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Entrepreneurial Spawning and Firm Characteristics

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We analyze the implications of the decision to spawn or to retain a new product for the nature and evolution of the firm. In our model, a new product is spawned if the fit between the product and its parent firm organization is not adequate. We focus on the impact of the firm's history of spawning decisions on firm characteristics such as size, focus, profitability, and innovativeness, and analyze its role in shaping firm dynamics. In accordance with the empirical literature, our model predicts that older firms innovate less, spawn less, are more diversified and less profitable, and that firms with more valuable general or specialized resources innovate and spawn more. Echoing seemingly contradictory empirical findings, our model predicts that small, focused firms (large, diversified firms) innovate and spawn more, and are more profitable when sample heterogeneity is driven by the importance of organizational fit (the value of general resources).

Key words: spawning; spinoffs; spinouts; general and specialized resources; firm organization; organizational fit; firm size; focus; profitability; innovativeness; spawning dynamics
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1. Introduction

Entrepreneurial spawning—the process whereby an existing firm gives birth to a new firm set up by one or more employees departed from the existing firm—is prevalent in many new industries.[1] It is well known, for example, that Fairchild Semiconductors has been the forebear of a great many Silicon Valley semiconductor firms, the "mother hen of the Northern California semiconductor industry" (Rogers 1985, p. 24). In his history of the genesis of Silicon Valley, Hall (1998, p. 437) writes that "about half of the eighty-five or so U.S. semiconductor companies of the 1980s were direct or indirect spin-offs from [Fairchild]."[2] Similar observations have been made of many industries: disk drives (Agarwal et al. 2004, Christensen 1993, Franco and Filson 2006), lasers (Klepper and Sleeper 2005, Sherer 2006), tires (Buenstorf and Klepper 2009), and automobiles (Klepper 2007).

When a new product—or an idea for a new product—is developed at a firm, the firm has the choice between spawning the product and retaining it. When the firm retains the product, it adds the product and the option to develop "follow-on" products to its portfolio of assets. It does not when it spawns the product. Every decision to spawn or retain a new product, therefore, alters the size and boundaries of the spawning firm, its scope, and its potential for developing follow-on products to the new product. The purpose of the present paper is to examine the implications of the spawning versus retention decision for the nature and evolution of the firm. Our main contribution is to provide a unified theoretical framework that is built on bargaining over each spawning versus retention decision and that views the firm as having been shaped by its history of such decisions. This perspective has not been developed in the literature. Five characteristics describe the firm: its frequency of spawning, its propensity to innovate, its size, its focus, and its profitability. These characteristics evolve over time and differ by firm age. Our analysis of firm characteristics and firm dynamics applies to established firms as much as it does to new firms created by spawning: as soon as a new firm starts developing new products of its own, it faces the same decision between spawning and retention as do more established firms;

[1] Entrepreneurial spawning is also referred to as "spinning off" or "spinning out."

[2] Hall (1998) cites Hanson (1982, p. 110), who observes that "[t]hroughout the sixties, bright young engineers spun out of Fairchild like so many enterprizing Minervas from the head of Zeus. New start-ups abounded: three new chip makers in 1966, another three in 1967, thirteen in 1968, eight more in 1969; their names a seemingly endless set of permutations on a few basic syllables—tech, tronic, inter, micro, ics, tron, etc."

these decisions determine the new firm's characteristics and how it evolves over time.

Spawning sees an employee start a new firm to bring a new product to market. Why does the employee not do so at the firm at which he originally developed the product? We follow Cassiman and Ueda (2006) in arguing that the employee starts a new firm when the new product does not fit the existing firm well. In this view, spawning is an efficient response to a lack of organizational fit, that is, to the inadequacy between existing firm organization and the requirements for the profitable management of the new product. Firm organization is a specialized resource of the firm; our analysis, therefore, can be viewed as drawing upon the resource-based view of the firm to derive the implications of spawning for firm characteristics.

In our model, every firm starts with a single product and two agents, an entrepreneur to exploit the product and a researcher to explore for new products.[3] Investment in exploration is endogenous; it is chosen and carried by the entrepreneur. When the researcher has developed a new product, entrepreneur and researcher engage in efficient Nash bargaining to decide whether to spawn the new product to a new firm or to retain the product within the existing firm. The researcher becomes the entrepreneur who sets up the new firm in the former case, he becomes a manager at the existing firm in the latter case. There is spawning to a new firm when the new product presents little fit with the organization of the existing firm. The benefit of spawning is the choice by the new firm of an organization better fitting the new product, its cost that of setting up the new firm.

Regardless of whether there is spawning or retention, every new product developed provides an opportunity to explore for further new products. Spawning sees this opportunity migrate with the new product to the new firm, retention sees it remain at the existing firm. The promise of follow-on product development potentially affects both the investment made in developing new products and the spawning versus retention decision. Two assumptions, discussed in more detail in §3, help keep our analysis tractable. First, the entrepreneur has no claim on the value of follow-on products when the researcher leaves the firm in disagreement. Second, the development of follow-on products proceeds along similar lines in both the existing firm and the new firm.

The development of follow-on products increases the number of products on the market; we account for the resulting increase in competition by way of a time-increasing "squeeze" on profits.

[3] We borrow the terminology "exploitation" and "exploration" from March (1991).

The first step in solving the model is to compute the threshold organizational fit: a new product whose fit with existing firm organization exceeds the threshold is retained within the firm, one whose fit does not is spawned to a new firm. The threshold fit determines the frequency of spawning; it directly affects the investment the firm makes in exploration, firm size, and firm focus; it indirectly affects firm profitability through firm focus. We analyze the sequence of spawning versus retention decisions and their consequences for firm characteristics. Ceteris paribus, a firm that spawns more grows more slowly, because it retains fewer new products that would otherwise contribute to the firm's organic growth. Spawning increases firm focus, because the spawning of lesser fitting products increases the average fit of products retained within the firm. As focus improves profitability, ceteris paribus, spawning increases firm profitability, too. The ceteris paribus qualification is important: spawning also increases a firm's incentive to invest in exploration, because spawning makes new products more profitable; more new products may increase firm size, despite the spawning of a larger fraction of these products. The relation between spawning and firm characteristics is therefore nontrivial.

Much of our analysis revolves around the distinction between general and specialized resources. The spawning versus retention decision is affected by the importance of specialized resources, but unaffected by the value of general resources. This is because the perfectly fitting organization that is the product of spawning is a specialized but not a general resource. Innovativeness increases in both the value of general resources and the importance of specialized resources. This is because both increase the profits to be had from—and the incentive to invest in—developing a new product. Size increases and focus decreases in the value of general resources, as more valuable general resources are made to bear on a larger, more disparate portfolio of products. In contrast, size generally decreases and focus increases in the importance of specialized resources, because a greater importance attached to specialization limits organizations to a small portfolio of related products.

As time proceeds and firms develop new products, firms grow in size, they lose focus, and they experience a decline in profitability.[4] Increased competition among more numerous products compounds the detrimental effect of decreased focus on profitability. Lower profitability discourages spawning, because it impedes the recovery of the fixed cost of setting up

[4] We measure profitability by average profit per product; this is a natural measure in our product-based setting. Average profit per product equals return on assets when investment per product is equal across products and normalized to one.

a new firm, carried only in case of spawning. The frequency of spawning therefore decreases over time, thereby decreasing the incentive to invest in innovation. We show that older firms spawn and innovate less and that they are larger, less focused, and less profitable. Hence, the equilibrium we characterize is a nonstationary equilibrium. We further show that, in case there is limited as opposed to infinite supply of agents, there is a slowdown in the dynamics of spawning and firm profitability, due to reduced investment by entrepreneurs in exploration.

The predictions of our model are generally consistent with the available empirical evidence, that of Franco and Filson (2006) and Gompers et al. (2005) in particular. These authors study empirically the relation of spawning with firm characteristics. Our model predicts and their findings confirm that older firms spawn less and that firms with more valuable resources (know-how, patents) spawn more. All of our predictions are induced by spawning, but some extend beyond spawning and may help shed new light on issues perhaps still controversial. Our central prediction is this: The spawning-induced relation between endogenous firm characteristics that are jointly determined by firm resources depends crucially on whether the relation is due primarily to general or specialized resources. Consider, for example, the relation between focus and profitability. Our work suggests that these two endogenous firm characteristics are positively related where the relation is due to organizational fit; they are negatively related where the relation is due to general resources for those firms that have highly valuable general resources. This may account for the somewhat mixed empirical evidence regarding the relation between focus/diversification and performance/value.[5]

This paper proceeds as follows. Section 2 reviews the literature and discusses resources and fit. Section 3 presents the model. Section 4 solves the model to derive the key elements of the analysis, specifically the threshold organizational fit and the investment in exploration. Section 5 examines the firm characteristics of interest and derives their comparative statics. Section 6 examines the dynamics of spawning over time and their implications for the evolution of firm characteristics; it further discusses an extension where we relax the assumption of an infinite supply of labor. Section 7 discusses supporting empirical evidence and derives a number of testable implications. Section 8 concludes.

[5] There is an extensive literature on the relation between diversification and performance, starting with the seminal work of Berger and Ofek (1995) and Lang and Stulz (1994). See, for example, Campa and Kedia (2002), Gertner et al. (1994), Graham et al. (2002), Maksimovic and Phillips (2002), Rajan et al. (2000), Schoar (2002), Villalonga (2004), and Whited (2001).

