain types of ideas that are not in their core areas. With the success of firms no doubt dependent on their ability to evaluate ideas of their employees, it might be expected such spinoffs would be more likely in less successful firms. Yet the evidence strongly points in the opposite direction, with more successful firms having higher spinoff rates. Alternatively, in the second type of model the ideas might be rejected because they would cannibalize the firm's sales and hence profits. But many of the ideas that spinoffs from the leading auto and laser firms pursued were actually initiated and first worked on by their parents, which is consistent with cannibalization fears only if the firms could not anticipate where the ideas would lead. This is hard to rule out from the limited evidence on spinoffs. But if this were important, one would imagine that most employees would be able to understand why their ideas were rejected and would not be so frustrated with their employers. It is also not clear why fears of cannibalization would be heightened when a firm was acquired or would be related to the age of the firm, thus providing no explanation for these findings.

The third type of model featuring learning is consistent with one aspect of the findings about spinoffs, namely the tendency for better firms to have higher spinoff rates and better-performing spinoffs. But these theories imply that spinoffs should do similar things to their parents based on their common knowledge. Yet the evidence indicates that the leading spinoffs commonly pursue ideas their parents rejected. So what exactly are the spinoffs learning from their parents, and why should disagreements be the impetus for so many spinoffs? Moreover, if learning is the motive for spinoffs, why would spinoffs be more likely when firms are acquired? Acquisitions conceivably could promote learning. However, acquisitions by firms in the same industry might

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[7] It is possible that employees get their ideas rejected because they do not want to fully reveal them in order to protect them from being copied by their employers. However, the frustration expressed by so many employees when their ideas are rejected suggests that partial revelation is not the problem.

be expected to promote the most learning, yet spinoffs seem especially likely when firms are acquired by firms in other industries. Moreover, the increase in spinoff formation associated with acquisitions seems to be concentrated in too short a window around the time of acquisitions to be consistent with learning theories.

Thus, all three types of explanations for spinoffs come up short in important ways. The fact that many leading spinoffs arise out of disagreements within their parent firms is difficult for existing theories to accommodate. Existing theories also do not address why acquisitions, particularly by firms from another industry, increase spinoff rates or why age should affect spinoff rates. In the next section we propose a new model of spinoffs based on disagreements, and we explore its ability to accommodate the empirical evidence.

IV. Disagreements and Spinoffs: A New Model

To model disagreements, we need to confront the fact that firms are not unitary actors but are composed of decision makers with potentially different views about what the firm should do. Accordingly, we assume that a firm is composed of multiple individuals, each of which has some influence on the firm's decisions. At any given moment, optimal choices are not known, but over time they are slowly learned as employees receive signals about the true environment facing the firm. The signals are noisy and differ across members of the firm, leading to disagreements about what the firm should do. The firm's choice is a weighted average of the choices favored by each of its decision makers, with weights based on the positions of individuals and perhaps their ownership share of the firm. Employees leave to start their own firms when their view of what the firm should do differs sufficiently from the firm's choice about how to proceed.

The essence of the model is that employees want to be involved with a firm that does what they believe to be the "right thing." In our view, sufficient attention has already been paid to contracting difficulties caused by employees being all too willing to screw their employers by not revealing discoveries they were paid to make, and by employers being unable to commit to state-contingent rewards that would persuade employees to be honest. We assume in contrast that individuals at higher echelons of firms are concerned with the value of the firm's activities, rather than with how they can manipulate their own payoff through deception or omission. On the other side of the same coin, we assume firms have no interest in ripping off their senior employees.[8] We assume there is considerable uncertainty about what the "right thing" is, and this

[8] This is not a radical approach. It simply applies to the higher echelons of the firm Akerlof's [1982] widely-admired but widely-ignored sociological characterization of the workplace, where "the average worker works harder than is

generates genuine disagreements about the choice of strategy for a firm. These disagreements need not be predicated upon any particular discovery, whether private or common knowledge.

There is, however, an intellectual challenge in modeling disagreements. Presumably each individual must, in the language of Bayesian learning, reveal his posterior mean to his colleagues if he wants to participate in the decision-making process. But this revelation also allows each individual to infer precisely his colleagues' private signals. Efficiently incorporating these signals into his own beliefs, the revised posterior mean will then be the same for everyone. Aumann [1976] has shown under very general conditions that if the posteriors of two Bayesians with common priors are common knowledge, their posteriors must be the same; Geanakoplos and Polemarcharkis [1982] show further that if two agents with common priors exchange their efficient posteriors back and forth they will arrive at the common knowledge posterior; and McKelvey and Page [1986] have extended these results to n individuals.

These results leave two ways in which disagreements can persist. First, one can drop the common prior assumption. Although it has a substantial tradition in behavioral finance, beginning with Harrison and Kreps [1978], there has been some debate about whether doing so is reasonable (Aumann [1987, 1988], Gul [1988], Morris [1995]).[9] The consensus seems to be against dropping the common prior. Moreover, in our setting it seems reasonable to assume that firms are formed by individuals that want to work together because they hold similar beliefs. Second, one can drop the efficiency of individuals' updating algorithms. Some authors have assumed that individuals are overconfident in the sense that the posterior mean is a biased estimate of the true mean.[10] Others have assumed that decision-makers overweight the information content of their private signals relative to publicly available information. This second approach has also been dubbed a form of overconfidence.

Our approach 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 term asymmetric weighting of private and non-private signals (in favor of the former) as "solipsism."

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necessary according to the firm's work rules, and in return for this donation of goodwill and effort, he expects a fair wage from the firm."

[9] See Van den Steen [2001] for an extensive review.

[10] This is the central assumption in Amador and Landier [2003]. However, the assumption is subsequently justified by appeal to issues of asymmetric information and moral hazard. See Malmendier and Tate [2002, 2003] for applications of the assumption to corporate investment and acquisitions.

The distinction between overconfidence and solipsism has substance: solipsism is a necessary condition for disagreement; overconfidence 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 overweight 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 (e.g. receiving accurate signals) to happen to them more often than they do to others (Weinstein [1980], Kunda [1987]).

The Dynamics of Disagreement

Our formal model is an extension of the Jovanovic and Nyarko [1995] Bayesian learning model to teams of decision makers. Suppose a firm is operated by *n* individuals, each of which has some degree of decision-making authority or influence. Each individual is concerned with maximizing the expected value of the firm, rather than his own private returns. All individuals know that firm value is given by $v = -(\theta - x)^2$, where x is the activity undertaken by the firm and θ is a target. No one knows the target, but at time t individual i=1, 2, . . ., n, believes it is a draw from a normal distribution with mean θ_{it} and variance σ_{it}^2. Given his beliefs, i calculates that the optimal strategy is $x=\theta_{it}$, yielding an expected payoff of $v_{it} = -\sigma_{it}^2$. The activity actually chosen by the firm is a compromise, $x = \overline{\theta}_t = \sum_{i=1}^{n} \phi_i \theta_{it}$, of everyone's beliefs. The parameters ϕ_i are time-invariant weights attached to individual expectations, with $\sum_{i=1}^{n} \phi_i = 1$. The weight ϕ_i can be interpreted as i's decision-making influence.