2. Literature Review

Our work naturally belongs to the extensive literature on spawning. It also builds on theories of firm resources, organization, and fit. We review these in turn.

Within the spawning literature, our paper is most closely related to Cassiman and Ueda (2006), whose focus on fit we adopt. Whereas Cassiman and Ueda's primary focus is on the spawning decision itself, we are interested in analyzing the consequences of that decision for the firm. Other prior work has attributed spawning to incentives and information considerations. Amador and Landier (2003) induce spawning by attributing greater contractual flexibility to external, venture capital financing than to internal financing. Anton and Yao (1995) make the decision to spawn revolve around the allocation of intellectual property rights. De Bettignies and Chemla (2008) analyze corporate venturing, a form of spawning that they ascribe to corporations' desire to retain "star" managers in a "competition for talent" with venture capitalists. Chatterjee and Rossi-Hansberg (2012) attribute spawning to the breakdown in trade that may occur under asymmetric information. Franco and Filson (2006) limit innovation to firms and employees to imitation; they introduce spawning by assuming that an employee who wishes to innovate has to start his own firm. Gromb and Scharfstein (2005) see spawning as serving to improve managerial incentives by increasing the penalty of failure, greater in a start-up than in an established firm. Hellmann (2007) analyzes the incentive effects of spawning in a setting in which an employee must choose between exerting effort on a core task and on another, innovative task. Klepper and Thompson (2010) explain the decision to spawn with disagreements between employer and employee. Sevilir (2010) views spawning as serving to improve employee incentive to innovate, by increasing employee default payoff in bargaining over the value of innovation. Although they do not consider spawning as such, Jovanovic and Nyarko (1995) and Mitchell (2000) attribute the limitations in firm scope that are cause and consequence of spawning to the greater cost of performing more diverse, less familiar tasks.

Organizational fit-based rationales for spawning such as ours posit that incumbents have limited ability or capacity to manage diverse projects. Such limitation has been viewed as being contradicted by the observations that (i) spawning often involves products that are central to spawning firms' missions and (ii) better-performing firms spawn more; the firms they spawn in turn perform better (Klepper and Thompson 2010). We note that there need be no contradiction between limited ability or capacity and centrality once one recognizes that organizational fit applies as much to market or process as to product. Consider, for example, Christensen's (1997) finding, noted by Cassiman and Ueda (2006, p. 271), that "two-thirds of the spin-offs in the hard disk drive industry entered new submarkets, which did not fit the established firms' existing customer base." An established hard disk drive manufacturer that had been presented the opportunity to develop a new disk drive for a new market segment might quite reasonably have concluded that it did not have the ability or capacity to service the new segment, despite disk drives being central to the manufacturer's mission. We establish the greater extent of spawning by better-performing firms in §5.

Gans (2011) analyzes the phenomenon of "reverse spawning," whereby an incumbent firm chooses to acquire an entrant that has developed a new product or, alternatively, to license the new product from the entrant. Gans focuses on dynamic innovation considerations, specifically the effect of acquisition or licensing on the probability of follow-on innovation. Our paper abstracts from dynamic innovation considerations.

As previously noted, our paper builds on theories of firm resources, organization, and fit, and on the resource-based view of the firm in particular.[6] The resource-based view attributes a firm's ability to create value to those resources and capabilities in the possession of the firm that have the twin properties of being scarce and imperfectly mobile. Resources are "firm-specific assets and factors of production, such as patents, brand-name reputation, installed base, and human assets;" distinctive capabilities are "activities that the firm does especially well in comparison to its competitors" (Besanko et al. 1996, p. 543). Scarcity and imperfect mobility create limits to competition that make it possible for the firm to earn the "supernormal" profits that reflect the creation of value.

As recognized by Penrose (1959) early on, resources differ in versatility: Some are quite general in that they can create value in a wide variety of uses, others are specialized to some uses but not to others.[7] An example of a general resource may be proficiency with the general purpose technologies (GPT) analyzed by Bresnahan and Trajtenberg (1996) and Jovanovic and Rousseau (2005).[8] The value of general resources will be denoted α in our model.

An example of a specialized resource is firm organization, defined by Roberts (2004, p. 16) to be "the means through which [firm] activities are to be carried out and [firm] strategy is to be implemented."[9] That firm organization is specialized to specific tasks and environments has long been recognized by management scholars. Referring to Chandler's (1962) seminal work, Besanko et al. (1996, pp. 687–688) write that "the organizational structures of large vertically and horizontally integrated firms developed in response to the strategic choices their managers made. These choices, in turn, developed as the firm's managers responded to changes in its market and technological environment." More recently, Roberts (2004, p. 11) writes that "there needs to be a fit between strategy and organization and between those and the technological, legal, and competitive environment." The preceding statements make clear the specialized nature of firm organization: specific tasks and environments call for specific organizations; specific organizations are suited only to specific tasks in specific environments. How suitable a given organization is for a given task in a given environment defines organizational fit. Firm organization will be denoted o in our model; organizational fit will be denoted ω.

Henderson and Clark (1990) provide empirical evidence in support of the importance of organizational fit: in a study of the photolithographic alignment equipment industry, they find that leading firms were unable to accommodate "architectural innovations," that is, "innovations that change the way in which the components of a product are linked together" (Henderson and Clark, p. 10). They ascribe their finding to leading firms' handicap due to "a legacy of [organization-] embedded and *partially irrelevant* architectural knowledge" (Henderson and Clark, p. 18, emphasis added).[10] In the terminology of the present work, fit—or the lack thereof—between product and organization proved to be of the utmost importance for those new products that incorporated

[6] The resource-based view of the firm can be said to have originated with Penrose's (1959) seminal analysis; it has been further developed by Wernerfelt (1984), Dierickx and Cool (1989), Barney (1991), and Peteraf (1993), among others.

[7] Penrose (1995, p. 54) writes, "[l]et us imagine [that] productive services are A, B, C, D, E, F, and G. F and G may be useful only in a particular firm; C, D, and E only to a particular group of firms, B only in manufacturing industry, while A may be of such general character that it would be useful in any type of productive activity." Penrose distinguishes between resources and the services that resources can render. This is a distinction that the later, more recent literature has not maintained.

[8] Jovanovic and Rousseau (2005, p. 1184) define GPT as "changes that transform both household life and the ways in which firms conduct business." They identify only two such technologies: electricity and information technology.

[9] An organization comprises people, an architecture, routines, and a culture (Roberts 2004, p. 17).

[10] Henderson and Clark's (1990) finding suggests that a firm cannot simply "shake off" the legacy embedded in its organization. Evidence that organizational choice is to a large extent irreversible is provided by Carroll and Hannan (2000) and Jovanovic and Rousseau (2001): the organization chosen at birth is imprinted into the firm; corporate inertia makes subsequent organizational change extremely difficult.

architectural innovations relative to existing products. The importance of organizational fit will be denoted β in our model.

3. The Model

Our model has three main components: firms, products, and agents. Time evolves in discrete fashion from date 0 onward. At date 0, one agent is endowed with one product and creates an initial firm. As we explain below, the initial firm spawns more firms, which in turn spawn yet more firms.

A firm f is an organization that exploits existing products and explores for new products. Exploitation generates profit, whereas exploration generates new products, which are in turn exploited to generate profit. The firm's organization is represented by a point on the real line. Each product is also represented by a point on the real line. Setting up a new firm costs $\kappa \in \mathbb{R}^+$.

The firm initially consists of a single product, $\theta_f \in \mathbb{R}$, and two agents: an entrepreneur, E, and a researcher, R, whom E employs. The entrepreneur E chooses firm f's organization, $o_f \in \mathbb{R}$, at the date, t_f, at which E creates the firm. That choice is irreversible.[11] The entrepreneur E then exploits product θ_f. The researcher R seeks to develop new products. Once R has succeeded in developing a new product, $\theta_i \in \mathbb{R}$, R abandons exploration for exploitation: a researcher is indispensable to the exploitation of the product he has developed; no agent simultaneously can engage in exploitation and exploration.

Every new product provides new opportunities for further exploration and hence future profit. When a new product is developed, two new researchers must be employed. A first researcher, R', performs at firm f the exploration task previously performed by former researcher R. A second researcher, R'', pursues the new opportunity for exploration presented by the successful development of the new product. The process then repeats itself. There is an infinite supply of homogeneous agents.[12] With the exception of the first agent at date 0, agents begin as researchers employed by entrepreneurs to explore for new products. Once an agent has developed a new product, the agent exploits that product forever.