Individual i's expected value of the compromise decision is

$$E_{it}[v] = -E_{it}\left[\left(\theta - \overline{\theta}_t\right)^2\right]$$

$$= -E_{it}\left[\left((\theta-\theta_{it})+(\theta_{it}-\bar{\theta}_t)\right)^2\right]$$

$$= -E_{it}\left[(\theta-\theta_{it})^2\right]-(\theta_{it}-\bar{\theta}_t)^2$$

$$= -\sigma_{it}^2-(\theta_{it}-\bar{\theta}_t)^2, \tag{1}$$

where in the third line the fact that any Bayesian posterior is unbiased implies $E_{it}(\theta-\theta_{it})=0$. From *i*'s perspective the firm will do worse the more he disagrees with the firm's decision, and he may want to do something about it. We focus attention on *i*'s possible departure to form his own startup. Doing so will be attractive if the cost is not too high and if by so doing he can operate a firm using a strategy closer to his own beliefs. Let the cost be *k* (we shall call this the entry cost), and assume that *i* can form a new team consisting of individuals holding exactly the same subjective beliefs as his.[11] The expected value of the spinoff is then $E_{it}[w]=-k-\sigma_{it}^2$, so *i* prefers to strike out on his own whenever

$$z_{it}^2 \equiv (\theta_{it}-\bar{\theta}_t)^2 \geq k. \tag{2}$$

For any set of weights, $\{\phi_i\}_{i=1}^n$, the decision to leave depends only on the subjective means, and not at all on the precision of those beliefs. Understanding the spinoff process is therefore reduced to the task of understanding how expected values come to differ sufficiently to induce individuals to strike out on their own. This difference will, however, be related to the precision of beliefs.

To see how subjective means come to differ over time, assume that the firm is founded at time 0 by a group of *n* individuals, all of whom share the same prior that θ is a random draw from $N(0,\sigma_\theta^2)$. Once each period, these individuals receive private and noisy signals, $s_{it}=\theta+\varepsilon_{it}$, where the ε_{it} are random draws from a normal distribution with zero mean and variance σ_ε^2. Although all signals have variance σ_ε^2, each individual believes his own signals to have variance $\gamma\sigma_\varepsilon^2$ and his colleagues' signals to have variance $\gamma\beta\sigma_\varepsilon^2$. Individuals are labeled overconfident if $\gamma<1$, and solipsistic if $\beta>1$. In the limit as $\beta\to\infty$ individuals only respond to their own private signals.

Individual *i*'s posterior after receiving *t* private signals is normal with mean

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[11] The assumption reflects the notion that firms are formed by groups of individuals with a common prior.

$$\tilde{\theta}_{it} = \frac{t\sigma_\theta^2 \overline{s}_{it}}{t\sigma_\theta^2 + \gamma\sigma_\varepsilon^2}, \tag{3}$$

and variance

$$\tilde{\sigma}_{it}^2 = \frac{\gamma\sigma_\theta^2\sigma_\varepsilon^2}{t\sigma_\theta^2 + \gamma\sigma_\varepsilon^2}, \tag{4}$$

where $\overline{s}_{it} = t^{-1}\sum_{\tau=1}^{t} s_{i\tau}$ is the mean of *i*'s private signals to date *t*.

As β and γ 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 $(n-1)t$ signals from his colleagues. Standard Bayesian formulae for normal conjugates then imply that *i*'s expectation of the target is

$$\theta_{it} = \frac{t\sigma_\theta^2}{(\beta + n - 1)t\sigma_\theta^2 + \beta\gamma\sigma_\varepsilon^2}\left(\beta\overline{s}_{it} + \sum_{j\neq i}\overline{s}_{jt}\right), \tag{5}$$

with posterior variance

$$\sigma_{it}^2 = \frac{\beta\gamma\sigma_\theta^2\sigma_\varepsilon^2}{(\beta + n - 1)t\sigma_\theta^2 + \beta\gamma\sigma_\varepsilon^2}, \tag{6}$$

The firm's decision is a weighted average of each team member's subjective mean:

$$\begin{aligned}\overline{\theta}_t &= \frac{t\sigma_\theta^2}{(\beta + n - 1)t\sigma_\theta^2 + \beta\gamma\sigma_\varepsilon^2}\left(\beta\sum_{i=1}^{n}\phi_i\overline{s}_{it} + \sum_{i=1}^{n}\phi_i\sum_{j\neq i}\overline{s}_{jt}\right) \\ &= \frac{t\sigma_\theta^2}{(\beta + n - 1)t\sigma_\theta^2 + \beta\gamma\sigma_\varepsilon^2}\sum_{i=1}^{n}\left(1 + (\beta - 1)\phi_i\right)\overline{s}_{it}\,. \end{aligned} \tag{7}$$

Hence,

$$z_{it} = \frac{(\beta - 1)t\sigma_\theta^2}{(\beta + n - 1)t\sigma_\theta^2 + \beta\gamma\sigma_\varepsilon^2}\left(\overline{s}_{it} - \sum_{i=1}^{n}\phi_i\overline{s}_{it}\right). \tag{8}$$

If β=1*,* then $z_{it} \equiv 0$. That is, without solipsism, disagreement is not possible.

The Hazard of Spinoff Formation

The empirical evidence shows that the likelihood that a firm spawns a spinoff initially increases with age, but declines with age for older firms. In this subsection, we show that this age profile for spinoff formation is predicted by the model.