The entrepreneur E selects in each period the investment to be made in exploration that determines the arrival rate of new products; E bears the cost of exploration in his capacity as owner of the firm. We denote E's cost of exploration in period $t > t_f$ by $c(q_t)$, where q_t denotes the probability that researcher R develops a new product in the same period. We assume the following:

$$c(q_t) = \tfrac{1}{2} q_t^2. \tag{1}$$

Firm f's organization, o_f, plays a pivotal role in our analysis. It determines both the location in $\mathbb{R}$ of the new product θ_i born of exploration at firm f and the profit to be had from exploiting that product. The former determination is direct, the latter indirect through the fit between firm organization and the new product. The distribution of θ_i is centered at o_f: $\theta_i \sim U[o_f - \delta, o_f + \delta]$, where $\delta \in \mathbb{R}^+$.[13] Organizational fit, $\omega_i \in [0, 1]$, is defined to be the complement of the normalized distance between organization, o_f, and product, θ_i: $\omega_i \equiv 1 - |(\theta_i - o_f)/\delta|$.[14] Exploiting product θ_i generates a perpetual, per-period profit flow:

$$\pi_{i,\tau} = (\alpha + \beta\omega_i) s_\tau, \tag{2}$$

where $\tau \in (t, +\infty)$. The parameter $\alpha \in \mathbb{R}^+$ denotes the value of general resources, the parameter $\beta \in \mathbb{R}^+$ the importance of organizational fit, ω_i; the product $\beta\omega_i$, therefore, can be viewed as denoting the value of the firm's specialized resources. The time-varying parameter s_τ denotes the effect of product market competition on per-period profit. We assume that (i) α and β are scaled so that $s_0 = 1$, (ii) $s_\tau \in [0; 1]$ for all $\tau > 0$, and (iii) $\partial s_\tau / \partial \tau \le 0$ for all $\tau \ge 0$.[15] As time passes and new products are developed, the number of products on the market increases, product market competition increases and profits decrease. Cash flows are discounted at the rate $\rho \in \mathbb{R}^+$.

The new product θ_i that researcher R developed while employed at firm f need not be exploited at firm f. It can instead be exploited at a new firm, f^+, created specifically for that purpose. The new product is then spawned from firm f to firm f^+, which is assumed to inherit firm f's value of general resources, α, importance of fit, β, and cost of exploration, $c(q_t)$ in (1).[16] The inheritance of $c(q_t)$ and the centering of new product distribution on firm organization combine to make new product development proceed along similar lines in both f and f^+.

[11] Carroll and Hannan (2000) and Jovanovic and Rousseau (2001) argue that organizational imprint and structural inertia preclude changes to firm organization.

[12] Section 6.3 considers the case of a limited supply of agents.

[13] Garicano and Rossi-Hansberg (2012) analyze the importance of firm organization for innovation.

[14] Fit is maximal, $\omega_i = 1$, where product and organization coincide, $\theta_i = o_f$; fit is minimal, $\omega_i = 0$, where the product is most peripheral, $\theta_i = o_f \pm \delta$.

[15] We impose no further restrictions on s_τ, which we take to be exogenous. Note that the time index τ is industry but not product specific: it measures the passing of time since the beginning of the industry at date 0.

[16] Agarwal et al. (2004) provide strong evidence of inheritance by spawned from spawning firms.

The advantage of ceding the exploitation of the new product to the new firm is that the firm can choose organization, o_{f^+}, perfectly fitting the product: $o_{f^+} = \theta_i$. This increases per-period profit in (2), from $(\alpha+\beta\omega_i)s_\tau$ to $(\alpha+\beta)s_\tau$.[17] The disadvantage of spawning is that it involves incurring the cost κ of setting up the new firm. There is therefore a trade-off between fit and setup cost, the former favoring spawning, the latter retention. As shown below, there is a threshold fit, ω_t^*, at which the opposing effects of fit and setup cost exactly offset each other and exploitation profits are identical under spawning and retention. The threshold fit is such that a new product that presents a lesser fit with firm organization, $\omega_i \in [0; \omega_t^*)$, is spawned to the new firm f^+, whereas a product that presents a greater fit, $\omega_i \in [\omega_t^*; 1]$, is retained within the original firm f.

Regardless of whether the new product θ_i is spawned or retained, researcher R abandons exploration for exploitation. Researcher R becomes a manager, M, of firm f in case there is retention; he becomes an entrepreneur in his own right, E^+, in case there is spawning of the new product to the new firm f^+. Researcher R' performs at firm f the exploration task previously performed by former researcher R. Researcher R'' pursues the new opportunity for exploration presented by the new product; he is employed by firm f in case there has been retention, by firm f^+ in case there has been spawning.

When the researcher R has developed a new product θ_i, R bargains with the entrepreneur E over the value created by the new product. We assume that bargaining is costless and that it is conducted under symmetric information. We denote by $\gamma \in [0,1]$ the researcher's bargaining power and consider the generalized Nash bargaining solution. We assume that if bargaining ends in disagreement then (i) neither E nor R can exploit the new product, (ii) R can walk away from the firm and arrange for the new product's follow-on products to be developed outside the firm, and (iii) E's payoff from follow-on products is zero in this case. These assumptions reflect (i) the notion that both entrepreneur and researcher are essential for the exploitation of the new product, (ii) the option for the innovating researcher to sell his ideas for follow-on products in the "market for ideas" (Gans and Stern 2003), and (iii) the difficulty for the entrepreneur to enforce a claim on products with a tangible history that lies entirely outside his firm, because of the limited reach of intellectual property rights (Anton and Yao 1995).

[17] We abstract from strategic product market interactions between original and new firm. Gans and Stern (2003) analyze these firms' decision to cooperate or to compete.

We impose two parameter restrictions: (PR1) $\lim_{t\to\infty} s_t > \kappa\rho/\beta$ and (PR2) $\alpha+\beta \le \rho$. The first restriction ensures that the threshold fit, ω_t^*, exceeds zero. The second restriction ensures that the probability of developing a new product, q_t, does not exceed one.

The sequence of events is as follows. We divide period t, $t > t_f$ into two subperiods, starting at dates t and $t+\epsilon$, respectively. At date t, entrepreneur E of firm f incurs the cost $c(q_t)$ of exploration by researcher R. At date $t+\epsilon$, R develops a new product θ_i with probability q_t; R abandons exploration for exploitation in this case. The new product is spawned or is retained. If the product is spawned to a new firm f^+, the former researcher becomes entrepreneur, $R \to E^+$. If the product remains within firm f, the former researcher becomes manager, $R \to M$. In either case, there are two new researchers, R' and R'', the former employed by firm f and the latter by firm f^+ if there has been spawning and f if there has been retention.

4. Solution

Suppose researcher R employed by entrepreneur E of firm f has developed a new product θ_i at date $t+\epsilon$. The value created by the new product has two components, that of exploiting the new product and that of exploring for the new product's follow-on products. Researcher R and entrepreneur E bargain costlessly and under symmetric information over whether to spawn or to retain the new product and how to divide the value the new product creates. The disagreement payoff from exploiting the new product is zero for both parties. The disagreement payoff from the new product's follow-on products is zero for E.

We characterize the threshold fit ω_t^* that describes the spawning versus retention decision, and the probability of successful exploration q_t. We show in the appendix that ω_t^* equates the value of exploiting the new product under spawning and retention. Both the threshold fit ω_t^* and the probability of successful exploration q_t do not depend on the value of exploring for the new product's follow-on products. This last feature of the equilibrium follows from two implications of our assumptions.

First, the value of exploring for follow-on products is the same whether there is spawning or retention. This is a consequence of the assumption that the development of follow-on products proceeds along similar lines in both an existing firm and a new firm. Second, since that value is the same under spawning and retention, it follows that E receives nothing of the value of exploring for the new product's follow-on products, even when R remains at the firm. That is, even if E can legally enforce a claim on the value of exploring for follow-on products in case exploration is conducted within the firm, efficient bargaining dictates that E relinquish any such claim, since R has the outside option of leaving and realizing the disagreement payoff that leaves nothing to E. Thus, in the efficient bargaining outcome, only the value created by the exploitation of the new product is shared between the two parties.

Formally, we have the following:

Lemma 1. *The threshold fit in period t equals the following*:

$$\omega_t^* = 1 - \frac{\rho\kappa}{\beta s_t^e}, \tag{3}$$

where

$$s_t^e \equiv \sum_{\tau=t+1}^{\infty} \frac{\rho s_\tau}{(1+\rho)^{\tau-t}}. \tag{4}$$

A new product θ_i with fit ω_i is spawned to a new firm if $\omega_i < \omega_t^*$; it is retained within the existing firm otherwise.

The factor s_t^e is a "per-period equivalent" of the effect of competition over the life of the product.[18] We note that parameter restriction (PR1) in §3 ensures $\omega_t^* > 0$: there can always be spawning.

We then calculate the probability of successful exploration, q_t. We show the proof in the appendix.

Lemma 2. *The probability of successful exploration in period t equals the following*:

$$q_t = \frac{(1-\gamma)s_t^e}{\rho}\left[\alpha + \beta\left(\frac{1+\omega_t^{*2}}{2}\right)\right]. \tag{5}$$

We note that parameter restriction (PR2) ensures $q_t \leq 1$. The results of Lemmas 1 and 2 together make tractable the derivation of firm characteristics in §5.

5. Firm Characteristics

In this section, we consider a number of firm characteristics such as the frequency of spawning, the probability of successful exploration, size, focus, and profitability. We then derive their comparative statics. The results of Propositions 1–5 are summarized in Table 1.

5.1. Frequency of Spawning

The frequency of spawning is identical to the threshold fit ω_t^* in (3); this is immediate from the observation that a new product θ_i has fit ω_i uniformly distributed over the unit interval, $[0, 1]$, and that spawning occurs if $\omega_i < \omega_t^*$. We have the following:

Proposition 1. *The frequency of spawning decreases in the setup cost κ; it increases in the importance of fit β; it is unaffected by the value of general resources α and the bargaining power of the agent γ.*

[18] The properties of s_τ in §3 imply $s_t^e \in [0; 1]$ and $\partial s_t^e/\partial t \leq 0$ for all $t \geq 0$.