The mean signals $\bar{s}_{it}$, i=1, 2, . . . , n, are normally distributed and independent across individuals, each with (unknown) mean θ and (true) variance σ_ε^2/t. It then follows that z_{it} is normal with zero mean and variance

$$\mathrm{var}(z_{it}) = \frac{(\beta-1)^2 t\sigma_\theta^4\sigma_\varepsilon^2\left(1-2\phi_i+H\right)}{\left((\beta+n-1)t\sigma_\theta^2+\beta\gamma\sigma_\varepsilon^2\right)^2}, \tag{9}$$

where $H=\sum_{i=1}^n \phi_i^2$ is the Herfindahl index of decision-making authorities.[12] Hence, i prefers to strike out on his own if

$$\frac{\chi_{it}^2(\beta-1)^2 t\sigma_\theta^4\sigma_\varepsilon^2\left(1-2\phi_i+H\right)}{\left((\beta+n-1)t\sigma_\theta^2+\beta\gamma\sigma_\varepsilon^2\right)^2} \geq k,$$

where χ_{it}^2 is a chi-squared random variable with one degree of freedom. Rearranging, exit is preferred by i if

$$\chi_{it}^2 \geq \frac{k\left((\beta+n-1)t\sigma_\theta^2+\beta\gamma\sigma_\varepsilon^2\right)^2}{(\beta-1)^2 t\sigma_\theta^4\sigma_\varepsilon^2(1-2\phi_i+H)}. \tag{10}$$

Figure 1 illustrates inequality (10). The curve **AA** traces out the right hand side as a function of t. It is u-shaped, with a minimum at $t=\beta\gamma\sigma_\varepsilon^2/\left((\beta+n-1)\sigma_\theta^2\right)$, and limits of $+\infty$ at t=0 and as $t\to\infty$. The unbounded limits reflect the facts that all individuals begin with the same prior and that they will eventually learn the common true parameter value if they receive a sufficient number of signals. Thus, for t small enough and large enough, it is unlikely that a draw from the $\chi_{(1)}^2$ distribution will be large enough to induce a spinoff. Note also that for β=1, the right hand side of (10) is infinite. Figure 1 also plots sequences of the left hand side of (10) for two individuals. The sequence for individual i first exceeds **AA** at point **a**, which is when he departs

[12] As $(1-2\phi_i+H)\equiv(1-\phi_i)^2+\sum_{j\neq i}\phi_j^2$, it is clearly positive.

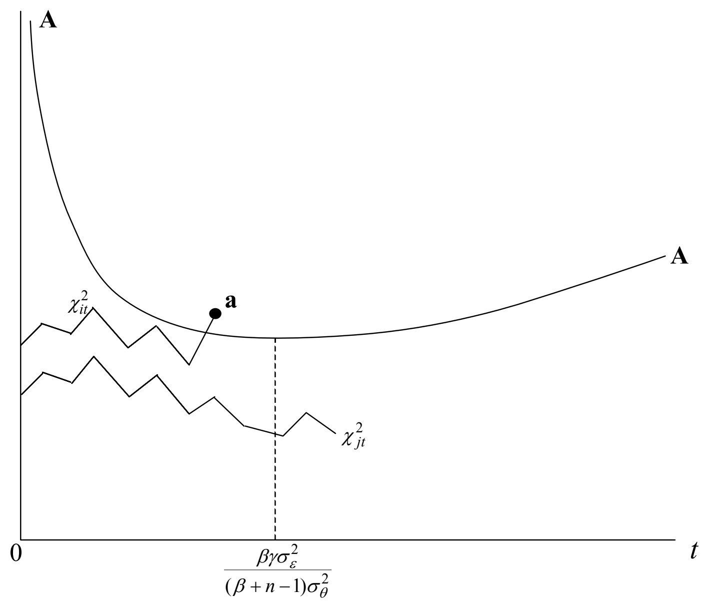

FIGURE 1. The dynamics of spinoff formation.

to form his own firm. The sequence for individual *j* never crosses **AA**, so this individual does not depart the firm. It is clear from Figure 1 that the hazard of *i* forming a spinoff must start out at zero, then rise to some strictly positive value (because a χ^2 random variable has unbounded support), and eventually decline back to zero as the firm ages.

PROPOSITION 1. *The hazard of spinoff formation initially rises from zero, but eventually asymptotically declines to zero.*

Assuming β>1, most parameter changes induce an unambiguously-signed change in the probability that at any given *t* inequality (10) is satisfied. The right-hand side of (10) is strictly increasing in γ, k and ϕ_i for all positive *t,* and strictly decreasing in *H* and σ_θ^2 for all positive *t*. In contrast, changes in σ_ε^2 have an ambiguous effect on the right hand side of (10), which is increasing [decreasing] in σ_ε^2 for $t < [>] \sigma_\varepsilon^2 / \sigma_\theta^2$. Let p_t denote the unconditional probability that at any given *t* inequality (10) is satisfied. Then the hazard of spinoff formation in period *t* is $h_t = p_t \Big/ \left(1 - \sum_{i=1}^{t} p_{t-i}\right)$, and it has the following properties:

PROPOSITION 2. *For any t*=1, 2, 3, . . ., *and* β>1, *the spinoff hazard is strictly decreasing in* γ, k, *and* ϕ_i, *and strictly increasing in H* and σ_θ^2. *The hazard is strictly decreasing in* σ_ε^2 *for* $t \le \sigma_\varepsilon^2 / \sigma_\theta^2$, *and is ambiguously related to* σ_ε^2 *thereafter.*

Intuitively, spinoffs are more likely in industries with low entry costs and high uncertainty about the appropriate activity. Low entry costs just make it easier to leave. The greater the uncertainty about θ, the more attention individuals pay to their private signals and the more likely they are to disagree. Overconfidence matters <u>only</u> if β>1, in which case spinoffs are decreasing in γ. Conditional on the concentration of decision-making authority, individuals with less authority are more likely to leave. Finally, conditional on ϕ_i, greater concentration of decision-making authority induces higher spinoff formation rates. Concentration of decision-making authority matters even if individual *i* has no authority, because increased concentration makes the "compromise decision" more erratic. Changes in σ_ε^2 have an ambiguous effect on spinoff formation.[13]

The Effect of Acquisitions

A robust result from the empirical studies is that spinoffs are more likely to occur around the time that a firm is acquired, and this is particularly the case if the acquirer comes from outside the industry. This phenomenon is a natural consequences of our theory. Acquisitions change the distribution of decision-making authority. New individuals are brought from outside the acquired firm and reorganizations take place inside it. Consider a situation in which an individual *i* is currently not planning to leave a firm that is then acquired. If the reorientation of the firm moves the firm's decision toward *i*'s beliefs, he still will not leave and there is no consequence for the spinoff hazard. But if *i*'s decision-making influence is reduced, the firm's decision moves away from *i*'s beliefs, possibly enough to induce immediate exit.

PROPOSITION 3. A*cquisitions that change the distribution of decision-making authority induce a short-term spike in the hazard of spinoff formation.*

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[13] The ambiguity arises from two countervailing effects of an increase in the precision of the signals. On the one hand, more precise signals induce greater sensitivity of the posterior mean to signals and increase the likelihood that posteriors diverge. On the other hand, more precise signals increase the rate of learning, so that the posteriors of all individuals converge on the true parameter value more quickly. The former effect dominates for *t* small, while the latter dominates for larger values of *t*. Thus, when learning is more difficult, in the sense that σ_ε^2 is larger, spinoffs are likely to occur later in a parent firm's life.

In some instance an acquisition may eliminate a maverick CEO and prevent impending departures. But acquisitions that accomplish this must be undertaken *before* frustrated employees have left, requiring some remarkable prescience on the part of the acquiring firm. Such cases are likely to be rare.

Spinoff Quality

Assume that at time t individual i forms a spinoff, which implies that there is a sufficiently large distance between θ_{it} and $\overline{\theta}_t$ to justify the entry cost. The value of the spinoff is then $w_{it} = -(\theta - \theta_{it})^2 - k$. But even ignoring the entry cost, it turns out that spinoffs will on average be bad ideas, in the sense that the expected initial quality of i's firm is lower than the current quality of its parent. The intuition is simply that the mean of $(n-1)$ posteriors is likely to be closer to the true value than a single posterior that diverges from this mean.

More formally, recall that $\sqrt{k}$ is the smallest distance between i's posterior mean and the compromise decision necessary to induce i to form a spinoff. Then the expected quality of the spinoff, $E\left[w_{it}\right]+k$, is less than the expected quality of the parent, $E\left[v_t\right]$, if

$$E\left[-\left(\theta-\theta_{it}\right)^2+\left(\theta-\overline{\theta}_t\right)^2 \middle| \left|\theta_{it}-\overline{\theta}_t\right| \geq \sqrt{k}\right] < 0 . \tag{11}$$

It is easy to show that inequality (11) holds for k=0, because in this special case we have

$$\begin{aligned} E\left[-\left(\theta-\theta_{it}\right)^2+\left(\theta-\overline{\theta}_t\right)^2 \middle| \left|\theta_{it}-\overline{\theta}_t\right| \geq \sqrt{k}\right]\Bigg|_{k=0} \\ &= E\left[\overline{\theta}_t^2\right]-E\left[\theta_{it}^2\right] \\ &= \frac{t\sigma_\theta^4\sigma_\varepsilon^2}{\left((\beta+n-1)t\sigma_\theta^2+\beta\gamma\sigma_\varepsilon^2\right)^2}\left(\sum_{i=1}^n\left(1+2(\beta-1)\phi_i\right)^2-\left(\beta^2+(n-1)\right)\right) \\ &= \frac{(\beta-1)^2(H-1)t\sigma_\theta^4\sigma_\varepsilon^2}{\left((\beta+n-1)t\sigma_\theta^2+\beta\gamma\sigma_\varepsilon^2\right)^2} \\ &< 0 , \end{aligned} \tag{12}$$

where the second line exploits the fact that $E(\theta)$=0. Proving the same for the general case appears to be infeasible, because we need to further condition on the difference between θ_{it} and $\overline{\theta}_t$.[14] In Appendix A we therefore evaluate the properties of (11) numerically. The results are summarized in Figure 2. In all cases, the expected value of the spinoff is less than the expected value of the parent, although for some parameter values the difference is small.

PROPOSITION 4. *For β>1*, (a) *The initial quality of a spinoff is on average lower than the quality of its parent.* (b) *The average gap between the quality of a parent and its spinoff at the time the spinoff is formed is increasing in β and σ_θ^2, decreasing in γ and k, and exhibits a u-shape* as ϕ_i, *n*, *t, and σ_ε^2 increase.*

As one might anticipate, greater degrees of solipsism and overconfidence lead to spinoffs of relatively poor quality. Spinoffs also have lower quality relative to their parents in industries where the variance of the prior, σ_θ^2, is large. As Jovanovic and Nyarko [1995] have shown, σ_θ^2 is positively related to the amount there is to learn over the life of a firm or technology, the amount that is actually learned over any interval of time, as well as to the amount of inequality in efficiency among a cohort of firms. Hence, *ceteris paribus*, in industries with greater inequality and more learning, spinoffs are also likely to have lower relative quality.

Recall that high entry barriers require large disagreements to induce spinoffs, and large disagreements also imply large differences in the strategies chosen by parent and spinoff. One might therefore expect the relative quality of spinoffs to be declining in the size of entry barriers. Somewhat surprisingly, the opposite is true. It turns out that the effect of high entry barriers on the minimum difference in beliefs necessary to induce a spinoff is more than offset by the requirement that departing individuals must also be more confident about their beliefs when entry barriers are high. Thus, the possibility of highly misleading signals is lower the higher are entry barriers.

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[14] The term $\overline{\theta}_t^2 - \theta_{it}^2$ consists of sums of products of positively-correlated normal variables. Some analytical results and approximations are known for the distribution of such products only in special cases (Craig [1936], Aroian [1947]), and modern work has resorted to numerical and Monte Carlo methods (e.g. Ware and Lad [2003]).