Table 1 Comparative Statics

	Spawning frequency ω_t^*	Innovativeness q_t	Firm size $\mathbb{E}[l_t]$	Firm focus $\mathbb{E}[\bar{\omega}_t]$	Profitability $\mathbb{E}[\pi_t]$
α	0	+	+	−	−/+[a]
β	+	+	−[b]	+[b]	+[b]
κ	−	−	+	−	−
γ	0	−	−	+	+

[a] There exists α^* such that − if $\alpha < \alpha^*$ and + if $\alpha > \alpha^*$.
[b] If $\alpha/\beta > 1/4$.

The results are intuitive. A higher setup cost decreases the attractiveness of spawning, for it is incurred only in case of spawning. The attractiveness of spawning naturally increases in the importance of fit, for only in case of spawning can there be perfect fit between firm organization and new product. The value of general resources does not affect the attractiveness of spawning, for general resources have no differential effect on the value of the product spawned or retained. The same holds true of the bargaining power of the agent.

5.2. Innovativeness

We refer to the probability of successful exploration, q_t in (5), as innovativeness. Because there is a monotone relationship between q_t and cost $c(q_t)$, the results of Proposition 2 below can alternatively be interpreted as referring to R&D expenditure, $c(q_t)$—typically an observable variable. We have the following:

Proposition 2. *Innovativeness increases in the value of general resources α and the importance of fit β; it decreases in the bargaining power of the agent γ and the setup cost κ.*

Innovativeness naturally increases in the value of general resources and the importance of fit: the more profitable is a new product, the more is invested in exploration, the larger is the probability of developing a new product. Note that there are two effects of the importance of fit on innovativeness: a direct effect apparent in (5) and an indirect effect through the threshold fit, ω_t^*. These two effects combine to increase innovativeness; the indirect effect does so by increasing spawning, which increases the profitability of a new product through perfect fit.

The setup cost has only an indirect effect on innovativeness: increased setup cost decreases the threshold fit; it thereby decreases spawning and precludes perfect fit; imperfect fit decreases new product profitability, investment in exploration, and innovativeness.

In contrast, the bargaining power of the agent has only a direct effect on innovativeness. In a model such as ours where investment in exploration is decided upon by the principal, the lesser payoff to the principal that is a consequence of increased agent bargaining power decreases the principal's incentive to invest in exploration; it thereby decreases innovativeness.

5.3. Firm Size

Denote by $\mathcal{I}_t$ the portfolio of products exploited by firm f at date t; these are the products developed by the firm in periods τ, $t_f+1 \le \tau < t$, which the firm chose to retain rather than to spawn.[19] Denote by $I_t \equiv |\mathcal{I}_t|$ the number of products in $\mathcal{I}_t$ and let I_t proxy firm size. Firm size starts at 1, as the firm is born with a single product. Associated with each of the firm's products is an opportunity for exploration, which succeeds at the development of a new product with probability q_τ; the new product is retained by the firm with probability $1-\omega_\tau^*$. Aggregating products developed and retained by the firm over time, the expected size of firm f at date t equals the following:

$$\mathbb{E}[I_t] = \prod_{\tau=t_f+1}^{t-1} (1+q_\tau(1-\omega_\tau^*)). \tag{6}$$

We have the following:

Proposition 3. *Firm size increases in the value of general resources α and in the setup cost κ; it decreases in the importance of fit β if $\beta < 4\alpha$, and in the bargaining power of the agent γ.*

The greater innovativeness due to more valuable general resources ($dq_t/d\alpha > 0$) increases firm size ($d\,\mathbb{E}[I_t]/d\alpha > 0$): more new products developed means more new products retained when spawning frequency remains unchanged ($d\omega_t^*/d\alpha = 0$); more new products retained to be exploited in turn means larger size. What is true of the value of general resources is not necessarily true of the importance of fit: the increase in spawning frequency due to more important fit ($d\omega_t^*/d\beta > 0$) may offset the concurrent increase in innovativeness ($dq_t/d\beta > 0$); the net effect is indeterminate. We find that the former effect dominates and that size decreases in the importance of fit ($d\,\mathbb{E}[I_t]/d\beta < 0$) when the condition $\alpha/\beta > \omega_t^*(1-\omega_t^*)$ holds. The marginal effect of an increase in the importance of fit ($-q_t d\omega_t^*/d\beta < 0$) then dominates the inframarginal effect ($(1-\omega_t^*)dq_t/d\beta > 0$). The product $\omega_t^*(1-\omega_t^*)$ is small for firms for which ω_t^* is large (firms in young industries with few products and little competition, that is, with large s_t^e) and for firms for which ω_t^* is small (firms in old industries with many products and much competition, that is, with small s_t^e). The product $\omega_t^*(1-\omega_t^*)$ reaches its maximum at $\omega_t^* = 1/2$. A sufficient condition for size to decrease in fit ($d\,\mathbb{E}[I_t]/d\beta < 0$) is, therefore, that $\beta < 4\alpha$, that is, that the importance of fit not be "too large" relative to the value of general resources.

The opposing effects of decreased spawning frequency ($d\omega_t^*/d\kappa < 0$) and decreased innovativeness ($dq_t/d\kappa < 0$) also apply in the case of increased setup cost, but the former effect always dominates in such case: the setup cost has a greater effect on spawning frequency than on innovativeness in our model; size increases in setup costs ($d\,\mathbb{E}[I_t]/d\kappa > 0$). This result is no doubt model specific; that it is quite intuitive—firms are larger if setting up new firms is costlier—suggests the model is well specified.

Agent bargaining power has a similar but opposite effect to the value of general resources: greater agent bargaining power decreases innovativeness ($dq_t/d\gamma < 0$), lower innovativeness decreases firm size if spawning frequency is unchanged ($d\omega_t^*/d\gamma = 0$); size decreases in agent bargaining power ($d\,\mathbb{E}[I_t]/d\gamma < 0$).

5.4. Firm Focus

The next firm characteristic is firm f's focus at date t, that is, the similarity or diversity of the products in the firm's portfolio at that date. A natural measure of focus is the average distance between the firm's organization, o_f, and the products exploited by the firm at date t: the smaller is that distance, the more focused is the firm. As organizational fit is the complement of the normalized distance between product and organization (see §3), focus is then the average fit between firm f's organization and the products in its portfolio, $\mathcal{I}_t$,

$$\bar{\omega}_t \equiv I_t^{-1} \sum_{i\in\mathcal{I}_t} \omega_i. \tag{7}$$

The larger is average fit, the more focused is the firm. Firm focus equals 1 at birth, as the single product with which the firm is born determines the firm's organization, $o_f = \theta_f$.

We leave the expression for expected firm focus, $\mathbb{E}[\bar{\omega}_t]$, to the proof of Proposition 4 in the appendix, for that expression is made markedly more complicated than the expression for expected firm size in (6) by the need to account not only for the number of innovations retained by the firm at date t but also for the specific periods in which these innovations occurred: innovations that occurred and were retained during different periods present different fits with firm organization because of changing threshold fits. We have the following:

Proposition 4. *Firm focus decreases in the value of general resources α and the setup cost κ; it increases in the importance of fit β if $\beta < 4\alpha$, and in the bargaining power of the agent γ.*

Focus decreases in the value of general resources ($d\,\mathbb{E}[\bar{\omega}_t]/d\alpha < 0$), a consequence of increased innovativeness ($dq_t/d\alpha > 0$): the new products developed

[19] Firm f's portfolio of products at date t clearly depends on t_f as well as on t. We consider a fixed t_f and reflect only the dependence on t for notational simplicity.

by a firm generically differ from that firm's organization; more new products imply greater difference, that is, less focus. Increased innovativeness ($dq_t/d\beta > 0$) is offset by increased spawning frequency ($d\omega_t^*/d\beta > 0$) in the case of an increase in the importance of fit if, as for size and for the same reason, α is not "too small" and β consequently not "too large," $\beta < 4\alpha$; focus increases in the importance of fit in such case ($d\mathbb{E}[\bar{\omega}_t]/d\beta > 0$). The dominant effect of spawning frequency extends to the case of the setup cost: focus decreases in setup costs ($d\mathbb{E}[\bar{\omega}_t]/d\kappa < 0$), a consequence of decreased spawning frequency ($d\omega_t^*/d\kappa < 0$). As was the case for firm size, agent bargaining power has a similar but opposite effect to the value of general resources: focus increases in agent bargaining power ($d\mathbb{E}[\bar{\omega}_t]/d\gamma > 0$), a consequence of decreased innovativeness ($dq_t/d\gamma < 0$).