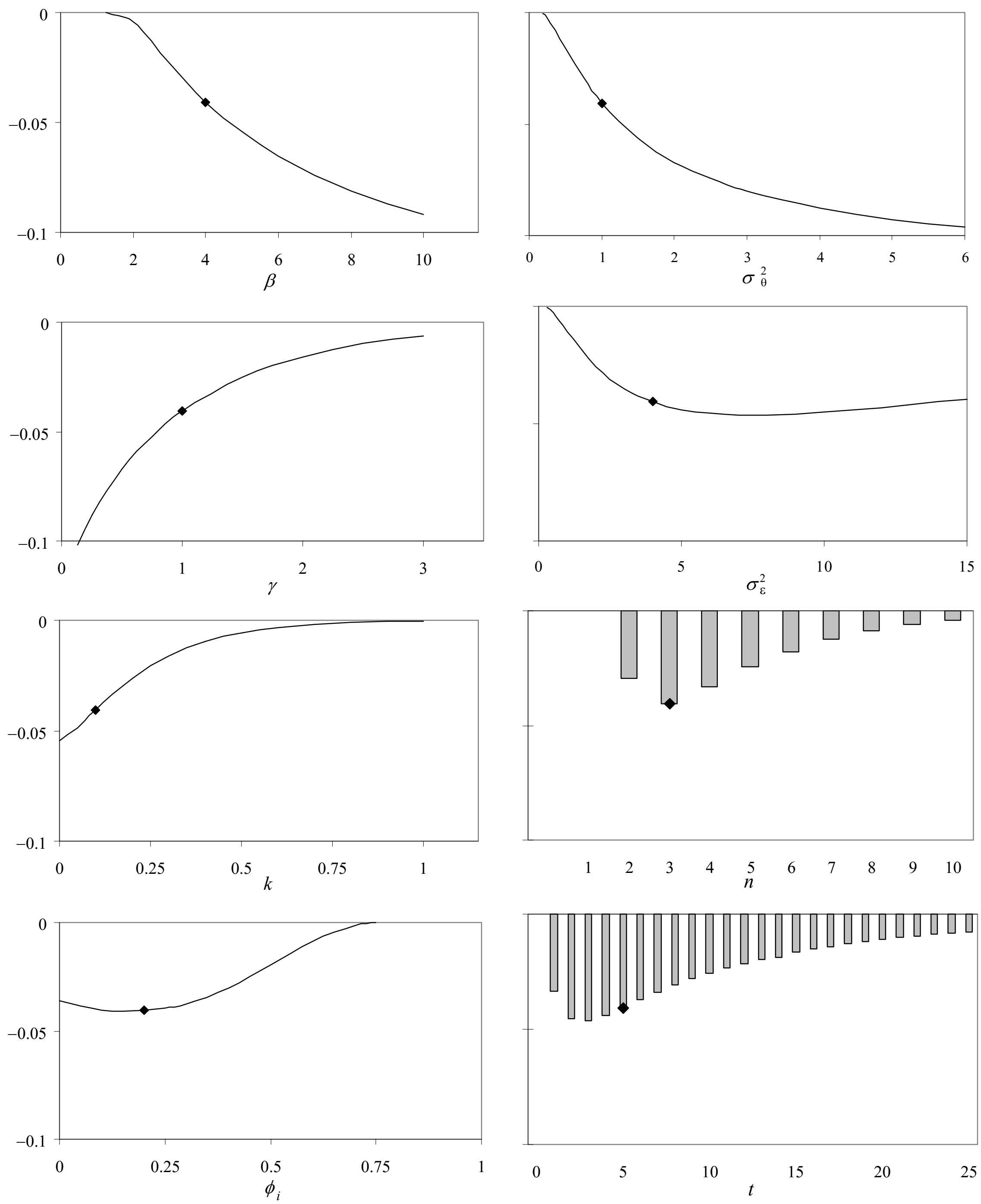


FIGURE 2. Expected quality of spinoff minus expected quality of parent. Diamond symbol on each graph indicates the baseline value used to generate all the other figures. The forms of the curves were verified for parameter ranges wider than those shown here.

Greater solipsism, greater overconfidence, greater prior uncertainty about the "right thing to do," and lower entry costs all raise the hazard of spinoff formation and reduce quality, suggesting that we would expect to observe a negative association between rates of spinoff formation and spinoff quality. However, this association must be tempered by the presence of several non-monotonic comparative statics results. Increases in *i*'s decision-making authority, in the size of the managerial team, in the signal noise, and in the age of the parent all have non-monotonic effects on spinoff quality, causing it first to fall and then to rise as each parameter increases. Most notably, because this variable is most readily measured, the spinoffs with the lowest relative quality are those that form when the parent is of intermediate age. Spinoffs from both young and old parents are on average higher quality. These comparative statics are on the whole intuitive, and they are related to the non-monotonic relationship between these parameters and inequality in efficiency among firms explored by Jovanovic and Nyarko [1995] in their simpler setting.

The non-monotonic relationship between the relative quality of the spinoff and the number of decision makers in the parent firm represents the tradeoff between two opposing forces. On the one hand, the parent firm's decision is a weighted sum of n posteriors and hence the expected quality of the decision improves as n increases. On the other hand, the posterior of individual i is also a weighted sum of n posteriors, so that the average quality of any spinoff formed also increases in n. For small values of n, the former effect dominates, so the *relative* quality of the spinoff declines as n rises. For larger values of n the latter effect dominates. Of course, increasing n has a smaller effect on the quality of the spinoff the greater the degree of solipsism. Thus, one would expect that increasing β not only increases the average gap between the qualities of parent and spinoff, it also postpones to higher values of n the point at which the second effect dominates. Figure 3, which repeats the plot for n from Figure 2 with different values of β, confirms that this is the case. For our baseline value of β=4, the expected quality difference is greatest at n =3. For β=25, it is greatest at n=5, while for β=100 it is greatest at n=8. In the limit as $\beta \to \infty$, i's posterior does not benefit from the signals of his colleagues, and in this case the difference in relative quality asymptotically attains its greatest value as $n \to \infty$.

Our result that on average spinoffs will perform worse than their parents is a distinctive prediction of the model. Other theories envision spinoffs as either exploiting especially valuable ideas developed within their parent firm, pursuing ideas their parent rejected for parochial reasons or because of bureaucratic inertia, or competing on even terms with their parent based on knowledge gleaned from working for their parent. All of these theories suggest that on average spinoffs will perform as well if not better than their parent firms. Our model certainly leaves open the possibility that some spinoffs will outperform their parents, but predicts on average that

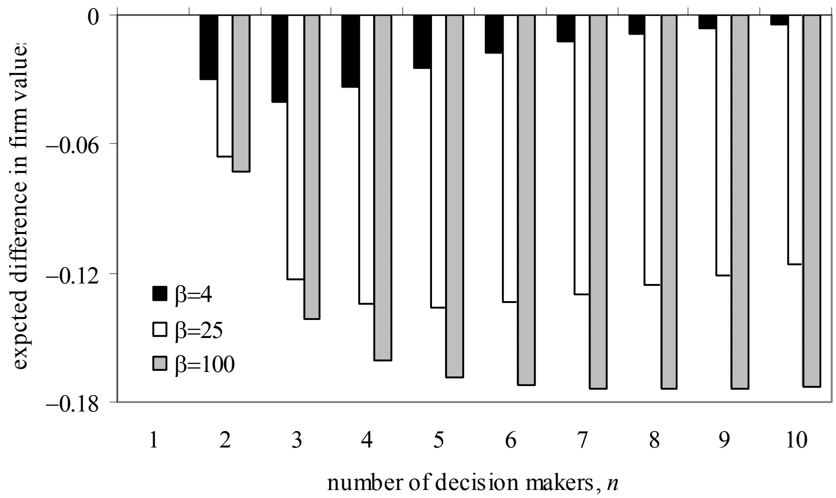


FIGURE 3. Expected quality of spinoff minus expected quality of parent.

this will not occur. Note that if there are technological spillovers, which seems inevitable, spinoffs could turn out to be socially productive even if on average they perform worse than their parents. This could help explain the observation by Klepper [2003b] that spinoffs played an important role in advancing the technology of the U.S. automobile industry.

We can exploit the data collected in Klepper [2004] on all automobile firms to compare the performance of spinoffs and their parents. For each firm, we can compute the number of years it produced automobiles, which is a kind of all-purpose measure of firm performance. By definition, a firm has to produce automobiles for some amount of time in order for it to be a parent, guaranteeing a minimal number of years of survival for parents. On the other hand, spinoffs could fail at any point. Consequently, it might be expected that a greater percentage of spinoffs would fail at young ages than their parents, but if spinoffs performed comparably to their parents then at older ages spinoffs and parents would have comparable survival rates. To test this, we construct Kaplan Meier survival curves for automobile spinoffs and their parents, which are reported in Figure 4.[15] For each age, the curves indicate the natural log of the percentage of spinoffs and parents surviving to that age (the slope of the curves at each age reflects the hazard of exit). As expected, spinoffs had lower survival rates than their parents at young ages. Consistent with our model, these lower survival rates persisted at older ages. For example, at age 20 the percent of survivors was 9% for spinoffs and 26% for their parents, and at age 40 the spinoff survival rate was 3% versus 11% for their parents. No doubt there were many

[15] There were 145 spinoffs and 88 firms that accounted for the 145 spinoffs. The best firms spawned more spinoffs (Klepper [2004]), but we included only one observation for each parent so that our test would be conservative.

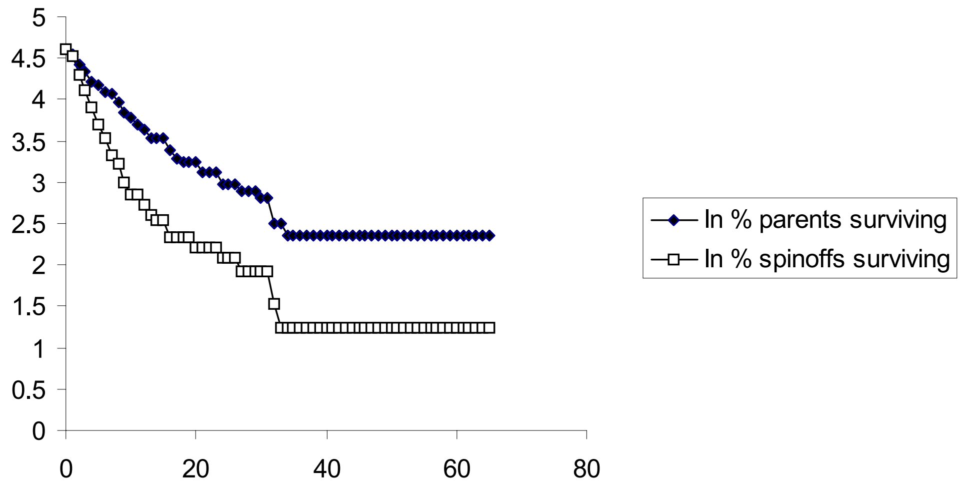


FIGURE 4: Survival curves for spinoffs and parents in the automobile industry.

reasons parents survived longer than their spinoffs, but the results are encouraging regarding the model.

Parent Quality and the Spinoff Hazard

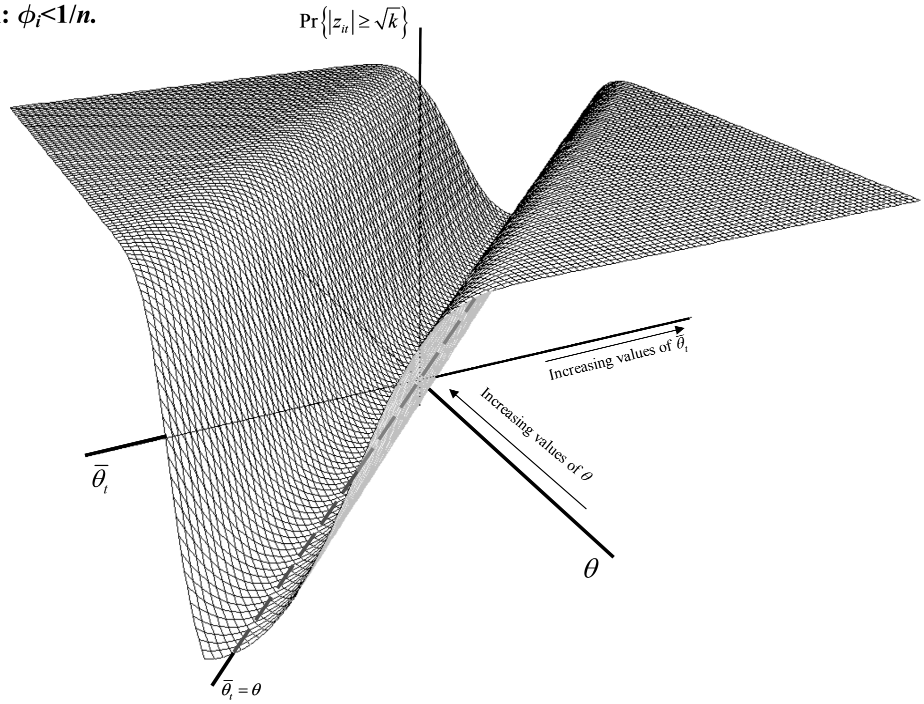
A robust regularity identified in the empirical literature is that better-quality parents produce more spinoffs. It turns out that our abstract model predicts the opposite. A formal proof is difficult. We restrict attention to the special case in which $\phi_j = (1-\phi_i)(1-n)^{-1}$ for all $j \neq i$, and provide a numerical evaluation. Figure 5 provides representative plots of the hazard that individual i forms a spinoff for given values of the unknown parameter, θ, and the firm's decision, $\overline{\theta}_t$.[16] Panel A plots the case in which i has less decision-making influence than the remainder of the team, while panel B plots the case in which he has more influence. Both graphs are symmetric around an axis where the decision, $\overline{\theta}_t$, equals the unknown target, θ, and they have a minimum along that axis. That is, the probability that individual i chooses to leave the parent firm is lowest for high-quality firms.[17]

PROPOSITION 5. *The hazard of spinoff formation is decreasing in firm quality*.

[16] Appendix B provides the formal derivations. After suitable scaling of the axes, different sets of parameter values produce very similar graphs.

[17] Because this result holds for $\phi_i > n^{-1}$ and $\phi_i < n^{-1}$, it is noteworthy that parental quality does *not* matter in the symmetric case, where $\phi_i = n^{-1}$ (see appendix).

PANEL A: ϕ_i<1/*n*.



PANEL B: ϕ_i>1/*n*.