5.5. Profitability

Our measure of firm f's profitability at date t is the average profit per product exploited by the firm at that date. The expected profitability of firm f at date t equals the following:

$$\mathbb{E}[\pi_t] \equiv \mathbb{E}\left[\sum_{i\in\mathcal{I}_t} \pi_{i,t}\, I_t^{-1}\right] = (\alpha + \beta\,\mathbb{E}[\bar{\omega}_t])s_t. \qquad (8)$$

Profitability equals $\alpha + \beta$ at birth, as focus then equals 1 and $s_0 = 1$. We have the following:

Proposition 5. *Profitability increases in the importance of fit β if $\beta < 4\alpha$ and in the bargaining power of the agent γ; it decreases in the setup cost κ; profitability may increase or decrease in the value of general resources α.*

Changes in profitability due to changes in the bargaining power of the agent and to the setup cost are due entirely to the effects of these variables on firm focus: profitability increases in the bargaining power of the agent because focus increases in this variable; profitability decreases in the setup cost because focus decreases. Changes in profitability due to changes in the importance of fit have two effects: an indirect effect through focus and a direct effect apparent in (8). Where focus increases in the importance of fit, both effects combine to increase profitability in response to an increase in the importance of fit. In contrast, the indirect effect of the value of general resources through focus counters its direct effect: focus decreases in the value of general resources but the first term inside the parentheses in (8) increases; the net result is indeterminate.[20]

[20] We show in the appendix that profitability increases in the value of general resources, α, for α greater than some minimum value α^*: $d\mathbb{E}[\pi_t]/d\alpha > 0$ for $\alpha > \alpha^*$. This is because the direct effect is linear whereas the indirect effect through focus is or eventually becomes concave.

6. Evolution of Firm Characteristics

We now examine the evolution of firm characteristics over time. We note that an increase in firm age, $t - t_f$, has the same effect on firm characteristics as does an increase in industry age, t.[21] This is because we consider a fixed t_f. We first consider the case where there is no product market competition: $s_\tau = 1$ for all $\tau \geq 0$. Our purpose in doing so is to show that firm size, focus, and profitability evolve over time despite the constancy of all model parameters: the mere passage of time is enough to alter firm characteristics. We then consider the case of product market competition. We derive the resulting spawning dynamics and examine their implications for the evolution of firm characteristics.

6.1. No Product Market Competition

The constancy of s_τ over time clearly implies those of the threshold fit, ω_t^*, and innovativeness, q_t; this is immediate from Equations (3) and (5), respectively. Proposition 6 shows that firm size ($\mathbb{E}[I_t]$), focus ($\mathbb{E}[\bar{\omega}_t]$), and profitability ($\mathbb{E}[\pi_t]$) nonetheless evolve with age.

Proposition 6. *Firm size increases in age, whereas firm focus and profitability decrease.*

Size increases in age as the firm adds new products to the single product with which it was born; focus decreases as innovations accumulate that are generically different from firm organizational form. The decrease of profitability in age is entirely attributable to the decrease of focus in age.[22] In short, older firms' larger and more disparate product portfolios decrease firm focus and profitability and increase firm size.

The result in Proposition 6 that firm profitability decreases in firm age even as all parameters are constant can be interpreted as such: older firms' lower profitability need not imply a decline in the value of these firms' resources due to some aging process (Loderer and Waelchli 2009); it may simply reflect these firms' application of their constantly valuable resources to a larger, more disparate portfolio of products.

6.2. Product Market Competition

We now consider the more natural case of product market competition. We have the following:

Proposition 7. *When there is product market competition, the frequency of spawning and innovativeness decrease in age, as do firm focus and profitability; firm size increases in age.*

[21] Industry age is t because the initial firm was founded at date 0; firm age is $t - t_f$ because firm f was founded at date t_f.

[22] Unlike profitability, total profits increase in age, a direct consequence of increasing firm size. This result does not necessarily extend from the present case of no product market competition to that of product market competition: the negative effect of competition on profits may offset the positive effect of size.

As time elapses and product market competition increases, the attractiveness of spawning decreases because the lower profits due to greater product market competition impede the recovery of the setup cost carried only in case of spawning. Innovativeness, too, decreases over time, as the decreasing profitability of new products discourages investment in exploration.[23] Note from Equation (5) that there are two effects of product market competition on innovativeness: a direct effect as well as an indirect effect through spawning frequency; less frequent spawning implies the less frequent attainment of the perfect fit at which profits are maximized.

Proposition 7 reproduces the Gompers et al. (2005) finding that spawning decreases in firm age: older firms tend to be active in more mature, less profitable industries (Loderer et al. 2010); these firms devise fewer innovations, of which a smaller fraction is spawned; the combined effect is to decrease spawning by older firms.[24]

6.3. Limited Supply of Researchers

Our analysis has thus far assumed an infinite supply of researchers. We now consider the case where the supply of researchers is limited.[25] With limited researcher supply, increased demand for researchers over time eventually creates competition for researchers. This strengthens their bargaining position.

We represent researchers' increasingly stronger bargaining position by making their previously constant bargaining power γ a nondecreasing function of time, γ_t. Competition among researchers may initially keep researcher bargaining power at its minimum value γ, in which case the dynamics are the same as in the case of infinite researcher supply, but as supply limits manifest themselves, γ_t weakly increases over time.

The primary effect of limited researcher supply is a decrease in innovativeness q_t. An increase in researchers' bargaining power γ_t implies that entrepreneurs capture a reduced share of the value of exploiting the new products born of exploration. This decreases their incentives to invest in exploration, thereby reducing q_t.[26]

The decrease in q_t causes a generalized slowdown in firm dynamics. It is still the case that, as in §§6.1 and 6.2, size increases and focus and profitability decrease over time, but they do so more slowly than under infinite researcher supply: firms that develop fewer new products grow and diversify more slowly and experience a slower decline in profitability.[27]

7. Empirical Evidence and Testable Implications

We discuss some supporting empirical evidence and derive a number of testable implications. We first examine the relations between the endogenous variables that are spawning, focus, and profitability and the exogenous variables that are age, setup costs, the value of general resources, and the importance of fit. We start with firm age, $t - t_f$. Gompers et al. (2005) find that older firms spawn fewer new firms, Denis et al. (1997) find that older firms are more diversified, and Loderer and Waelchli (2009) find that they are less profitable. As noted in §§6.1 and 6.2, all three findings are consistent with the predictions of our model.

Gompers et al. (2005) find that firms that have higher patent quality spawn more. Franco and Filson (2006) find that firms that have higher know-how spawn more. These two findings are consistent with the predictions of our model, regardless of whether patent quality and know-how are viewed as being primarily in the nature of general resources, α, or in that of fit, β: the extent of spawning is the product $q_t\omega_t^*$; we know q_t to be increasing in α and β and ω_t^* to be increasing in β.[28]

We now turn to examining the relations among the various endogenous variables that are spawning, size, focus, innovativeness, and profitability. The nature of theses relations depends crucially on the specific exogenous variable that is varied. Consider, for example, the relation between spawning and focus. Initially consider the case where $d\mathbb{E}[I_t]/d\beta < 0$ and $d\mathbb{E}[\bar{\omega}_t]/d\beta > 0$.[29] From the results in §5 that spawning frequency (ω_t^*) and innovativeness (q_t) increase in the importance of fit (β), we conclude that more focused firms spawn more if cross-sectional variation in a sample is dominated by differences in the importance

[23] Product market competition thus disrupts what may be described as the steady state—in spawning and in innovativeness—of §6.1.

[24] Gompers et al. (2005) caution that their measure of firm age is noisy.

[25] Firms in a given industry may face a limit in the supply of researchers because of other industries' competing demands for researchers.

[26] Recall from Proposition 2 that $\partial q_t/\partial\gamma < 0$ with infinite researcher supply and note that $\gamma_t \geq \gamma$ for all t with limited researcher supply.

[27] See the proofs of Propositions 6 and 7 with infinite researcher supply and note that, in addition to $\gamma_t \geq \gamma$, $\gamma_t - \gamma_{t-1} \geq 0$ for all t with limited researcher supply and q_t smaller than with infinite researcher supply.

[28] An obvious question is how to measure empirically the value of general resources and the importance of fit. An example of a proxy for (mostly) general resources is the Gompers et al. (2005) citation-based value of patents; fit on the other hand could, for example, be proxied by the Brynjolfsson et al. (2002) measure of organizational capital.

[29] As stated in §5, this case is likely to arise when the industry is young or old, or when the importance of fit is not too large relative to the value of general resources.

of fit. If, however, $d\mathbb{E}[\bar{\omega}_t]/d\beta < 0$, or if sample variation is driven by heterogeneity in the value of general resources (α), then firms that spawn more should have less focus.[30] Thus, empirical tests that examine the relation between spawning and focus may find contrasting results, depending on whether sample heterogeneity is driven primarily by the importance of fit or the value of general resources and, in the former case, depending on the maturity of the industry or the relative importance of fit and general resources.[31]

Our model predicts the following. If sample heterogeneity is driven primarily by the importance of fit, smaller, more innovative, and more focused firms spawn more and are more profitable when the importance of fit is not too large relative to the value of general resources. If the driving force of heterogeneity is the value of general resources and profitability increases in that value, larger, more diversified firms innovate and spawn more and are more profitable. If profitability decreases in the value of general resources, larger, more diversified firms innovate and spawn more but are less profitable. These predictions suggest that observed correlations between firm characteristics such as spawning frequency and focus can be used to infer whether sample heterogeneity is driven primarily by the value of general resources or by the importance of specialized resources.

The predictions may also help reconcile otherwise contradictory empirical evidence. Consider, for example, the relation between size and profitability or, more generally, value. Recent studies document a negative relation between these two endogenous variables.[32] Yet, this has not always been so: Hall and Weiss (1967) document a positive such relation for the time period 1956–1962. The distinction between the value of general resources and the importance of fit may help reconcile these contrasting results, if profitability increases in the value of general resources and if size decreases and focus increases in the importance of fit: it is conceivable that the relation between size and profitability was driven in earlier periods primarily by the value of general resources; the importance of fit may have become of primary importance only later, accounting for the reversal of the relation.

The same distinction may help account for the contrasting evidence regarding the relation between focus and profitability or value. Most studies have documented a positive relation, but a few have documented a negative relation. In particular, an argument has been made that related diversification creates value.[33] Suppose that the decision to remain focused is driven primarily by the importance of fit, that to diversify by the value of general resources. Both resources and fit increase profitability if profitability increases in the value of general resources, but general resources decrease focus whereas fit keeps focus high where the importance of fit is not too large relative to the value of general resources. The relation between focus and profitability is therefore positive where driven by the importance of fit, negative where driven by the value of general resources. To the extent that there are few truly general resources, and that a diversifying firm's resources may be more directly applicable to related than to unrelated industries, the value of not entirely general resources may account for the positive relation between related diversification and profitability/value.

The preceding discussion has considered the value of general resources and the importance of organizational fit to be exogenous. A caveat is that they are unlikely to be strictly exogenous in reality. To the extent they can do so, firms presumably choose value of resources and importance of fit to maximize profit and perhaps others characteristics such as size or innovativeness too. Furthermore, conditions that determine the value of general resources and the importance of fit likely determine at least some characteristics of interest as well: a positive industry shock simultaneously should increase profitability, the value of (not entirely) general resources, and the importance of having an organization closely fitting the industry, that is, the importance of fit. Value and fit are then, to some extent at least, endogenous; there are omitted variables. Although there rarely are complete solutions to the problems of endogeneity and omitted-variable bias, some comfort is to be had from the observations that (i) value-creating resources are by necessity imperfectly mobile, the extent to which firms can choose value and fit is therefore limited; and (ii) industry conditions can to some extent be controlled for. This being said, an empirical test of the implications put forward in the present paper unquestionably requires devising an appropriate identification strategy.[34]

8. Conclusion

Entrepreneurial spawning is the process whereby an existing firm gives birth to a new firm setup by

[30] Although spawning frequency is unaffected by the value of general resources, spawning increases in that value because of increased innovativeness.

[31] The industry maturity condition likely is easier to test than the relative importance of resources condition, but it becomes a sufficient condition only in the somewhat restrictive cases where there is always spawning when the industry is young ($\omega_t^* \to 1$ as $t \to 0$) and there is never spawning when the industry is old ($\omega_t^* \to 0$ as $t \to \infty$).

[32] See most recently Loderer and Waelchli (2009).

[33] See Montgomery (1994) and Villalonga (2004).

[34] We thank an anonymous referee for raising the important issues of endogeneity and omitted-variable bias.

one or more employees departed from the existing firm. Although the phenomenon of spawning itself has been quite extensively studied, its implications for firm characteristics such as size, focus, profitability, and innovativeness have received relatively little attention. Our paper aims at filling the gap between the phenomenon of spawning and its implications for selected firm characteristics.

We motivate spawning by the desire to achieve organizational fit; fit measures the degree to which firm organization is adapted to firm products. Spawning occurs when an employee who develops a new product finds it beneficial to start a new firm to commercialize that product, because the product presents little fit with the organization of the firm at which the employee originally is employed. There is a trade-off between organizational fit and the cost of setting up a new firm.

From this basic trade-off, we derive the implications of spawning for firm size, profitability, focus, and innovativeness. We analyze how the value of a firm's general resources, the importance of organizational fit, the cost of setting up a new firm, firm age, and the bargaining power of innovating employees affect the aforementioned firm characteristics. Firms that have more valuable general resources spawn more, as do firms that have more important organizational fit. As firms mature, they spawn less and innovate less, they are less profitable and more diversified. For those firms that have highly valuable general resources, focus and profitability are positively related when the relation is due to organizational fit; they are negatively related when the relation is due to general resources.

Our model accounts for much of the empirical evidence on the relation between spawning and firm characteristics. It suggests at the same time new empirical tests based upon the distinction between the value of general resources and the importance of fit.

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Appendix

Proof of Lemma 1. Suppose researcher R has developed a new product θ_i at date $t+\epsilon$. The value created by this new product has two components: that of exploiting product θ_i itself and that of the new opportunity for exploration product θ_i provides.

Denote by $v^{\text{in}}_{t+\epsilon}(\omega_i)$ the value at date $t+\epsilon$ of exploiting within firm f the new product θ_i (which has fit ω_i with the firm's organization). Denote by $v^{\text{out}}_{t+\epsilon}$ the value of exploiting θ_i within a new firm f^+.[35] We have the following:

$$v^{\text{in}}_{t+\epsilon}(\omega_i) \equiv \sum_{\tau=t+1}^{\infty} \frac{(\alpha+\beta\omega_i)s_\tau}{(1+\rho)^{\tau-t}}, \tag{9}$$

$$v^{\text{out}}_{t+\epsilon} \equiv \sum_{\tau=t+1}^{\infty} \frac{(\alpha+\beta)s_\tau}{(1+\rho)^{\tau-t}} - \kappa. \tag{10}$$

We can write the following:

$$v^{\text{in}}_{t+\epsilon}(\omega_i) = \frac{(\alpha+\beta\omega_i)s^e_t}{\rho}, \tag{11}$$

$$v^{\text{out}}_{t+\epsilon} = \frac{(\alpha+\beta)s^e_t}{\rho} - \kappa, \tag{12}$$

where the factor s^e_t is such that

$$\frac{s^e_t}{\rho} = \sum_{\tau=t+1}^{\infty} \frac{s_\tau}{(1+\rho)^{\tau-t}}. \tag{13}$$

The value the entrepreneur E derives from exploiting already existing products is unaffected by the spawning decision to either exploit the new product θ_i within firm f or in a new firm f^+. The researcher derives no value from these existing products.

Denote by $V_{t+\epsilon}|_{R\to M}$ and $V_{t+\epsilon}|_{R\to E^+}$ the values at date $t+\epsilon$ of the new opportunity for exploration provided by product θ_i, if conducted within firm f and firm f^+, respectively. Researcher R becomes manager M in the former case and entrepreneur E^+ in the latter.

The distribution of products θ_j born of exploration at firm f from date $t+1$ onward is centered at the firm's organization o_f: $\theta_j \sim U[o_f-\delta, o_f+\delta]$. By assumption, the distribution of products born of exploration at firm f^+ from date $t+1$ onward is centered at firm f^+'s organization o_{f^+}: $\theta_j \sim U[o_{f^+}-\delta, o_{f^+}+\delta]$. Given that α, β, and $c(q_t)$ are the same for the two firms, it follows that $V_{t+\epsilon}|_{R\to M} = V_{t+\epsilon}|_{R\to E^+}$.

By assumption, if R leaves firm f, E receives nothing of $V_{t+\epsilon}|_{R\to E^+}$. That is, when E and R bargain over the spawning decision, at date $t+\epsilon$, the reservation strategy of R is to leave, in which case he receives $V_{t+\epsilon}|_{R\to E^+}$ in full. Therefore, whatever the bargaining outcome in equilibrium, R will always be fully compensated for the value of his outside option $V_{t+\epsilon}|_{R\to E^+}$ before the remaining surplus is shared. Given that $V_{t+\epsilon}|_{R\to M} = V_{t+\epsilon}|_{R\to E^+}$, it follows that, for R to stay in firm f, E must relinquish all claim on $V_{t+\epsilon}|_{R\to M}$. The value of the new opportunity for exploration presented by product θ_i is shared between R and the researchers which,

[35] That $v^{\text{in}}_{t+\epsilon}$ but not $v^{\text{out}}_{t+\epsilon}$ depends on ω_i is a natural consequence of the choice of organization perfectly fitting the new product, θ_i, in the new firm.

one after the other, are employed to pursue this opportunity; R captures a fraction $1-\gamma$ of this value, irrespective of whether he becomes a manager ($R\to M$) or an entrepreneur ($R\to E^+$).

In the efficient bargaining outcome, E therefore shares with R the value of exploiting product θ_i, and receives nothing of $V_{t+\epsilon}|_{R\to M}$ or $V_{t+\epsilon}|_{R\to E^+}$; E receives $(1-\gamma)v^{\text{in}}_{t+\epsilon}(\omega_i)$ if the product is exploited within firm f, or $(1-\gamma)v^{\text{out}}_{t+\epsilon}$ if it is exploited within a new firm f^+; R receives $\gamma v^{\text{in}}_{t+\epsilon}(\omega_i)+(1-\gamma)V_{t+\epsilon}|_{R\to M}$ if the product is exploited within firm f, or $\gamma v^{\text{out}}_{t+\epsilon}+(1-\gamma)V_{t+\epsilon}|_{R\to E^+}$ if it is exploited within a new firm f^+. They therefore retain the new product θ_i if it has fit ω_i such that

$$v^{\text{in}}_{t+\epsilon}(\omega_i)+(1-\gamma)V_{t+\epsilon}|_{R\to M}\ge v^{\text{out}}_{t+\epsilon}+(1-\gamma)V_{t+\epsilon}|_{R\to E^+};\quad (14)$$

they spawn the new product otherwise. Given that $V_{t+\epsilon}|_{R\to M}=V_{t+\epsilon}|_{R\to E^+}$, the threshold fit, ω^*_t, at which the values of spawning and retention are equated therefore solves $v^{\text{in}}_{t+\epsilon}(\omega^*_t)=v^{\text{out}}_{t+\epsilon}$. Rearranging gives (3). □

Proof of Lemma 2. Working backward in time, we now calculate the probability of successful exploration, q_t, selected by the entrepreneur at date t.