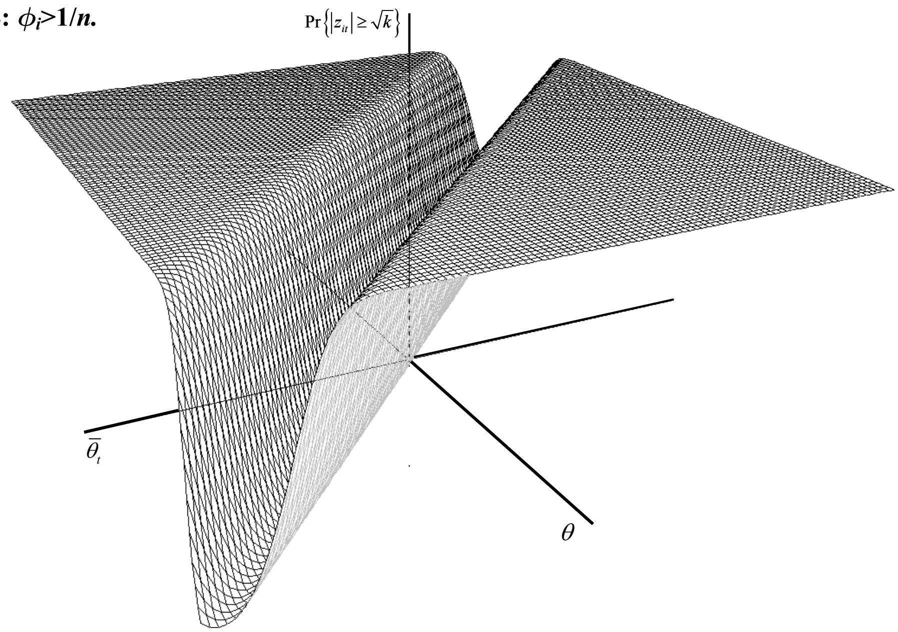


FIGURE 5. Representative plots of probability that individual *i* chooses to form a spinoff, as a function of the unknown target value, θ, and the firm's decision, $\bar{\theta}_t$.

Factors other than disagreements appear to be the driving force behind the empirical finding that better-quality firms spawn more spinoffs. There is, however, a very simple extension to the model that can overturn proposition 5. Assume that firm value is given by $v = -\zeta(\theta - x)^2$, where ζ is a parameter varying from firm to firm that measures the quality of the decision-making group, and assume that spinoffs inherit their parent's ζ. Then, individual i will choose to form a spinoff the first instance that $(\theta_{it} - \overline{\theta}_t) \geq k / \zeta$. That is, an increase in ζ acts just like a reduction in the entry-cost, which is positively-related to the spinoff hazard. Consequently, if ζ varies sufficiently across firms, the model would predict a positive relationship between firm quality and the spinoff hazard.

V. Discussion

Our model of spinoffs is based on the idea that disagreements naturally arise in the course of doing business, and under certain circumstances they will lead to spinoffs. The model is preliminary and rather abstract. Nonetheless, it already generates some distinctive predictions that resonate with prior findings, suggesting that this is a promising line of inquiry. First, the model predicts that the hazard rate of spinoffs initially rises with the age of the prospective parent firm, but eventually declines to zero. This accords with findings for autos (Klepper [2004]) and lasers (Klepper and Sleeper [2003]). Second, the model predicts that spinoffs are more likely in industries where there is considerable uncertainty about the target, which seems consistent with the prevalence of spinoffs in high-tech and younger industries (Garvin [1983]). Third, the model predicts that spinoffs have on average lower quality than their parents and this accords with some preliminary evidence for autos reported in this paper.

The model also predicts that spinoffs are more likely when there is a strongly hierarchical structure in decision-making, as measured by the Herfindahl index of concentration of decision-making authority, and that individuals with less decision-making influence will be more likely to start spinoffs. These last two results seem to be at the heart of why acquisitions increase the chance of spinoffs. They shift control of decision making to the acquirer. If the acquirer has a distinctive "culture" then managers of the incumbent firm will have little influence on the decisions of the acquirer, raising the prospect of a culture clash in which employees leave to pursue their ideas in their own firms. This seems consistent with Mitton's [1990] observations about how acquisitions of San Diego biotech firms by nonbiotech firms led to spinoffs.

Our model needs to be developed further to accommodate the full range of common patterns that we detailed about spinoffs. The model does not allow for heterogeneity across firms, hence it cannot address why better firms have more and better spinoffs. In fact, our model predicts that better firms have fewer spinoffs, while the relationship between parent and firm quality is ambiguous. We suspect the explanation lies in spinoffs inheriting an aspect of quality form their parents. We are undecided about whether this is because better firms are able to hire more able team members, some of whom subsequently form spinoffs, or whether employees of better firms are able to learn more. Perhaps both factors are in play, but at least one such mechanism needs to be built into the model.

We also need to draw out and test other distinctive implications of our model. One promising direction concerns the effect of spinoffs on industry performance. Most models of spinoffs suggest that spinoffs will harm their parents, which accords with Phillips' [2002] findings for Silicon Valley law firms. Our theory suggests a more benign view of spinoffs. Although on average they do worse than their parents, some spinoffs will inevitably do much better. Spinoffs therefore provide parents, and quite possibly the industry as a whole, the opportunity to observe the outcome of decisions that incumbents had chosen not to make. When such spillovers exist, all firms in the industry may learn much more quickly when spinoffs are prevalent. We suspect that this benign role of spinoffs may be quantitatively import (this seems to be the case for autos, where spinoffs played a major role in the development and diffusion of new technology), but this mechanism is absent from the model.

While there is much to do, our findings to date are encouraging about the model. We intend to structure the model further to accommodate the full range of findings about spinoffs and then use data from multiple industries to test its distinctive implications. If we want to sort out the welfare implications of spinoffs and appropriate public policies to deal with them, we will need to push all theories, including ours, much harder. Given how well spinoffs performed in the high-tech industries where they have been studied, the agenda seems well worth engaging.

Appendices

A. *Derivation of the distribution of spinoff quality relative to parent quality for k>0.*

Let

$$y_{it}=\frac{t\sigma_\theta^2\left[1+(\beta-1)(1-\phi_i)\right]\overline{s}_{it}}{(\beta+n-1)t\sigma_\theta^2+\beta\gamma\sigma_\varepsilon^2}, \tag{A.1}$$

and

$$y_{jt}=\frac{t\sigma_\theta^2\left[(n-1)+(\beta-1)(1-\phi_i)\right]}{(\beta+n-1)t\sigma_\theta^2+\beta\gamma\sigma_\varepsilon^2}\sum_{j\neq i}\overline{s}_{jt}\ . \tag{A.2}$$

Clearly, y_{it} and y_{jt} are independent and normally distributed. Using (A.1) and (A.2) in (5) and (7) yields

$$\left|\overline{\theta}_t-\theta_{it}\right|=\left|\frac{(\beta-1)(1-\phi_i)y_{jt}}{(n-1)+(\beta-1)(1-\phi_i)}-\frac{(\beta-1)(1-\phi_i)y_{it}}{1+(\beta-1)\phi_i}\right|. \tag{A.3}$$

Hence, i's departure requires that $y_{jt}\le a_-$ or $y_{jt}\ge a_+$, where

$$a_-=\left(\frac{(n-1)+(\beta-1)(1-\phi_i)}{1+(\beta-1)\phi_i}\right)y_{it}-\left(1+\frac{n-1}{(\beta-1)(1-\phi_i)}\right)\sqrt{k}$$

and

$$a_+=\left(\frac{(n-1)+(\beta-1)(1-\phi_i)}{1+(\beta-1)\phi_i}\right)y_{it}+\left(1+\frac{n-1}{(\beta-1)(1-\phi_i)}\right)\sqrt{k}\ .$$