The expected value at date t of a product successfully developed at date $t+\epsilon$ is

$$v_t\equiv\int_0^{\omega^*_t}v^{\text{out}}_{t+\epsilon}\,d\omega_i+\int_{\omega^*_t}^1 v^{\text{in}}_{t+\epsilon}(\omega_i)\,d\omega_i.\quad (15)$$

Evaluating v_t in (15), we obtain the following:

$$v_t=\frac{s^e_t(\alpha+\beta)}{\rho}-\kappa-(1-\omega^*_t)\left[\frac{s^e_t\beta}{\rho}\left(\frac{1-\omega^*_t}{2}\right)-\kappa\right].\quad (16)$$

From (3), we have $\kappa=(s^e_t\beta/\rho)(1-\omega^*_t)$. Substituting κ into (16), yields the following:

$$v_t=\frac{s^e_t}{\rho}\left[\alpha+\beta\left(\frac{1+\omega^{*2}_t}{2}\right)\right].\quad (17)$$

Denote by V^E_t the expected values at date $t\ge t_f$ of *future* products to entrepreneur E. From the point of view of the entrepreneur E, the unit-period choice of cost of resources, $c(q_t)$, earns $q_t(1-\gamma)v_t$ in expectation. Extending to all dates, given that the entrepreneur has no claim on the new opportunities for exploration presented by new products developed in his firm, the expected value at date t, to the entrepreneur E, of all future products developed by successive researchers is

$$V^E_t=\max_{q_t}\left\{-c(q_t)+q_t(1-\gamma)v_t+\frac{V^E_{t+1}}{1+\rho}\right\}.\quad (18)$$

The period t choice of q_t does not affect V^E_{t+1} as innovation probabilities are independent across time. Differentiating with respect to q_t, the entrepreneur E's optimal q_t solves the first-order condition $\partial V^a_t/\partial q_t=0$, which gives the following:

$$q_t=(1-\gamma)v_t.\quad □\quad (19)$$

Proof of Proposition 1. From (3), it is immediate that $d\omega^*_\tau/d\alpha=0$, $d\omega^*_\tau/d\beta>0$, $d\omega^*_\tau/d\kappa<0$, and $dq_t/d\gamma=0$. □

Proof of Proposition 2. Using q_t in (5) and ω^*_τ in (3), we have the following:

$$q_t=\frac{(1-\gamma)s^e_t}{\rho}\left[\alpha+\frac{\beta}{2}\left(1+\left[1-\frac{\rho\kappa}{\beta s^e_t}\right]^2\right)\right].\quad (20)$$

It is immediate that $dq_t/d\alpha>0$, $dq_t/d\beta>0$, $dq_t/d\kappa<0$, and $dq_t/d\gamma<0$. □

Proof of Proposition 3. Substitute ω^*_τ in (3) into $n_\tau\equiv q_\tau(1-\omega^*_\tau)$ to obtain the following:

$$n_\tau=(1-\gamma)\kappa\left[\frac{\alpha}{\beta}+\frac{1}{2}(1+\omega^{*2}_\tau)\right].\quad (21)$$

Denote by $N_t\equiv\prod_{\tau=t_f+1}^{t-1}(1+n_\tau)$, so $\mathbb{E}[I_t]=N_t$. We have, for $\Xi\in\{\alpha,\beta,\kappa,\gamma\}$,

$$\frac{d\mathbb{E}[I_t]}{d\Xi}=\sum_{\tau=t_f+1}^{t-1}\left(\frac{dn_\tau}{d\Xi}\frac{N_t}{1+n_\tau}\right),\quad (22)$$

where

$$\frac{dn_\tau}{d\Xi}=-\frac{n_\tau}{1-\gamma}\frac{d\gamma}{d\Xi}+-\frac{n_\tau}{\kappa}\frac{d\kappa}{d\Xi}+(1-\gamma)\kappa\left[\frac{d(\alpha/\beta)}{d\Xi}+\omega_\tau\frac{d\omega^*_\tau}{d\Xi}\right].\quad (23)$$

—For $\Xi=\alpha$: $d\omega^*_\tau/d\alpha=0$, so $dn_\tau/d\alpha=(1-\gamma)\kappa/\beta>0$. Therefore, $d\mathbb{E}[I_t]/d\alpha>0$.

—For $\Xi=\beta$: $d\omega^*_\tau/d\beta=\rho\kappa/(\beta^2 s^e_t)=(1-\omega^*_\tau)/\beta$, so $dn_\tau/d\beta=((1-\gamma)\kappa/\beta)[-\alpha/\beta+\omega^*_\tau(1-\omega^*_\tau)]$. Therefore, $d\mathbb{E}[I_t]/d\beta<0$ iff $-\alpha/\beta+(1-\omega^*_\tau)\omega^*_\tau<0$ for all τ. The sufficient condition $\alpha/\beta>1/4$ is obtained by noting that $(1-\omega^*_\tau)\omega^*_\tau$ is maximized at $\omega^*_\tau=1/2$.

—For $\Xi=\kappa$: $d\omega^*_\tau/d\kappa=-\rho/(\beta s^e_t)=-(1-\omega^*_\tau)/\kappa$, so $dn_\tau/d\kappa=n_\tau/\kappa-(1-\gamma)\omega^*_\tau(1-\omega^*_\tau)=(1-\gamma)[\alpha/\beta+\omega^{*2}_\tau+\frac{1}{2}(1-\omega_\tau)^{*2}]>0$. Therefore, $d\mathbb{E}[I_t]/d\kappa>0$.

—For $\Xi=\gamma$: $d\omega^*_\tau/d\gamma=0$, so $dn_\tau/d\gamma=-n_\tau/(1-\gamma)<0$. Therefore, $d\mathbb{E}[I_t]/d\gamma<0$. □

Proof of Proposition 4. Let a history h_t register a particular sequence of product developments and retentions having occurred over the time period $t_f+1\le\tau\le t-1$; let H_t denote the set of all possible histories, h_t, at date t. Let $i_{\tau|h_t}$ be an indicator function that takes the value 1 if history h_t reveals that a new product was successfully developed by and retained within firm f in period τ, $t_f+1\le\tau\le t-1$; $i_{\tau|h_t}$ takes the value 0 if (i) either there was no new product developed in period τ or (ii) the new product developed in preiod τ was spawned to a new firm. Finally, let $I_{t|h_t}=\sum_{\tau=t_f+1}^{t-1}i_{\tau|h_t}$ be the number of new products retained by firm f until date t starts, in the course of a given history h_t. Denote again $n_\tau\equiv q_\tau(1-\omega^*_\tau)$.

Consider a given history, h_{t-1}, at date $t-1$. The conditional expectation of the firm focus at date t, given history h_{t-1}, is

$$\begin{aligned}\mathbb{E}[\bar\omega_t]_{|h_{t-1}}&=(1-n_{t-1}I_{t-1|h_{t-1}})\bar\omega_{t-1|h_{t-1}}+n_{t-1}I_{t-1|h_{t-1}}\\&\quad\cdot\left(\frac{I_{t-1|h_{t-1}}\bar\omega_{t-1|h_{t-1}}+\frac{1}{2}(1+\omega^*_{t-1})}{I_{t-1|h_{t-1}}+1}\right),\\&=\bar\omega_{t-1|h_{t-1}}-n_{t-1}\left(1-\frac{1}{I_{t-1|h_{t-1}}+1}\right)\\&\quad\cdot\left(\bar\omega_{t-1|h_{t-1}}-\frac{1+\omega^*_{t-1}}{2}\right).\end{aligned}\quad (24)$$

Taking expectations over all possible histories h_{t-1}, we write the following:

$$\mathbb{E}[\bar{\omega}_t] = \mathbb{E}[\bar{\omega}_{t-1}] - n_{t-1}\mathbb{E}\left[\left(1 - \frac{1}{I_{t-1}+1}\right) \cdot \left(\bar{\omega}_{t-1} - \frac{1+\omega^*_{t-1}}{2}\right)\right]. \quad (25)$$

Denoting $m_{t-1} \equiv n_{t-1}(1 - 1/(\mathbb{E}[I_{t-1}] + 1))$, we have the following:

$$\mathbb{E}[\bar{\omega}_t] = \mathbb{E}[\bar{\omega}_{t-1}] - m_{t-1}\left(\mathbb{E}[\bar{\omega}_{t-1}] - \frac{1+\omega^*_{t-1}}{2}\right), \quad (26)$$

$$m_{t-1} = n_{t-1}\left(1 - \left[1 + \prod_{\tau=t_f+1}^{t-2}(1+n_\tau)\right]^{-1}\right). \quad (27)$$

Differentiating, we have for $\Xi \in \{\alpha, \beta, \kappa, \gamma\}$,

$$\frac{d\,\mathbb{E}[\bar{\omega}_t]}{d\Xi} = (1-m_{t-1})\frac{d\,\mathbb{E}[\bar{\omega}_{t-1}]}{d\Xi} + \frac{m_{t-1}}{2}\frac{d\omega^*_{t-1}}{d\Xi} - \left(\mathbb{E}[\bar{\omega}_{t-1}] - \frac{1+\omega^*_{t-1}}{2}\right)\frac{dm_{t-1}}{d\Xi}, \quad (28)$$

where $1-m_{t-1} \geq 0$, $m_{t-1}/2 \geq 0$, and $\mathbb{E}[\bar{\omega}_{t-1}] - (1+\omega^*_{t-1})/2 \geq 0$.