We begin by conditioning on the unobserved θ. It is then easy to see that the expected difference in the values of parent and spinoff, conditional on i forming a spinoff, is

$$\mu(\theta)\equiv E\left[-\left(\theta-\overline{\theta}_t^2\right)+\left(\theta-\theta_{it}^2\right)\left\|\overline{\theta}_t-\theta_{it}\right|\ge\sqrt{k};\theta\right]=$$

$$\int_{-\infty}^{\infty}\left\{\left[1-\int_{a_-}^{a_+}d\Psi_j(y_{jt})\right]^{-1}\left[\int_{-\infty}^{a_-}h(y_{jt},y_{it};\theta)d\Psi_j(y_{jt})+\int_{a_+}^{\infty}h(y_{jt},y_{it};\theta)d\Psi_j(y_{jt})\right]\right\}d\Psi_i(y_{it}), \tag{A.4}$$

where

$$h(y_{jt},y_{it};\theta)=\left(\theta-(y_{jt}+y_{it})\right)^2-\left(\theta-\left(\frac{\beta y_{it}}{1+(\beta-1)\phi_i}+\frac{(n-1)y_{jt}}{(n-1)+(\beta-1)(1-\phi_i)}\right)\right)^2,$$

$$\Psi_i(y_{it})\equiv N\left(\theta\eta_t\left(1+(\beta-1)\phi_i\right),\frac{\eta_t^2\sigma_\varepsilon^2}{t}\left(1+(\beta-1)\phi_i\right)^2\right),$$

and

$$\Psi_j(y_{jt}) \equiv N\left(\theta\eta_t\left((n-1)+(\beta-1)(1-\phi_i)\right), \frac{\eta_t^2(n-1)\sigma_\varepsilon^2}{t}\left(1+\frac{(\beta-1)(1-\phi_i)}{n-1}\right)^2\right).$$

Finally, we take expectations over θ, giving

$$E\left[-\left(\theta-\bar{\theta}_t^2\right)+\left(\theta-\theta_{it}^2\right)\left\|\bar{\theta}_t-\theta_{it}\right|\geq\sqrt{k}\right]=\int_{-\infty}^{\infty}\mu(\theta)d\Psi(\theta), \tag{A.5}$$

where θ is normally distributed with zero mean and variance σ_θ^2. Equation (A.5) must be evaluated numerically. Figure 2 plots the results. The calculations were conducted using Derive™ 6, on a Dell Dimension 4600 with 512MB RAM. Numerical approximations were carried out with accuracy to 10 significant digits.

B. *Derivation of the spinoff hazard as a function of parent quality.*

We continue to focus on the probability that individual *i* chooses to form a spinoff at time *t*, and for ease of notation we assume that $\phi_j = (1-\phi_i)(1-n)^{-1}$ for all $j \neq i$. That is, we assume that the posteriors of all individuals except for *i* are weighted equally in arriving at the firm's decision.

Given a decision $\bar{\theta}_t$, the probability that *i* chooses to leave is given by

$$\Pr\left\{|z_{it}|>\sqrt{k}\right\}=1-\int_{a_t}^{b_t}dF\left(s_{it}\mid\bar{\theta}_t\right), \tag{B.1}$$

where the limits,

$$a_t=\frac{\bar{\theta}_t}{\eta_t(n+\beta-1)}-\frac{\sqrt{k}}{\eta_t(\beta-1)}\ , \quad b_t=\frac{\bar{\theta}_t}{\omega_t(n+\beta-1)}+\frac{\sqrt{k}}{\omega_t(\beta-1)}\ ,$$

with

$$\eta_t=\frac{(\beta-1)t\sigma_\theta^2}{(\beta+n-1)t\sigma_\theta^2+\beta\gamma\sigma_\varepsilon^2}\ ,$$

are obtained from a rearrangement of (8). By Bayes' rule, (B.1) can be written as

$$\Pr\left\{|z_{it}|>\sqrt{k}\right\}=1-\int_{a_t}^{b_t}\frac{\psi\left(s_{it}\mid\bar{\theta}_t\right)\psi\left(\bar{s}_{it}\right)}{\psi\left(\bar{\theta}_t\right)}ds_{it}\ . \tag{B.2}$$

where, as the notation in (B.1) suggests, the densities turn out all to be Gaussian. The first unconditional density, $\psi(s_{it})$, is normal with mean θ and variance σ_ε^2/t. The decision, $\bar{\theta}_t$, is the weighted sum of *n* independent normals. Hence, $\psi(\bar{\theta}_t)$ is a normal density with mean

$\left(\left(1+(\beta-1)(1-\phi_i)/(n-1)\right)(n-1)+\left(1+(\beta-1)\phi_i\right)\right)\eta_t\theta$ and variance $\left(\left(1+(\beta-1)(1-\phi_i)/(n-1)\right)^2(n-1)+\left(1+(\beta-1)\phi_i\right)^2\right)\eta_t^2\sigma_\varepsilon^2/t$. Finally, the conditional density, $\psi(\overline{\theta}_t \mid s_{it})$ is the convolution of n–1 independent normals evaluated at $\overline{\theta}_t = \sum_{j\neq i} s_{jt} - s_{it}$. It is therefore also a normal density function, with mean $\left(\left(1+(\beta-1)(1-\phi_i)/(n-1)\right)(n-1)+\left(1+(\beta-1)\phi_i\right)\right)\eta_t(\theta+s_{it})$ and variance $(n-1)\eta_t^2\sigma_\varepsilon^2 \ \left(1+(\beta-1)(1-\phi_i)/(n-1)\right)^2/t$. There is no closed-form expression for (B.2), which is evaluated numerically in Figure 5 for the cases $\phi_i < n^{-1}$ and $\phi_i > n^{-1}$.

A special analytical result exists for the symmetric case $\phi_i = n^{-1}$. In this case, (B.2) simplifies to

$$\Pr\left\{\left|z_{it}\right| > \sqrt{k}\right\} = 1-\operatorname{erf}(y),$$

where erf is the error function, $2\pi^{-0.5}\int_0^y e^{-v^2}dv$, and

$$y = \frac{\sqrt{n(n-1)k}}{\sqrt{2}(n-1)(\beta-1)}\left(\frac{\gamma\beta\sigma_\varepsilon}{\sigma_\theta^2\sqrt{t}}+\frac{(\beta+n-1)\sqrt{t}}{\sigma_\varepsilon}\right).$$

Neither $\overline{\theta}_t$ nor θ appear in the expression, so the hazard of a spinoff is independent of the quality of the parent.

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