Now, the firm focus at the beginning of the second period, $\bar{\omega}_{t_f+1} = 1$. The firm size being $I_{t_f+1} = 1$, we have $m_{t_f+1} = n_{t_f+1}/2$. Therefore, $\mathbb{E}[\bar{\omega}_{t_f+2}] = 1 - \frac{1}{4}n_{t_f+1}(1-\omega^*_{t_f+1})$ and

$$\frac{d\,\mathbb{E}[\bar{\omega}_{t_f+2}]}{d\Xi} = \frac{n_{t_f+1}}{4}\frac{d\omega^*_{t_f+1}}{d\Xi} - \left(\frac{1-\omega^*_{t-1}}{4}\right)\frac{dn_{t_f+1}}{d\Xi}. \quad (29)$$

We now analyze Equations (28) and (29) for each parameter $\Xi \in \{\alpha, \beta, \kappa, \gamma\}$ in turn:

—For $\Xi = \alpha$: From the proof of Proposition 3, we have $d\omega^*_\tau/d\alpha = 0$ and $dn_\tau/d\alpha > 0$, for all τ. From (29), we obtain $d\,\mathbb{E}[\bar{\omega}_{t_f+2}]/d\alpha < 0$. From (27), we have $dm_{t-1}/d\alpha > 0$ for all t. From (28) and $d\,\mathbb{E}[\bar{\omega}_{t_f+2}]/d\alpha < 0$, we obtain $d\,\mathbb{E}[\bar{\omega}_{t_f+3}]/d\alpha < 0$. Working forward in time, up to date t, we obtain $d\,\mathbb{E}[\bar{\omega}_t]/d\alpha < 0$.

—For $\Xi = \beta$: $d\omega^*_\tau/d\beta > 0$ and $dn_\tau/d\beta < 0$, for all τ, if $\alpha/\beta > 1/4$. From (29), we obtain $d\,\mathbb{E}[\bar{\omega}_{t_f+2}]/d\beta > 0$, if $\alpha/\beta > 1/4$. From (27), we have $dm_{t-1}/d\beta < 0$. From (28) and $d\,\mathbb{E}[\bar{\omega}_{t_f+2}]/d\beta > 0$, we obtain $d\,\mathbb{E}[\bar{\omega}_{t_f+3}]/d\beta > 0$, if $\alpha/\beta > 1/4$. Working forward in time, up to date t, we obtain $d\,\mathbb{E}[\bar{\omega}_t]/d\beta > 0$, if $\alpha/\beta > 1/4$.

—For $\Xi = \kappa$: $d\omega^*_\tau/d\kappa < 0$ and $dn_\tau/d\kappa > 0$, for all τ. From (29), we obtain $d\,\mathbb{E}[\bar{\omega}_{t_f+2}]/d\kappa < 0$. From (27), we have $dm_{t-1}/d\kappa > 0$. Working forward in time, up to date t, we obtain $d\,\mathbb{E}[\bar{\omega}_t]/d\kappa < 0$.

—For $\Xi = \gamma$: $d\omega^*_\tau/d\gamma = 0$ and $dn_\tau/d\gamma < 0$ for all τ. From (29), we obtain $d\,\mathbb{E}[\bar{\omega}_{t_f+2}]/d\gamma > 0$. From (27), we have $dm_{t-1}/d\gamma < 0$. Working forward in time, up to date t, we obtain $d\,\mathbb{E}[\bar{\omega}_t]/d\gamma > 0$.

Expression of expected focus. For completeness, the expected mean of focus or a given history h_t equals the following:

$$\bar{\omega}_{t\,|\,h_t} \equiv \frac{1}{I_{t\,|\,h_t}}\sum_{\tau=t_f+1}^{t-1} i_{\tau\,|\,h_t}\left(\frac{1+\omega^*_\tau}{2}\right). \quad (30)$$

In each period τ the probability of obtaining $i_{\tau\,|\,h_t}$ new in house innovations from $I_{\tau\,|\,h_t}$ innovation processes is given by the binomial distribution:

$$\Pr(i_{\tau\,|\,h_t} \mid I_{\tau\,|\,h_t}) = \binom{I_{\tau\,|\,h_t}}{i_{\tau\,|\,h_t}}(n_\tau^{i_{\tau\,|\,h_t}}(1-n_\tau)^{I_{\tau\,|\,h_t} - i_{\tau\,|\,h_t}}). \quad (31)$$

The probability of history h_t is then the following:

$$\Pr(h_t) = \prod_{\tau=t_f+1}^{t-1}\binom{I_{\tau\,|\,h_t}}{i_{\tau\,|\,h_t}}(n_\tau^{i_{\tau\,|\,h_t}}(1-n_\tau)^{I_{\tau\,|\,h_t} - i_{\tau\,|\,h_t}}). \quad (32)$$

Taking expectations over all histories, the expected focus of firm f at a date t, $\mathbb{E}[\bar{\omega}_t] = \sum_{h_t \in H_t}\Pr(h_t)\bar{\omega}_{t\,|\,h_t}$,

$$\mathbb{E}[\bar{\omega}_t] = \sum_{h_t\in H_t}\left(\frac{1}{I_{t\,|\,h_t}}\sum_{\tau=1}^{t} i_{\tau\,|\,h_t}\left(\frac{1+\omega^*_\tau}{2}\right)\prod_{\tau=t_f+1}^{t-1}\binom{I_{\tau\,|\,h_t}}{i_{\tau\,|\,h_t}} \cdot (n_\tau^{i_{\tau\,|\,h_t}}(1-n_\tau)^{1-i_{\tau\,|\,h_t}})\right). \quad \square \quad (33)$$

Proof of Proposition 5. We have $d\,\mathbb{E}[\bar{\omega}_t]/d\alpha < 0$ and $d\,\mathbb{E}[\pi_t]/d\alpha = (1+\beta(d\,\mathbb{E}[\bar{\omega}_t]/d\alpha))s_t$. Let α^* be the level of α such that $d\,\mathbb{E}[\bar{\omega}_t]/d\alpha|_{\alpha=\alpha^*} = -1/\beta$. Then, $d\,\mathbb{E}[\pi_t]/d\alpha < 0$ for all $\alpha < \alpha^*$, and $d\,\mathbb{E}[\pi_t]/d\alpha \geq 0$ for all $\alpha \geq \alpha^*$.

From $d\,\mathbb{E}[\bar{\omega}_t]/d\beta > 0$ if $\alpha/\beta > 1/4$, we have, $d\,\mathbb{E}[\pi_t]/d\beta = (\beta(d\,\mathbb{E}[\bar{\omega}_t]/d\beta) + \mathbb{E}[\bar{\omega}_t])s_t > 0$ if $\alpha/\beta > 1/4$. From $d\,\mathbb{E}[\bar{\omega}_t]/d\kappa < 0$, we have $d\,\mathbb{E}[\pi_t]/d\kappa = \beta(d\,\mathbb{E}[\bar{\omega}_t]/d\kappa)s_t < 0$. From $d\,\mathbb{E}[\bar{\omega}_t]/d\gamma > 0$, we have $d\,\mathbb{E}[\pi_t]/d\gamma = \beta(d\,\mathbb{E}[\bar{\omega}_t]/d\gamma)s_t > 0$. $\square$

Proof of Propositions 6 and 7. We have $\Delta\mathbb{E}[I_t] \equiv \mathbb{E}[I_t] - \mathbb{E}[I_{t-1}] = q_{t-1}(1-\omega^*_{t-1})\mathbb{E}[I_{t-1}] > 0$. From (26), $\Delta\mathbb{E}[\bar{\omega}_t] \equiv \mathbb{E}[\bar{\omega}_t] - \mathbb{E}[\bar{\omega}_{t-1}] = -m_{t-1}(\mathbb{E}[\bar{\omega}_{t-1}] - (1+\omega^*_{t-1})/2)$. Given that $m_{t-1} > 0$ and $\mathbb{E}[\bar{\omega}_{t-1}] - (1+\omega^*_{t-1})/2 \geq 0$, we have $\Delta\mathbb{E}[\bar{\omega}_t] < 0$.

Denoting $\Delta\mathbb{E}[\pi_t] \equiv \mathbb{E}[\pi_t] - \mathbb{E}[\pi_{t-1}]$, given that $s_t \leq s_{t-1}$, we have $\Delta\mathbb{E}[\pi_t] \leq \beta\Delta\mathbb{E}[\bar{\omega}_t] < 0$. Denoting $\Delta\omega^*_t \equiv \omega^*_t - \omega^*_{t-1}$, given that $s^e_t \leq s^e_{t-1}$, we have $\Delta\omega^*_t = ((\rho\kappa)/\beta)(1/s^e_{t-1} - s^e_t) \leq 0$. Denoting $\Delta q_t \equiv q_t - q_{t-1}$, we have $\Delta q_t = (((1-\gamma)s^e_t)/\rho) \cdot [\alpha + (\beta/2)(1 + [1 - (\rho\kappa)/(\beta s^e_t)]^2)] - (((1-\gamma)s^e_{t-1})/\rho)[\alpha + (\beta/2)(1 + [1-(\rho\kappa)/(\beta s^e_{t-1})]^2)] \leq 0$. $\square$

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